U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

SAFETY EVALUATION

Related to the
Kairos Power LLC
Construction Permit Application for
the Hermes Test Reactor

Docket 50-7513

Completed: June 2023

Office of Nuclear Reactor Regulation

ABSTRACT

This safety evaluation documents the U.S. Nuclear Regulatory Commission (NRC) staff's technical review of the construction permit application submitted by Kairos Power LLC (Kairos) on September 29, 2021. The application is for the Hermes test reactor, which is proposed to be built in Oak Ridge, Tennessee.

The test reactor will support development of Kairos's fluoride salt-cooled, high-temperature reactor technology. The Hermes reactor will be a 35-megawatt thermal reactor using tristructural isotropic (TRISO) fuel particles embedded in a carbon matrix pebble. The fuel particles will contain high assay low enriched uranium. The reactor will be configured as a pebble bed with molten fluoride salt coolant. The reactor will use a functional containment implemented principally by the high temperature TRISO particle fuel.

The NRC accepted this application for review and the application was docketed on November 29, 2021. To determine compliance with regulatory requirements in Title 10 of the Code of Federal Regulations (10 CFR), the staff used acceptance criteria in NUREG-1537," Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors" issued in February 1996.

The NRC's Advisory Committee on Reactor Safeguards independently reviewed those aspects of the application that concern safety and provided the results of its review to the Commission in a report dated May 16, 2023. Appendix C to this safety evaluation includes a copy of the report.

This safety evaluation presents the staff's review of the Hermes construction permit application based on information submitted by Kairos through February 2023. On the basis of its review of the construction permit application, the staff has determined that the preliminary design and analysis of the Hermes test reactor, including the principal design criteria; design bases; information relative to materials of construction and general arrangement; and preliminary analysis and evaluation of the design and performance of structures, systems, and components of the facility: (1) provides reasonable assurance that the final design will conform to the design basis; (2) includes an adequate margin of safety; (3) describes the structures, systems, and components which will provide for the prevention of accidents and the mitigation of consequences of accidents; and (4) meets applicable regulatory requirements and satisfies applicable NRC guidance. Therefore, the staff recommends that the Commission make the necessary findings with respect to the safety of the construction permit in accordance with 10 CFR 50.35, "Issuance of construction permits"; 50.40, "Common standards"; and 50.50, "Issuance of licenses and construction permits."

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ABBREVIATIONS AND ACRONYMS

AAI	Accidental aircraft impact
AC	Alternating current
ACI	American Concrete Institute
ACRS	Advisory Committee on Reactor Safeguards
ADAMS	Agencywide Documents Access and Management System
AEA	Atomic Energy Act
AGR	Advanced Gas-Cooled Reactor
ALARA	As low as is reasonably achievable
ALOHA	Areal Locations of Hazardous Atmospheres
ASCE	American Society of Civil Engineers
ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
ASME	American Society of Mechanical Engineers
BLEVE	Boiling Liquid Expanding Vapor Explosion
BPS	Backup Power System
BPVC	Boiler and Pressure Vessel Code
CCS	Chemistry control system
CCWS	Component Cooling Water System
CP	Construction permit
DEIS	Draft Environmental Impact Statement
DEM	Discrete Element Method
DHRS	Decay heat removal system
DID	Defense-in-depth
DOE	Department of Energy
DRG	Design Review Guide
DRS	Design response spectrum
DSRS	Design Specific Review Standard
EAB	Exclusion area boundaries
EOF	Emergency operations facility
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
EPZ	Emergency Planning Zone
ER	Environmental Report
ESCS	Equipment and structural cooling subsystem
ESF	Engineered safety features
ESP	Early Site Permit
ETTP	East Tennessee Technology Park
FDT	Fire Dynamics Tools
FEMA	Federal Emergency Management Agency
FIS	Flood Insurance Study
FOCD	Foreign Ownership, Control, or Domination
FPGA	Field programmable gate array
FR	Federal Register
FSAR	Final safety analysis report
GDC	General Design Criteria
HEU	Highly enriched uranium
HRR	Heat rejection radiator
HTGR	High-temperature gas-cooled reactor
HVAC	Heating ventilation and air conditioning

I&C	Instrumentation and Control
IBC	International Building Code
IDCOR	Industry Degraded Core Rulemaking
IDLH	Immediately Dangerous to Life or Health
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IGS	Inert gas system
IMS	Inventory management system
IPyC	Inner pyrolytic carbon
ISRS	In-structure response spectra
KP-FHR	Kairos Power fluoride high temperature reactor
KTA	Kerntechnischer Ausschuss
LCO	Limiting Condition for Operation
LEU	Low-enriched uranium
LPZ	Low population zone
LSSS	Limiting Safety System Setting
LWR	Light water reactor
M&TE	Measuring and test equipment
MAR	Material at risk for release
MC&A	Material control and accounting
MCR	Main control room
MHA	Maximum hypothetical accident
ML	Manufacturing License
MSRE	Molten Salt Reactor Experiment
MSS	Material surveillance system
MW	Megawatt
NCDC	National Climatic Data Center
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
OCC	Overnight capital cost
OL	Operating license
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
PBR	Pebble bed reactors
PCS	Plant control system
PDC	Principal design criteria
PDR	Public Document Room
PEER	Pacific Earthquake Engineering Research
PHMSA	Pipeline and Hazardous Materials Safety Administration
PHSS	Pebble Handling and Storage System
PHTCS	Primary heat transport control system
PHTS	Primary heat transport system
PIR	Potential Impact Radius
PIRT	Phenomena Identification and Ranking Table
PMF	Probable maximum flood
PMP	Probable maximum precipitation
PMWP	Probable Maximum Winter Precipitation
PSAR	Preliminary Safety Analysis Report
PSHA	Probabilistic seismic hazard analysis
PSP	Primary salt pump
QA	Quality assurance

QAPD	Quality Assurance Program Description
R&D	Research and development
RAHS	Reactor auxiliary heating system
RAI	Requests for additional information
RBHVAC	Reactor building heating, ventilation and air conditioning
RCACS	Reactor coolant auxiliary control system
RCS	Reactor control system
RCSS	Reactivity control and shutdown system
REMP	Radiological environmental monitoring program
RG	Regulatory Guide
ROSP	Remote onsite shutdown panel
RP	Radiation protection
RPS	Reactor protection system
RSS	Reactor shutdown system
RQD	Rock Quality Designation
RTMS	Reactor thermal management system
RTS	Reactor trip system
RV	Reactor vessel
RVSS	Reactor vessel support system
SARRDL	Specified acceptable system radionuclide release design limits
SE	Safety evaluation
SFCS	Spent Fuel Cooling System
SiC	Silicon carbide
SL	Safety limits
SNM	Special nuclear material
SPT	Standard penetration tests
SR	Surveillance requirements
SSAR	Site Safety Analysis Report
SSC	Structures, systems, and components
SSI	Soil-structure interaction
TEMA	Tennessee Emergency Management Agency
TF	Tritium fluoride
TMS	Tritium Management System
TNT	Trinitrotoluene
TR	Topical Report
TRISO	Tristructural isotropic
TS	Technical specification
TSC	Technical support center
TVA	Tennessee Valley Authority
UC	Uranium carbide
UCO	Uranium oxycarbide
UFL	Upper and lower flammability limits
UHS	Ultimate heat sink
UPS	Uninterruptible power supplies
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
VCE	Vapor cloud explosion
WTP	Water Treatment Plants

1 THE FACILITY

This chapter of the safety evaluation (SE) provides a general introduction to the facility and an overview of the topics covered in detail in other chapters of this SE, including areas of review, regulatory criteria and guidance, review procedures and findings, and conclusions.

1.1 Introduction

This SE documents the results of the U.S Nuclear Regulatory Commission (NRC) staff's (the staff's) technical review of the construction permit (CP) application submitted by Kairos Power LLC (Kairos) under Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities," for a non-power test reactor facility. The non-power test reactor is referred to as Hermes. An environmental review was also performed for the Hermes CP application and its evaluation and conclusions are documented in a Draft Environmental Impact Statement (DEIS), published on September 26, 2022, for public comment as NUREG-2263, "Environmental Impact Statement for the Construction Permit for the Kairos Hermes Test Reactor."

By letter dated September 29, 2021, Kairos submitted its application for a CP, which, if granted, would allow Kairos to construct the non-power test reactor facility in Oak Ridge, Tennessee. By letter dated October 31, 2021, Kairos submitted an Environmental Report in support of its Hermes CP application. The Staff acknowledged receipt of Kairos's application for a CP in the *Federal Register* (FR) (86 FR 60077) on October 29, 2021. Kairos submitted the following in its CP application:

- Description and safety assessment of the site required by 10 CFR 50.34, "Contents of applications; technical information," paragraph (a)(1).
- Environmental report required by 10 CFR 50.30, "Filing of applications for licenses; oath or affirmation," paragraph (f).
- General information required by 10 CFR 50.33, "Contents of applications; general information."
- Agreement limiting access to classified information required by 10 CFR 50.37, "Agreement limiting access to Classified Information."

The staff conducted a docketing acceptance review of Kairos's application and, by letter dated November 29, 2021, determined that Kairos's CP application was complete and acceptable for docketing. The application was assigned Docket No. 50-7513. A notice of docketing of Kairos's application was published in the FR on December 1, 2021 (86 FR 68290). A notice of a 60-day opportunity to request a hearing and petition for leave to intervene was published in the FR on February 9, 2022 (87 FR 7503). No petitions were filed in response to the notice.

The safety review of the CP application for the 10 CFR Part 50 utilization facility is based on information in the application, as revised and supplemented. Unless otherwise stated, this SE evaluates the information contained in the original application dated September 29, 2021; the information in Revision 3 of Kairos's Preliminary Safety Analysis Report (PSAR), dated May 31, 2023, which supersedes the PSAR Revision 0 included in the original application; the information in Revision 1 of technical report KP-TR-017, "KP-FHR Core Design and Analysis Methodology," dated September 29, 2022, which supersedes the KP-TR-017, Revision 0, submitted with the original application; the information in Revision 2 of technical report KP-TR-

018, “Postulated Event Analysis Methodology,” dated February 24, 2023, which supersedes the KP-TR-018, Revision 0, submitted with the original application; and the information in the following application supplements:

- Transmittal of Responses-to NRC Questions 2.3-1 and 2.3-2 on the Hermes Preliminary Safety Analysis Report, dated February 3, 2022.
- Kairos Power Response to NRC Questions 2.4-1, 2.4-2, and 2.4-3 for PSAR Section 2.4 on Hermes Construction Permit Application, dated February 8, 2022.
- Kairos Power Response to NRC Questions 2.5-1, 2.5-2, 2.5-3, and 2.5-4 for PSAR Section 2.5 on Hermes Construction Permit Application, dated February 9, 2022.
- Kairos Power Transmittal of Reponses to NRC Requests for Confirmation of Information for Hermes Preliminary Safety Analysis Report Section 9.1, dated August 19, 2022.
- Kairos Power Response to NRC Request for Additional Information 348 and 339, dated August 31, 2022.
- Kairos Power Response to NRC Request for Additional Information 350, dated September 1, 2022.
- Kairos Power Transmittal of Response to NRC Question on DHRS Testing from PSAR Section 6.3 Audit on Hermes Preliminary Safety Analysis Report.” KP-NRC-2209-003. September 1, 2022.
- Kairos Power Additional Information Related to Construction Permit Application – PSAR Chapter 1, dated November 15, 2022.
- Kairos Power Transmittal of Reponses to NRC Question on Hermes Preliminary Safety Analysis Report, dated December 8, 2022.
- Kairos Power Transmittal of Changes to Preliminary Safety Analysis Report Chapter 6 and Response to NRC Question on DHRS Testing, KP-NRC-2212-003, dated December 19, 2022.

1.1.1 Areas of Review

The Hermes CP application review consisted of two concurrent reviews: (1) a safety review of the Hermes PSAR and (2) an environmental review of the Hermes Environmental Report. The staff reviewed the Hermes PSAR against applicable regulatory requirements using appropriate regulatory guidance and standards, as discussed below, to assess the sufficiency of the preliminary design of the Hermes test reactor. As part of this review, the staff evaluated descriptions and discussions of Hermes’s structures, systems, and components (SSCs), with special attention to design and operating characteristics, unusual or novel design features, and principal safety considerations. The preliminary design of Hermes was evaluated to ensure the sufficiency of principal design criteria (PDC), design bases, and information relative to materials of construction, general arrangement, and approximate dimensions, sufficient to provide reasonable assurance that the final design will conform to the design bases. In addition, the staff reviewed Kairos’s identification and justification for the selection of those variables, conditions, or other items that are determined to be probable subjects of technical specifications for the facility, with special attention given to those items that may significantly influence the final design. The SSCs were also evaluated to ensure that they would adequately provide for the prevention of accidents and the mitigation of consequences of accidents. The staff considered the preliminary analysis and evaluation of the design and performance of the SSCs of the Hermes facility with the objective of assessing the risk to public health and safety resulting from operation of the facility.

In accordance with the National Environmental Policy Act (42 [United States Code] USC § 4321 *et seq*.,) (NEPA), the staff prepared a DEIS based on its independent assessment of the information provided by Kairos and information developed independently by the staff. The staff conducted an independent evaluation of the application and conducted a systematic, interdisciplinary review of the potential impacts of the proposed action on the human environment and reasonable alternatives to Kairos's proposal. Before development of the DEIS, the staff issued a notice of intent and invited the public to provide information relevant to the environmental review. The staff also provided opportunities for governmental and general public participation during the public meeting on the DEIS and used publicly available guidance in the development of its DEIS. The DEIS, published as NUREG-2263, meets the requirements of 10 CFR Part 51, "Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions."

1.1.2 Regulatory Basis and Acceptance Criteria

The staff reviewed the Hermes PSAR against applicable regulatory requirements, using appropriate regulatory guidance and standards, to assess the sufficiency of the preliminary facility design and analysis for the issuance of a CP. The staff evaluated the sufficiency of the Hermes preliminary design, as described in the PSAR, based on Kairos's design methodology and ability to provide reasonable assurance that the final design will conform to the design bases and allow adequate margin for safety.

In accordance with paragraph (a) of 10 CFR 50.35, "Issuance of construction permits," a CP authorizing Kairos to proceed with the construction of the Hermes facility may be issued if the NRC makes the following findings:

1. The applicant has described the proposed design of the facility, including, but not limited to, the principal architectural and engineering criteria for the design, and has identified the major features or components incorporated therein for the protection of the health and safety of the public.
2. Such further technical or design information as may be required to complete the safety analysis, and which can reasonably be left for later consideration, will be supplied in the final safety analysis report (FSAR).
3. Safety features or components, if any, which require research and development have been described by the applicant and a research and development program will be conducted that is reasonably designed to resolve any safety questions associated with such features or components.
4. On the basis of the foregoing, there is reasonable assurance that: (i) such safety questions will be satisfactorily resolved at or before the latest date stated in the application for completion of construction of the proposed facility, and (ii) taking into consideration the site criteria contained in 10 CFR Part 100, "Reactor Site Criteria," the proposed facility can be constructed and operated at the proposed location without undue risk to the health and safety of the public.

As provided in 10 CFR 100.2, "Scope," the siting requirements in 10 CFR Part 100 "apply to applications for site approval for the purpose of constructing and operating stationary power and testing reactors pursuant to the provisions of [10 CFR Part 50]…". Kairos has submitted an application for a CP for a testing facility. Therefore, the staff evaluated the Hermes facility's site-specific conditions using the applicable criteria in 10 CFR Part 100, in addition to those in 10 CFR Part 50. The staff's review evaluated the geography and demography of the site; nearby industrial, transportation, and military facilities; site meteorology; site hydrology; and site geology, seismology, and geotechnical engineering to ensure that issuance of the CP will not be inimical to public health and safety. The staff's review also evaluated SSCs and equipment designed to ensure safe operation, performance, and shutdown when subjected to extreme weather, floods, seismic events, missiles (including aircraft impacts), chemical and radiological releases, and loss of offsite power.

The CP, if issued, would constitute an authorization for Kairos to proceed with construction. The staff's evaluation of the preliminary design and analysis of the Hermes facility does not constitute approval of the safety of any design feature or specification. Such approval will be made following the evaluation of the final design of the facility, as described in the FSAR as part of Kairos's operating license (OL) application for Hermes.

In addition to the findings listed in 10 CFR 50.35, a CP application must also provide sufficient information to allow the Commission to make the following determinations in accordance with 10 CFR 50.40, "Common standards," and 10 CFR 50.50, "Issuance of licenses and construction permits":

1. There is reasonable assurance: (i) that the construction of the facility will not endanger the health and safety of the public, and (ii) that construction activities can be conducted in compliance with the Commission's regulations.
2. The applicant is technically qualified to engage in the construction of its proposed facility in accordance with the Commission's regulations.
3. The applicant is financially qualified to engage in the construction of its proposed facility in accordance with the Commission's regulations.
4. The issuance of a permit for the construction of the facility would not be inimical to the common defense and security or to the health and safety of the public.
5. After weighing the environmental, economic, technical and other benefits of the facility against environmental and other costs and considering reasonable available alternatives, the issuance of this CP, subject to the conditions for protection of the environment set forth herein, is in accordance with Subpart A of 10 CFR Part 51 of the Commission's regulations and all applicable requirements have been satisfied.
6. The application meets the standards and requirements of the Atomic Energy Act and the Commission's regulations, and that notifications, if any, to other agencies or bodies have been duly made.

The staff's evaluation of Hermes's preliminary design and analysis was based primarily upon the following 10 CFR requirements:

- 10 CFR 50.2, "Definitions."
- 10 CFR 50.21, "Class 104 licenses; for medical therapy and research and development facilities," paragraph (c).
- 10 CFR 50.33, "Contents of applications; general information," paragraph (f).
- 10 CFR 50.34, "Contents of applications; technical information," paragraph (a), "Preliminary safety analysis report."
- 10 CFR 50.35, "Issuance of construction permits."
- 10 CFR 50.40, "Common standards."
- 10 CFR 50.41, "Additional standards for class 104 licenses."
- 10 CFR 50.50, "Issuance of licenses and construction permits."

- 10 CFR 50.55, “Conditions of construction permits, early site permits, combined licenses, and manufacturing licenses.”
- 10 CFR 50.58, “Hearings and report of the Advisory Committee on Reactor Safeguards.”
- 10 CFR Part 50, Appendix C, “A Guide for the Financial Data and Related Information Required to Establish Financial Qualifications for Construction Permits and Combined Licenses.”
- 10 CFR Part 50, Appendix E, “Emergency Planning and Preparedness for Production and Utilization Facilities.”
- 10 CFR 100.10, “Factors to be considered when evaluating sites.”
- 10 CFR 100.11, “Determination of exclusion area, low population zone, and population center distance.”

The regulations of 10 CFR 50.40, “Common standards,” require that:

> … the processes to be performed, the operating procedures, the facility and equipment, the use of the facility, and other technical specifications, or the proposals, in regard to any of the foregoing collectively provide reasonable assurance that the applicant will comply with the regulations in this chapter, including the regulations in part 20 of this chapter, and that the health and safety of the public will not be endangered.

With respect to 10 CFR Part 20 which is referred to in 10 CFR 50.40, the staff assessed whether Kairos had identified the relevant requirements for an operating facility and provided descriptions of the preliminary facility design to determine whether the PSAR provides an acceptable basis for the development of structures, systems, and components, and whether there is reasonable assurance that Kairos will comply with the regulations in 10 CFR Part 20 during Hermes facility operation. Because Kairos has not applied for licenses to receive, possess, use, transfer, or dispose of byproduct, source, or special nuclear material, the staff did not evaluate whether requirements in 10 CFR Part 20 would be met for the construction of the Hermes reactor. Several chapters in this SE reflect this aspect of the review of the CP application.

As required by 10 CFR 50.34(a)(3)(i), Kairos must describe the PDC for its Hermes facility in the PSAR. However, for the Hermes test reactor, Kairos is not required to follow 10 CFR Part 50, Appendix A, “General Design Criteria [GDCs] for Nuclear Power Plants,” which applies only to water-cooled nuclear power reactors. The PSAR states the following regarding the PDC for Hermes:

> Kairos Power has also developed a set of principal design criteria (PDC) applicable for the KP-FHR technology which has been reviewed and approved by the NRC in “Principal Design Criteria for the Kairos Power Fluoride Salt-Cooled High Temperature Reactor.” [ML20167A174] The application of these criteria to the SSCs of the test reactor are shown in Table 3.1-2. The site contains only one reactor, with no SSCs shared with another reactor unit, which satisfies PDC 5. Specific details regarding how the other PDC are met by the design are described in the individual sections throughout this safety analysis report and summarized in Table 3.1-3.

The staff reviewed Kairos’s description of Hermes PDCs as described in the PSAR Sections identified in Tables 3.1-2 and 3.1-3; and in the NRC approved topical report titled “Principal Design Criteria for the Kairos Power Fluoride Salt-Cooled High Temperature Reactor,” as applicable to the test reactor.

The staff used established guidance and acceptance criteria that it determined to be relevant to the review of the Hermes CP application, noting that much of this guidance was originally developed for completed designs of water-cooled nuclear reactors. In order to determine the acceptance criteria necessary for demonstrating compliance with 10 CFR regulatory requirements, the staff used:

- NUREG-1537, Part 1, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors, Format and Content," issued February 1996
- NUREG-1537, Part 2, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors, Standard Review Plan and Acceptance Criteria," issued February 1996

As appropriate, the staff used additional guidance (e.g., NRC regulatory guides, Institute of Electrical and Electronics Engineers standards, American National Standards Institute/American Nuclear Society [ANSI/ANS] standards, and NRC office instructions) in its review of the Hermes CP application. The additional guidance was used based on the technical judgment of the reviewer, as well as references in NUREG-1537, Parts 1 and 2; and the Hermes CP application.

1.1.3 Review Procedures

The staff's review of the Hermes application was informed by NUREG-1537, as well as other relevant guidance cited therein, cited in the application, or used based on the staff's technical judgment. In particular, Kairos's Hermes CP application only seeks authorization to construct the proposed Hermes facility. Therefore, the level of detail needed in the application and the staff's corresponding SE is different than that needed for an OL application and corresponding SE. For the purposes of issuing a CP, the Hermes facility may be adequately described at a functional or conceptual level in the PSAR. As such, Kairos has deferred providing some design and analysis details until the submission of its FSAR with its OL application.

The objective of the staff's evaluation was to assess the sufficiency of information contained in the Hermes application for the issuance of a CP in accordance with the requirements of 10 CFR Part 50. An in-depth evaluation of the Hermes design will be performed following the docketing of an OL application and its accompanying FSAR.

1.1.4 Resolving Technical Issues

For those technical areas that require additional information, the staff has several options:

1. The staff may determine that such technical issues must be resolved prior to the issuance of a CP.
2. The staff may determine that such information may be left until the submission of the OL application.
3. The staff may require that such technical issues be resolved prior to the completion of construction, but after the issuance of the CP.

Technical issues that fall within the scope of the first option require additional information to be provided in order to establish PDC and/or design bases so that the staff may have confidence that the final facility design will conform to the design basis. The staff resolves such technical issues through audits and requests for additional information (RAIs).

In the second and third options, the staff may also use audits or issue RAIs to resolve identified technical issues. These types of technical issues include those that require a design maturity beyond what is required by 10 CFR 50.34(a) to issue a CP. Although determining what constitutes a preliminary versus a final design may be somewhat subjective, according to 10 CFR 50.34(a), a preliminary design must include PDC, the design bases, and general facility arrangement and approximate dimensions. This information should be sufficient to provide reasonable assurance that the final design will conform to the design bases with adequate margin for safety. The staff may use audits or issue RAIs if it determines that doing so is necessary for the applicant to acknowledge certain technical deficiencies that could impact the final design. Appropriate responses include commitments to resolving these deficiencies either in the FSAR or before the completion of construction.

As part of its review of the Hermes CP application, the staff conducted the following audits:

- General Audit
- Audit of PSAR Chapter 2, “Site Characteristics”
- Audit of PSAR Section 4.5, “Nuclear Design,” and Chapter 13, “Accident Analysis”
- Audit of PSAR Section 6.3, “Decay Heat Removal System”
- Audit of PSAR Chapter 7, “Instrumentation and Control”

The audits and reviews are designed to maximize the efficiency of the staff’s review. During an audit, the applicant can respond to questions, the staff can readily evaluate the applicant’s responses, and the need for formal correspondence between the staff and the applicant is reduced, resulting in improved review efficiency. In this review, Kairos supplemented the PSAR and provided clarifications through its responses to the staff’s questions during audit meetings and in docketed correspondence. The staff documented the results of the Hermes audits in the following audit reports:

- Chapter 4 and 13 (Accident Analysis) Audit Report (ML23160A287)
- Decay Heat Removal System Audit Report (ML23115A480)
- General Audit Report (ML23160A287)
- Instrumentation and Control Audit Report (ML23115A480)
- Site Characteristics Audit Report (ML23115A480)

During its review of the Hermes CP application, the staff also prepared and issued three RAIs, 339, 348, and 350 and one request for confirmation of information (RCI), 349 on August 2, 2022. Kairos provided a response to RCI 349 in a letter dated August 19, 2022. Responses to RAIs 339 and 348 were provided by letter dated August 31, 2022 and the response to RAI 350 was provided by letter dated September 1, 2022. The staff evaluation and resolution of RCI 349 and RAIs 339, 348, and 350 are documented in SE Sections 9.1.2, “Inert Gas System,” 4.3, “Reactor Vessel System,” 13.1.10, “Prevented Events,” and 5.1, “Primary Heat Transport System,” respectively.

Additionally, SE Appendix A, “Post Construction Permit Activities - Construction Permit Conditions and Additional Items for the Operating License Application,” contains a listing of those elements of design, analysis, and administration identified as requiring additional research and development or resolution by Kairos. The staff determined that resolution of these items is not necessary for the issuance of a CP, but that Kairos should ensure that these items are fully addressed in the FSAR supporting a Hermes OL application. The staff is tracking these items to ensure they are considered during the review of an OL application for Hermes.

1.1.5 Ongoing Research and Development

The provisions of 10 CFR 50.34(a)(8) allow for ongoing research and development (R&D) to confirm the adequacy of the design of SSCs to resolve safety questions prior to the completion of construction. In accordance with 10 CFR 50.34(a)(8), and as described in PSAR Section 1.3.9, "Research and Development," Kairos has identified the following nine ongoing research and development activities:

- Perform a laboratory testing program to confirm fuel pebble behavior (PSAR Section 4.2.1).
- Develop a high temperature material surveillance sampling program for the reactor vessel and internals (Section 4.3.4).
- Perform testing of high temperature material to qualify Alloy 316H and ER16-8-2 (PSAR Section 4.3).
- Perform analysis related to potential oxidation in certain postulated events for the qualification of the graphite used in the reflector structure (Section 4.3).
- Development and validation of computer codes for core design and analysis methodology (Section 4.5).
- Develop a fluidic diode device (Section 4.6).
- Justification of thermodynamic data and associated vapor pressure correlations of representative species. (Section 5.1.3).
- Develop process sensor technology for key reactor process variables (Section 7.5.3).
- Develop the reactor coolant chemical monitoring instrumentation (Section 9.1.1).

In support of these activities, Kairos has provided descriptions of the affected SSCs and identified the additional development that is needed. By letter dated December 8, 2022, Kairos has stated that these research and development activities will be completed in advance of the completion of construction. Enclosure 1 of the application states that the latest date for completion of construction is expected to be December 31, 2026. Based on the schedule provided in the December 8, 2022, letter, research and development activities would be resolved in advance of the estimated completion of construction. As described in Appendix A to this SE, the staff is tracking these activities and will verify that they are resolved prior to the completion of construction.

1.1.6 Advisory Committee on Reactor Safeguards Review

To support the Advisory Committee on Reactor Safeguards (ACRS) in providing an independent review and report to the Commission regarding the Hermes CP application, the staff presented the results of its SE to the ACRS subcommittee on March 1, 23, 24, April 4, 18, 19, and 20, 2023 and to the full committee on May 3, 2023. After the meetings, the ACRS issued a letter to the Commission with their recommendations regarding the Hermes CP application to meet the requirements of 10 CFR 50.58, "Hearings and report of the Advisory Committee on Reactor Safeguards." The ACRS letter is provided in Appendix C.

1.1.7 Application Availability

Publicly available documents related to the Hermes CP application may be obtained online in the Agencywide Documents Access and Management System (ADAMS) Public Documents collection at https://www.nrc.gov/reading-rm/adams.html. To begin the search, select "ADAMS Public Documents" and then select "Begin Web-based ADAMS Search." For problems with ADAMS, please contact the NRC's Public Document Room (PDR) reference staff at 1-800-397-4209 or by email to PDR.Resource@nrc.gov.

The versions of the Hermes PSAR, submitted September 29, 2021, September 29, 2022, and February 24, 2023, are publicly available in ADAMS. Other public documents and correspondence related to this application may be found by searching Hermes's Docket Number, 50-7513, in ADAMS. Portions of the application or correspondence containing sensitive information (e.g., proprietary information) are being withheld form public disclosure pursuant to 10 CFR 2.390, "Public inspections, exemptions, requests for withholding."

1.1.8 NRC Staff Contact Information

The project manager for this SE was Benjamin Beasley, Senior Project Manager, Division of Advanced Reactors and Non-power and Utilization Facilities, U.S. Nuclear Regulatory Commission. Mr. Beasley may be contacted regarding this SE by telephone at 301-415-2062 or email at Benjamin.Beasley@nrc.gov. Appendix B, "Principal Contributors," to this SE provides a listing of principal contributors, including areas of technical expertise and chapters of authorship.

1.2 Summary and Conclusions on Principal Safety Considerations

The staff evaluated the descriptions and discussions of the proposed Hermes facility, as described in Kairos's CP application, as supplemented. Based on its review, the staff makes the following findings:

1. Applicable standards and requirements of the Atomic Energy Act and Commission regulations have been met.
2. The acceptance criteria in or referenced in NUREG-1537 have been satisfied for a preliminary design supporting a CP application where the criteria were found to be applicable to the design.
3. Required notifications to other agencies or bodies related to this licensing action have been duly made.
4. Based on the preliminary design of the facility, there is reasonable assurance that the final design will conform to the design basis with adequate margin for safety.
5. There is reasonable assurance that the facility can be constructed in conformity with the permit, the provisions of the Atomic Energy Act, and the Commission's regulations.
6. Kairos has considered the expected consequences of several postulated credible accidents and a maximum hypothetical accident, emphasizing those that could lead to a release of fission products. The staff has evaluated the accident analyses presented by Kairos in the PSAR and determined that the calculated potential radiation doses outside the Hermes site are not likely to exceed the guidelines of 10 CFR Part 100, "Reactor Site Criteria." Furthermore, SSCs have been designed to provide for the prevention of accidents and the mitigation of consequences of accidents.
7. Releases of radioactive materials and wastes from the facility are not expected to result in concentrations outside the limits specified by 10 CFR Part 20, Subpart D, "Radiation

Dose Limits for Individual Members of the Public," and are as low as is reasonably achievable (ALARA).

8. The financial information, technical analyses and programs, and organization as described in the application, as supplemented, demonstrate that Kairos is financially and technically qualified to engage in the construction of its proposed facility in accordance with the Commission's regulations.
9. The preliminary emergency plan provides reasonable assurance that Kairos will be prepared to assess and respond to emergency events.
10. The application presents information at a level of detail that is appropriate for general familiarization and understanding of the proposed facility.
11. The application describes the relationship of specific facility design features to reactor operation.
12. Issuance of the CP will not be inimical to the common defense and security or to the health and safety of the public.

Therefore, the staff finds that, subject to certain conditions, the preliminary design and analysis of the Hermes facility, as described in the PSAR, is sufficient and meets the applicable regulatory requirements and guidance for the issuance of a CP in accordance with 10 CFR 50.35.

Further technical information or design information required to complete the safety analysis in support of operation can reasonably be left for later consideration in the FSAR. Appendix A to this SE identifies certain permit conditions that the staff recommends the Commission include if the CP is issued. Additionally, Appendix A contains a listing of those elements of design, analysis, and administration identified as requiring additional development, description, or resolution by Kairos to support an OL application. The staff has determined that while resolution of these items is not necessary for the issuance of a CP, it is the responsibility of Kairos to ensure that these items have been fully addressed in the Hermes FSAR supporting an OL application. The staff is tracking these items and will verify their implementation during the staff's review of a Hermes OL application.

In addition, as discussed in PSAR Section 1.1.5, Kairos has identified several ongoing R&D activities to confirm the adequacy of the design of SSCs to resolve safety questions prior to the completion of construction. The staff is tracking these activities, which are also listed in Appendix A to this SE, and will verify that they are resolved prior to the completion of construction.

Based on these findings as documented in this SE, and subject to the permit conditions identified in Appendix A of this SE, the staff recommends that the Commission make the following conclusions for the issuance of a CP for the Hermes facility in accordance with 10 CFR 50.35, 50.40, and 50.50:

1. Kairos has described the proposed design of the Hermes facility, including, but not limited to, the principal architectural and engineering criteria for the design, and has identified the major features or components incorporated therein for the protection of the health and safety of the public.
2. Such further technical or design information as may be required to complete the safety analysis, and which can reasonably be left for later consideration, will be supplied in the FSAR.

3. Safety features or components that require R&D have been described by Kairos and an R&D program will be conducted that is reasonably designed to resolve any safety questions associated with such features or components.
4. On the basis of the foregoing, there is reasonable assurance that: (i) such safety questions will be satisfactorily resolved at or before the latest date stated in the application for completion of construction of the proposed facility, and (ii) taking into consideration the site criteria contained in 10 CFR Part 100, the proposed facility can be constructed and operated at the proposed location without undue risk to the health and safety of the public.
5. There is reasonable assurance: (i) that the construction of the Hermes facility will not endanger the health and safety of the public, and (ii) that construction activities can be conducted in compliance with the Commission’s regulations.
6. Kairos is technically qualified to engage in the construction of its proposed Hermes facility in accordance with the Commission’s regulations.
7. Kairos is financially qualified to engage in the construction of its proposed facility in accordance with the Commission’s regulations.
8. The issuance of a permit for the construction of the Hermes facility would not be inimical to the common defense and security or to the health and safety of the public.
9. After weighing the environmental, economic, technical, and other benefits of the facility against environmental and other costs and considering reasonable available alternatives, the issuance of the CP, subject to the conditions for protection of the environment set forth therein, is in accordance with Subpart A, “National Environmental Policy Act—Regulations Implementing Section 102(2),” of 10 CFR Part 51 of the Commission’s regulations and all applicable requirements have been satisfied.
10. The application meets the standards and requirements of the Atomic Energy Act and the Commission’s regulations, and notifications to other agencies or bodies have been duly made.

1.3 General Description

The staff evaluated the sufficiency of the general description of the Hermes facility, as presented in Hermes PSAR Section 1.3, “General Description of the Facility,” in part, using the guidance and acceptance criteria from Section 1.3, “General Description,” of NUREG-1537, Parts 1 and 2.

The PSAR states that the Hermes facility will be located within the East Tennessee Technology Park in Oak Ridge, Tennessee. The property is at the site of the former Oak Ridge Gaseous Diffusion Plant and is approximately 185 acres (74.8 hectares). From the 1950s through the mid-1980s, uranium enrichment operations occurred at the plant. Since then, the site has been restored to a brownfield by Department of Energy (DOE).

The PSAR states that Kairos intends to construct and operate Hermes at a reactor power of 35 megawatts thermal (design rated thermal power) for a licensed lifetime of 4 years. A description of the PDC for the facility is provided in PSAR Section 3.1.1, “Design Criteria.” The design criteria are based on NRC approved Kairos Power Topical Report KP-TR-003-NP-A.

In addition to the brief descriptions provided in PSAR Section 1.3, more detailed descriptions of the facility design features are provided for the following:

- Safety systems (PSAR Chapter 4 “Reactor Description,” Chapter 5, “Heat Transport System,” and Table 3.6-1, “Structures, Systems, and Components”)
- Engineered safety features (PSAR Chapter 6, “Engineered Safety Features”)
- Instrumentation, control, and electrical systems (PSAR Chapter 7 and Chapter 8)
- Reactor coolant and other auxiliary systems (PSAR Chapter 9, “Auxiliary Systems”)
- Radioactive waste management provisions or system and radiation protection (PSAR Chapter 11, “Radiation Protection Program and Waste Management”)

As described in subsequent SE chapters, the design of the Hermes facility includes engineered safety features to mitigate design-basis events or accidents, control and protection systems, equipment and processes related to handling and storage of byproduct material and special nuclear material, and fire protection systems. Additional controls are also provided by Hermes’s radiation protection program, ALARA program, radioactive waste management program, quality assurance program, fire protection program, and other programs that are described in the PSAR.

1.4 Shared Facilities and Equipment

The staff evaluated the sufficiency of the evaluation of shared facilities and equipment, as presented in Hermes PSAR Section 1.4, “Shared Facilities and Equipment,” using the guidance and acceptance criteria from Section 1.4, “Shared Facilities and Equipment,” of NUREG-1537, Parts 1 and 2. The acceptance criteria state that a non-power reactor facility should be designed to accommodate all uses or malfunctions of the shared facilities without degradation of the non-power reactor facility, and the non-power reactor should be designed to avoid the spread of contamination to any shared facilities or equipment.

Consistent with the review procedures of NUREG-1537, Part 2, Section 1.4, the staff confirmed that all facilities or equipment shared by the Hermes facility are discussed in the PSAR. As stated in Hermes PSAR Section 1.4, “[t]he facility is a single unit reactor that does not share any systems or equipment necessary to perform a safety function or for the safe operation of the plant with other facilities not covered by this [PSAR],” although some site infrastructure not credited to perform a safety function, for example, site utilities, may be shared with other nearby or onsite facilities.

Based on its review of the information in PSAR Section 1.4 and other PSAR chapters, the staff finds that there are no existing facilities or equipment that will be shared by the Hermes facility, that the scope of the PSAR includes the entire Hermes facility, and that the Hermes facility represents entirely new construction on property that is currently vacant. In addition, any site infrastructure that may be shared, such as utilities (e.g., offsite power), is not needed to perform a safety function based on the analyses discussed in other sections of this SE. Therefore, the staff concludes that the information in PSAR Section 1.4 on shared facilities and equipment is sufficient and meets the applicable regulatory requirements and guidance for the issuance of a CP in accordance with 10 CFR 50.35.

1.5 Comparison with Similar Facilities

The staff evaluated the sufficiency of Kairos’s comparison of the Hermes facility with other similar facilities, as presented in Hermes PSAR Section 1.5, “Comparison with Similar Facilities,” using the guidance and acceptance criteria from Section 1.5, “Comparison with Similar Facilities,” of NUREG-1537, Parts 1 and 2.

PSAR Section 1.5 states that the Hermes reactor will use pebble-based tristructural isotropic (TRISO) fuel with molten fluoride salt coolant. Kairos states that there are no existing or historical reactors that have used this specific fuel and coolant technology combination. However, Kairos states that the use of molten fluoride salt coolant was demonstrated in the Molten Salt Reactor Experiment (MSRE) at Oak Ridge National Laboratory.[1] In addition, the use of pebble-based fuel designs with pebbles containing graphite moderator and TRISO fuel particles has been demonstrated in high-temperature gas-cooled pebble bed reactors (PBRs), which the staff notes have been designed, constructed, and operated internationally. Kairos states that Hermes fuel is similar to the PBR fuel, but has slightly smaller pebbles, is cooled by a molten fluoride salt coolant instead of an inert gas, is buoyant in the coolant and includes an annular fuel layer within the pebble. TRISO particle fuel in stationary (non-pebble) particle form, (similar to the particles that would be contained within Hermes fuel pebbles) has been used in other high-temperature gas-cooled reactor (HTGR) designs, including the Peach Bottom Unit 1 and Fort St. Vrain power reactors that were constructed and operated in the United States.

PSAR Section 1.5.2.2 states that Hermes will use graphite as a moderator, which is similar to several other operating designs such as the Advanced Gas-Cooled Reactor (AGR) type reactors designed and operated in the United Kingdom. For comparison, the Hermes reactor will use a coolant containing a molten salt that is a mixture of lithium fluoride (LiF) and beryllium fluoride (BeF_2) (commonly referred to as Flibe) in addition to graphite reflector assemblies on the bottom, top, and sides of the active core to provide neutron moderation, while the AGRs used graphite for neutron moderation and carbon dioxide as coolant. PSAR Section 1.5.3 states that the Hermes auxiliary systems, such as inventory control and chemistry monitoring, while Flibe-based, are functionally similar to conventional systems used at other reactors. In addition, other Hermes auxiliary systems, including ventilation, cooling water, electrical power, and instrumentation and control systems, are also generally conventional in nature.

The staff notes that Kairos identified a number of similar facilities covering key aspects of the Hermes design. MSRE provides relevant experience with molten fluoride salt coolant, while PBR experience is relevant to the use of pebbles with TRISO fuel particles. In addition, TRISO particle fuel has been used in previous operating HTGRs. Finally, AGR experience is relevant to the use of graphite as a neutron moderator as is planned in the Hermes design. The staff notes that this collective experience of safe operation from multiple other reactor technologies with a number of key Hermes design features provides additional confidence in the inherent safety of those design features.

Consistent with the review procedures of NUREG-1537, Part 2, Section 1.5, the staff confirmed that the characteristics of any facilities compared with the proposed facility were similar and relevant. The staff also verified that the operating history of facilities cited by Kairos generally demonstrated consistently safe operation, use, and protection of the public.

Based on its review, the staff finds that the level of detail provided on comparisons with similar facilities satisfies the applicable acceptance criteria of NUREG-1537, Part 2, Section 1.5 (considering that Hermes would use a novel design that, while different from that of any existing or historical reactors, includes several key design features that are similar to those of other reactors), allowing the staff to make the following findings:

[1] The staff notes that the MSRE, which operated from 1965 to 1969 at power levels up to approximately 8 megawatts-thermal, utilized fuel dissolved in the salt coolant.

1. Kairos has compared the design bases and safety considerations of the Hermes facility with similar facilities, as practicable. The history of these facilities and their design features relevant to the Hermes demonstrates consistently safe operation that is acceptable to the staff.
2. Aspects of the Hermes design that are similar to features in other facilities that have been found acceptable to the staff, or otherwise demonstrated successful operation, should be expected to perform in a similar manner to these comparable features in other facilities.
3. Kairos is using test data and operational experience from facilities with similar components and design features in designing Hermes components, as practicable.

Therefore, the staff concludes that the comparisons with similar facilities, as described in PSAR Section 1.5, are sufficient and meet the applicable regulatory requirements and guidance for the issuance of a CP in accordance with 10 CFR 50.35.

1.6 Summary of Operations

The staff evaluated the sufficiency of the summary of Hermes operations, as presented in PSAR Section 1.6, “Summary of Operations,” using the guidance and acceptance criteria from Section 1.6, “Summary of Operations,” of NUREG-1537, Parts 1 and 2. Consistent with the review procedures of NUREG-1537, Part 2, Section 1.6, the staff verified that Kairos summarized the proposed operations of the Hermes facility.

PSAR Section 1.6 states that the purpose of the Hermes non-power reactor facility will be to test and demonstrate the key technologies, design features, and safety functions of Kairos’s KP-FHR technology, as well as to provide data and insights for the design and licensing of a KP-FHR commercial power reactor. Hermes would operate over its full range of power during a 4-year lifetime. In PSAR Section 4.1, Kairos states that the reactor will be designed with the capability to achieve power levels up to 35 megawatts-thermal. Kairos states that further information on Hermes operations and programs will be provided in an OL application.

Based on its review of the information in PSAR Section 1.6 and other PSAR chapters, the staff finds that Kairos’s information on proposed Hermes operation is consistent with relevant assumptions and analyses in later PSAR chapters in which any safety implications of the proposed operations are evaluated. Therefore, the summary of operations satisfies the applicable acceptance criteria of NUREG-1537, Part 2, Section 1.6. Accordingly, the staff concludes that the summary of operations, as described in PSAR Section 1.6, is sufficient and meets the applicable regulatory requirements and guidance for the issuance of a CP in accordance with 10 CFR 50.35. Further technical or design information required to complete the safety analysis may reasonably be left for later consideration in an OL application.

1.7 Compliance with the Nuclear Waste Policy Act of 1982

The Nuclear Waste Policy Act of 1982 (42 USC § 10101) provides that the U.S. government is responsible for the permanent disposal of high-level radioactive waste and spent nuclear fuel, but the cost of disposal should be the responsibility of the generators and owners of such waste and spent fuel. Hermes PSAR Section 1.7, “Compliance with the Nuclear Waste Policy Act of 1982,” states:

Kairos Power intends to enter into a contract with the Department of Energy (DOE) for the disposition of high-level waste and spent nuclear fuel. The contract will provide that the DOE accept title to the fuel and the obligation to take the spent fuel and/or high-level waste for storage or reprocessing. This will be discussed further in the application for the Operating License, consistent with Section 302(b)(1) of the Nuclear Waste Policy Act of 1982.

The staff evaluated the sufficiency of Kairos's compliance with the Nuclear Waste Policy Act using the guidance and acceptance criteria from Section 1.7, "Compliance with the Nuclear Waste Policy Act of 1982," of NUREG-1537, Parts 1 and 2. Staff noted that to be in compliance at the CP stage, Kairos needs to submit documentation showing communications in good faith between Kairos and the Department of Energy to enter into a contract for the disposition of high-level waste and nuclear fuel. By letter dated November 15, 2022, Kairos provided documentation from the Department of Energy that Kairos is actively and in good faith negotiating on a contract under section 302(b) of the Nuclear Waste Policy Act. Because Kairos has provided documentation of good faith negotiations with the Department of Energy, the staff finds that Kairos is in compliance with the Nuclear Waste Policy Act at the CP stage, consistent with NUREG-1537.

1.8 Facility Modifications and History

The staff evaluated the sufficiency of Kairos's descriptions of facility modifications and history, as presented in the Hermes PSAR Section 1.8, "Facility Modifications and History," using the guidance and acceptance criteria from NUREG-1537, Parts 1 and 2, Section 1.8, "Facility Modifications and History."

As stated in PSAR Section 1.8, "This report is an application for the new construction of a non-power reactor facility. There are no prior operating histories of existing Nuclear Regulatory Commission licensed facilities nor modifications to existing licensed facilities to report." The staff has determined that there are no existing facilities, there have been no modifications, and there is no history to report on the Hermes non-power test reactor facility.

Therefore, the staff concludes that Kairos's description of facility modifications and history in the PSAR Section 1.8 is sufficient and meets the applicable regulatory requirements and guidance for the issuance of a CP for a non-power test reactor facility in accordance with 10 CFR 50.35.

1.9 References

Kairos Power LLC, Topical Report Submittal Principal Design Criteria for the Kairos Power Fluoride Salt-Cooled, High Temperature Reactor, June 12, 2020, ML20167A174.

-----. "Submittal of the Preliminary Safety Analysis Report for the Kairos Power Fluoride Salt-Cooled, High Temperature Non-Power Reactor (Hermes)," September 29, 2021, ML21272A375.

-----. "Submittal of the Environmental Report for the Kairos Power Fluoride Salt-Cooled, High Temperature Non-Power Reactor (Hermes)," October 31, 2021, ML21306A131.

-----. "Transmittal of Responses-to NRC Questions 2.3-1 and 2.3-2 on the Hermes Preliminary Safety Analysis Report," February 3, 2022, ML22041A337.

-----. “Response to NRC Questions 2.4-1, 2.4-2, and 2.4-3 for PSAR Section 2.4 on Hermes Construction Permit Application,” February 8, 2022, ML22040A141.

-----. “Response to NRC Questions 2.5-1, 2.5-2, 2.5-3, and 2.5-4 for PSAR Section 2.5 on Hermes Construction Permit Application,” February 9, 2022, ML22040A336

-----. KP-TR-003-NP-A, "Principal Design Criteria for the Kairos Power Fluoride Salt-Cooled, High Temperature Reactor," Revision 1, June 2020, ML20167A174.

-----. “Transmittal of Reponses to NRC Requests for Confirmation of Information Hermes Preliminary Safety Analysis Report, Section 9.1, August 19, 2022, ML22231B228

-----. “Response to NRC Request for Additional Information 348 and 339,” August 31, 2022, ML22243A247

-----. “Response to NRC Request for Additional Information 350,” September 1, 2022, ML22252A149

-----. “Transmittal of Response to NRC Question on DHRS Testing from PSAR Section 6.3 Audit on Hermes Preliminary Safety Analysis Report,” September 1, 2022, ML22244A235

-----. “Submittal of the Preliminary Safety Analysis Report for the Kairos Power Fluoride Salt-Cooled, High Temperature Non-Power Reactor (Hermes), Revision 1,” September 29, 2022, Pkg. ML22272A593. (Includes KP-TR-017, “KP-FRN Core Design and Analysis Methodology,” Revision 1 (redacted version), as Enclosure 4.)

-----. “Submittal of the Preliminary Safety Analysis Report for the Kairos Power Fluoride Salt-Cooled, High Temperature Non-Power Reactor (Hermes), Revision 2,” February 24, 2023, Pkg. ML23055A672. (Includes KP-TR-018, “Postulated Event Analysis Methodology,” Revision 2 (redacted version), as Enclosure 3.)

-----. “Submittal of the Preliminary Safety Analysis Report for the Kairos Power Fluoride Salt-Cooled, High Temperature Non-Power Reactor (Hermes), Revision 3,” May 31, 2023, Pkg. ML23151A743.

-----. “Additional Information Related to Construction Permit Application – PSAR Chapter 1,” November 15, 2022, ML23019A360

-----. “Transmittal of Reponses to NRC Question on Hermes Preliminary Safety Analysis Report,” December 8, 2022, ML22342B282

-----. “Transmittal of Changes to Preliminary Safety Analysis Report Chapter 6 and Response to NRC Question on DHRS Testing,” December 19, 2022, ML22353A625

Nuclear Regulatory Commission (U.S.) (NRC). NUREG-1537, Part 1, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors, Format and Content,” February 1996, ML042430055.

-----. NUREG-1537, Part 2, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors, Standard Review Plan and Acceptance Criteria,” February 1996, ML042430048.

-----. “Acceptance for Docketing of the Hermes Non-power Test Reactor Construction Permit Application Submitted by Kairos Power LLC,” November 29, 2021, ML21319A354

-----. “Hermes Construction Permit Review Spring 2022 General Audit Plan,” February 10, 2022, ML22039A336.

-----. “Audit Plan for The Kairos Hermes Preliminary Safety Analysis Report Chapter 6, Section 6.3 Decay Heat Removal System,” February 17, 2022, ML22039A226.

-----. “Kairos Power LLC – Plan for an Audit of the Hermes Construction Permit Preliminary Safety Analysis Report Chapters 4 and 13.” February 23, 2022, ML22041B665.

-----. “Kairos Power LLC – Plan for an Audit of the Hermes Construction Permit Preliminary Safety Analysis Report Chapter 7 on Instrumentation and Control.” April 8, 2022. ML22089A166.

-----. “Audit Plan for Hermes Site Characteristics PSAR Chapter 2,” May 27, 2022, ML22143B016.

-----. “NRC Final Request for Additional Information 339 for Hermes Construction Permit Application Regarding Inspection of Vessel Internals and the Natural Circulation Flow Path,” August 2, 2022, ML22220A299.

-----. “NRC Final RAI 348 on Shutdown Rod Reliability and Defense in Depth.” August 2, 2022, ML22227A180.

-----. “NRC Final RAI 350 for Air Ingress into the Primary Heat Transport System,” August 2, 2022, ML22227A192.

-----. “NRC Final RCI 349 on Salt Purity in the Chemistry Control System and the Inert Gas System,” August 2, 2022, Accession No. ML22230D076.

-----. “NUREG 2263, “Environmental Impact Statement for the Construction Permit for the Kairos Hermes Test Reactor, Draft Report for Comment.” September 26, 2022, ML22259A126.

-----. “Summary Report for the Regulatory Audit of Kairos Power LLC Hermes Construction Permit Preliminary Safety Analysis Report – General Audit,” June 2023, ML23160A287.

-----. “Summary Report for the Regulatory Audit of Kairos Power LLC Hermes Construction Permit Preliminary Safety Analysis Report Site Characteristics (Chapter 2),” April 2023, ML23115A480.

-----. “Summary Report for the Regulatory Audit of Kairos Power LLC Hermes Construction Permit Preliminary Safety Analysis Report Chapters 4 and 13 (Accident Analysis),” June 2023, ML23160A287.

-----. “Summary Report for the Regulatory Audit of Kairos Power LLC Hermes Construction Permit Preliminary Safety Analysis Report Decay Heat Removal System (Chapter 6, Section 6.3),” April 2023, ML23115A480.

-----. “Summary Report for the Regulatory Audit of Kairos Power LLC Hermes Construction Permit Preliminary Safety Analysis Report Instrumentation and Control (Chapter 7),” April 2023, ML23115A480.

2 SITE CHARACTERISTICS

The purpose of evaluating the site characteristics of a proposed reactor facility is to determine whether the site selected is suitable for constructing and operating the proposed facility. Site characteristics include geography and demography; nearby industrial, transportation, and military facilities; meteorology; hydrology; and geology, seismology, and geotechnical engineering.

This chapter of the Kairos Power LLC (Kairos) Hermes construction permit (CP) safety evaluation (SE) describes the U.S. Nuclear Regulatory Commission (NRC) staff's (the staff's) technical review and evaluation of the preliminary information on site characteristics provided in Chapter 2, "Site Characteristics," of the Hermes preliminary safety analysis report (PSAR) Revision 3. The staff reviewed PSAR Chapter 2 against applicable regulatory requirements using regulatory guidance and standards to assess the sufficiency of the preliminary information on site characteristics for the issuance of a CP in accordance with Title 10, *Code of Federal Regulations* (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities." The staff's reviews and evaluations for areas relevant to PSAR Chapter 2, including regulations and guidance used, a summary of the application information reviewed, and evaluation findings and conclusions, are discussed in the SE sections below for each specific area of review. A summary and overall conclusions on the staff's technical evaluation of the Hermes site characteristics are provided in SE Section 2.6, "Summary and Conclusions on Site Characteristics."

2.1 <u>Geography and Demography</u>

2.1.1 Introduction

PSAR Section 2.1, "Geography and Demography," describes the proposed Hermes site and its surroundings, including population distributions for the area around the site.

2.1.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of the Hermes site geography and demography are as follows:

- 10 CFR 50.34, "Contents of applications; technical information," paragraph (a), "Preliminary safety analysis report," including 10 CFR 50.34(a)(1)(i), which requires that the PSAR include "A description and safety assessment of the site on which the facility is to be located, with appropriate attention to features affecting facility design. Special attention should be directed to the site evaluation factors identified in [10 CFR Part 100, "Reactor Site Criteria"]…."
- 10 CFR 50.35, "Issuance of construction permits."
- 10 CFR 50.40, "Common standards."
- 10 CFR 100.10, "Factors to be considered when evaluating sites," paragraph (b), which requires that in considering the acceptability of a site for a test reactor, the NRC consider the "Population density and use characteristics of the site environs including the exclusion area, low population zone, and population center distance."
- 10 CFR 100.11, "Determination of exclusion area, low population zone, and population center distance," paragraph (a), which provides criteria for the exclusion area boundaries

(EAB), low population zones (LPZ), and population center distance for a test reactor for the purposes of site evaluation.

The applicable guidance for the evaluation of the Hermes site geography and demography is as follows:

- NUREG-1537, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors,” Part 1, “Format and Content,” and Part 2, “Standard Review Plan and Acceptance Criteria,” Section 2.1, “Geography and Demography.”
- NRC Regulatory Guide (RG) 2.6, “Emergency Planning for Research and Test Reactors,” Revision 2.
- American National Standards Institute/American Nuclear Society (ANSI/ANS)-15.16-2015, “Emergency Planning for Research Reactors.”

2.1.3 Technical Evaluation

PSAR Section 2.1.1.1 states that the proposed site for the Hermes reactor is in the City of Oak Ridge, Roane County, Tennessee. As illustrated in PSAR Figure 2.1-1, the proposed site is located within the southwest extent of the Oak Ridge city limits; the city primarily extends to the northeast of the proposed site. PSAR Section 2.1.1.1 states that buildings K-31 and K-33 of a gaseous diffusion plant to enrich uranium, which were part of the U.S. Department of Energy (DOE) Oak Ridge Reservation (ORR), were previously located on the site. This area, which contained Buildings K-31 and K-33 as well as other nearby uranium enrichment facilities, is collectively called the East Tennessee Technology Park (ETTP). The site boundary encompasses approximately 185 acres (74.8 hectares).

PSAR Section 2.1.1.1 states that the site is adjacent to Poplar Creek, a tributary of the Clinch River arm of the Watts Bar Reservoir. Kairos states the latitude and longitude of the center-point of the proposed reactor are North 35° 56’ 15.9” and West 84° 24’ 11.2”.

PSAR Section 2.1.1.1 states that the site is located between the Cumberland Mountains (approximately 23.5 mi (38 km) to the northwest) and the Great Smoky Mountains (approximately 31.6 mi (51 km) to the southeast). Prominent human-made features within 5 mi (8 km) of the proposed site include (1) Oak Ridge National Laboratory (ORNL), approximately 4.8 mi (7.7 km) away; (2) the Clinch River Nuclear Site, approximately 3.6 mi (5.8 km) away; (3) Interstate-40 (I-40), approximately 4.9 mi (7.9 km) away; (4) a Heritage Railroad Corporation rail line, approximately 1,132 ft (345 m) away; and (5) a Norfolk Southern Railway Company rail line, approximately 3.5 mi (5.6 km) away. Natural features within 5 mi (8 km) of the proposed site include: (1) Poplar Creek, which is 0.2 mi (0.3 km) away; (2) the Clinch River arm of the Watts Bar Reservoir, 0.4 mi (0.6 km) away; and (3) Duct Island, approximately 0.6 mi (1 km) away. The nearest major metropolitan area is Knoxville, Tennessee, located approximately 25 mi (40 km) east of the proposed site. The surrounding area is mostly residential and agricultural except for the city of Oak Ridge.

PSAR Section 2.1.1.1 states that the proposed site and its surrounding area are flat. The reactor building would be the tallest building at the site, approximately 90 ft (27 m) above grade. Within 5 mi (8 km) of the proposed site, the topography varies from approximately 28 ft (8.5 m) below to approximately 760 ft (232 m) above the site elevation.

PSAR Section 2.1.1.2 identifies the Hermes EAB and the Emergency Planning Zone (EPZ) as coinciding with the site boundary and states that the Hermes licensee (i.e., Kairos) would have the authority over and control of this area, including the authority to exclude or remove personnel or property from the area (e.g., during an emergency). The LPZ is set to the area within 800 m (2,625 ft) from the reactor. PSAR Figure 2.1-3 illustrates the site boundary as well as the LPZ. Kairos states that the size of its EPZ is appropriate based on accident doses at the EPZ boundary (i.e., doses would not exceed the Environmental Protection Agency (EPA) protective action guides of 1 rem whole body or 5 rem thyroid) and based on the guidance given in ANSI/ANS-15.16-2015, “Emergency Planning for Research Reactors,” which is endorsed by RG 2.6, Revision 2.

In PSAR Section 2.1.2, Kairos provides the estimated resident and transient populations within 5 mi (8 km) of the proposed site for the year 2026 (the beginning of the requested licensing period) and for the year 2031 (the approximate end of the requested 4-year licensing period). Kairos presents the projected resident and transient populations in five distance bands, represented by concentric circles: 0 to 0.5 mi (0 to 0.8 km), 0.5 to 1 mi (0.8 to 1.6 km), 1 to 2 mi (1.6 to 3.2 km), 2 to 3 mi (3.2 to 4.8 km), and 3 to 5 mi (4.8 to 8 km). Each distance band is subdivided into 16 equal directional sectors; these sectors are illustrated and estimates for the sectors are presented in PSAR Figures 2.1-6 and 2.1-7. The population data are provided in PSAR Tables 2.1-1 and 2.1-2 for Roane County, Tennessee, and Morgan County, Tennessee, respectively.

As discussed in PSAR Section 2.1.2, Kairos estimated the 2026 and 2031 resident populations using 2010 census data. The population distribution in 2010 by census block groups is shown in PSAR Figure 2.1-4. PSAR Figure 2.1-5 shows the 2010 population data in the 16 directional sectors within each of the five distance bands. Kairos’s estimated population distributions for 2026 and 2031 are based on estimates for Roane and Morgan Counties from the Boyd Center for Business and Economic Research, the demographer for the State of Tennessee. Because there are no schools or lodging facilities within 5 mi (8 km) of the proposed site, Kairos concluded that there is zero transient population in the area.

The staff evaluated the sufficiency of the information on the geography and demography of the Hermes site that Kairos provided in PSAR Section 2.1, using the guidance and acceptance criteria from Section 2.1, “Geography and Demography,” in NUREG-1537, Parts 1 and 2. The staff used Google Maps and PSAR Figure 2.1-3, which includes a map of the site area, to verify that the point with the reactor coordinates provided in the PSAR falls within the proposed site. The staff also verified that this point is consistent with PSAR Figure 2.5-1, which illustrates the boring layout of the Hermes site. In addition, the staff independently verified the distance-direction relationships specified in the PSAR to area boundaries, roads, railways, waterways, and other significant features of the area using Google Maps. The staff verified that the Hermes EPZ size is appropriate and consistent with guidance in ANSI/ANS-15.16-2016, based on the Hermes preliminary maximum hypothetical accident (MHA) dose calculations in PSAR Chapter 13, which indicate that accident doses at the EPZ boundary (based on the assumption that the EAB and EPZ boundary is 250 m (820 ft) from the reactor) would not exceed EPA protective action guides of 1 rem whole body or 5 rem thyroid. The staff also verified that the EAB and LPZ sizes are appropriate and consistent with 10 CFR 100.11(a) based on the results of the MHA dose calculations in PSAR Chapter 13.

The regulation 10 CFR 100.11(a)(3) states that, in addition to an EAB and LPZ, an applicant should determine a “population center distance of at least one and one-third times the distance from the reactor to the outer boundary of the [LPZ] … the boundary of the population center shall be determined upon consideration of population distribution. Political boundaries are not controlling in the application of this guide." The 10 CFR Part 100 definition for "Population center distance" is "the distance from the reactor to the nearest boundary of a densely populated center containing more than about 25,000 residents." The staff determined that, based on U.S. Census data for 2020, the population of the City of Oak Ridge, Tennessee, is 31,402, and Oak Ridge is the largest city within 10 mi (16.1 km) of the proposed Hermes site. The staff notes that based on the population distribution data in PSAR Figures 2.1-5, 2.1-6, and 2.1-7, the densely populated portions of the City of Oak Ridge are to the northeast of the proposed site. In addition, the staff notes that Kairos's data indicate that current and future projected populations within 1 mi (1.6 km) of the proposed site are very small. As discussed above, the Hermes LPZ boundary is 800 m (2,625 ft) from the proposed reactor site. The staff notes that one and one-third times the distance to the LPZ is 1,067 m (3,500 ft), which is approximately two-thirds of a mile. Consequently, the staff finds that, although the proposed Hermes site is located within the limits of the City of Oak Ridge, the distance to the boundary of the nearest population center (based on population distribution information in the PSAR) is greater than one and one-third times the distance to the LPZ boundary and is therefore appropriate and consistent with 10 CFR 100.11(a)(3).

Based on its review, the staff determined that the geographical and demographical information provided in the PSAR is sufficiently detailed and accurate to provide the necessary bases to allow accurate assessments of the potential radiological impact on the public resulting from the siting and operation of the proposed Hermes facility, including analysis (e.g., dose calculations) presented in other PSAR chapters. The staff also finds that no geographic or demographic characteristics of the Hermes site render the site unsuitable for operation of the Hermes facility, and that the information provided meets the applicable acceptance criteria of NUREG-1537, Part 2, Section 2.1. Accordingly, the staff finds that the level of detail provided on geography and demography demonstrates an adequate design basis for the Hermes facility.

2.1.4 Conclusion

Based on its findings above, the staff concludes the information in Hermes PSAR Section 2.1 is sufficient and meets the applicable guidance and regulatory requirements identified in this SE section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40.

2.2 Nearby Industrial, Transportation, and Military Facilities

2.2.1 Introduction

Hermes PSAR Section 2.2, "Nearby Industrial, Transportation, and Military Installations," describes the present and projected future industrial, transportation, and military installations and operations in the area around the proposed Hermes site.

2.2.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of the industrial, transportation, and military installations nearby to the Hermes site are:

- 10 CFR 50.34, "Contents of applications; technical information," paragraph (a), "Preliminary safety analysis report," including 10 CFR 50.34(a)(1)(i), which requires that the PSAR include "A description and safety assessment of the site on which the facility is to be located, with appropriate attention to features affecting facility design. Special attention should be directed to the site evaluation factors identified in [10 CFR Part 100]…”.

- 10 CFR 50.35, “Issuance of construction permits.”
- 10 CFR 50.40, “Common standards.”
- 10 CFR 100.10, “Factors to be considered when evaluating sites,” paragraph (b), which requires that in considering the acceptability of a site for a test reactor, the NRC consider the “…use characteristics of the site environs...”.

The applicable guidance for the evaluation of the industrial, transportation, and military installations nearby to the Hermes site is as follows:

- NUREG-1537, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors,” Part 1, “Format and Content,” and Part 2, “Standard Review Plan and Acceptance Criteria,” Section 2.2, “Nearby Industrial, Transportation, and Military Facilities.”
- NRC RG 1.91, “Evaluations of Explosions Postulated to Occur at Nearby Facilities and on Transportation Routes Near Nuclear Power Plants,” Revision 2.

2.2.3 Technical Evaluation

The staff’s reviews of Kairos’s descriptions of nearby industrial, transportation, and military installations and analyses of associated potential accidents are discussed in the subsections below for (1) airports and air traffic, (2) waterways, (3) pipelines, (4) highways, (5) railways, and (6) nearby facilities (e.g., nearby industrial and nuclear facilities).

The staff notes that the proposed Hermes site is located less than four miles from the Tennessee Valley Authority (TVA) Clinch River site, for which the NRC issued an Early Site Permit (ESP) in 2019. In PSAR Section 2.2, Kairos cites certain information in the NRC-approved Clinch River ESP Site Safety Analysis Report (SSAR) regarding other facilities in the vicinity of the Clinch River site as also applicable for analyses of the proposed Hermes site. The staff finds that because of the proximity between the proposed Hermes site and the NRC-approved Clinch River site, certain information in the Clinch River ESP SSAR regarding nearby facilities is also applicable to the proposed Hermes site as discussed in further detail below.

2.2.3.1 Airports and Air Traffic

PSAR Section 2.2.2 describes the aircraft crash hazard at the proposed Hermes site. Kairos uses the methodology described in DOE-STD-3014-2006, “Accident Analysis for Aircraft Crash Into Hazardous Facilities,” for evaluating crash hazards.

2.2.3.1.1 Nearby Airports

In PSAR Section 2.2.2.1, Kairos discusses aircraft operations (i.e., landing and taking off) at the airports within 10 mi (16 km) of the proposed site. There are no existing commercial airports within this distance range. Airports within 10 mi (16 km) of the proposed site are shown in PSAR Figure 2.2-2. Liles Airport, in Harriman, Tennessee, is an inactive historic airport with no runways or airport facilities. Consequently, Kairos did not consider this airport further. Kairos also states that there are several private airports outside the 5 mi (8 km) radius of the proposed site that it eliminated from further consideration.

The staff finds Kairos's approach of eliminating the consideration of private airports outside the 8 km (5 mi) radius of the site to be reasonable because of the distance from the site and the small number of operations at these private airports, consistent with the guidance in Section 2.2.2 of NUREG–1537, Part 1.

In PSAR Section 2.2.2.1, Kairos identifies the Oak Ridge Airport as a future general aviation airport near the proposed site. This airport will be located less than 1 mi (1.6 km) from the proposed site. Construction of this airport is scheduled to begin in 2023 and the airport is scheduled to be in operation by 2025. PSAR Section 2.2.2.1 states that the proposed 5,000 ft (1,524 m) long runway of this airport would be oriented in such a way that the aircraft would not land or take off from this airport on a trajectory over the proposed site.

The Department of Energy (DOE) Environmental Assessment (EA) DOE/EA-2000 (Final), "Property Transfer to Develop a General Aviation Airport at the East Tennessee Technology Park Heritage Center," estimated that the Oak Ridge Airport would have 49,713 annual operations of which 25,472 operations would be by local aircraft and the remaining 24,241 would be by itinerant general aviation aircraft. The airport is proposed to be used by business leaders to fly into and out of Oak Ridge, Tennessee. Corporate jets, private airplanes, and emergency medical service aircraft would use this airport. Mostly piston-powered aircraft (92 percent of total operations) would use this airport. The remaining operations would be turbine-powered fixed wing aircraft (5 percent of total operations) and helicopters (3 percent of total operations). The Atlanta Air Route Traffic Control Center, or the Knoxville Terminal Radar Approach Control, would provide the required separation among all aircraft flying under the instrument flight rules in the area, including those operating at this airport. According to the DOE EA, all visual flight rules traffic is responsible for remaining clear of all aircraft in the vicinity. The DOE EA determined that the Beechcraft King Air 350i would be the most common aircraft to use the runway at the proposed Oak Ridge Airport.

The staff independently checked the AirNav database for any nearby airports in addition to those identified by Kairos. Oliver Springs Airport is 6 mi (10 km) away from the proposed site. It is a private airport and requires permission for use. Cox Farm Airport is approximately 15 mi (24 km) southeast of the proposed site and is also a private airport and requires permission for its use. McGhee Tyson Airport in Knoxville, Tennessee is the nearest public airport used by commercial airlines. The airport is approximately 24 mi (39 km) east of the proposed site with 135,415 annual operations by civilian and military flights. Approximately 32 percent of the operations are transient general aviation, 12 percent are local general aviation, 19 percent are commercial, 20 percent are air taxi, and 16 percent are military operations. The staff notes that based on the distance from the proposed Hermes site, it may be screened out of consideration based on the guidance in Section 2.2.2 of NUREG–1537, Part 1.

Based on the preceding discussion, the staff finds that Kairos has appropriately identified the nearby airports for determining potential crash hazards from aircraft operations, consistent with the guidance in NUREG-1537. Because the nearby airports, with the exception of the future Oak Ridge Airport, are either too far away or have too few annual operations, the staff finds that operations at nearby airports, except the Oak Ridge Airport, would pose negligible crash hazards to the proposed facility.

2.2.3.1.2 Nearby Victor and Jet Routes

As shown in PSAR Figure 2.2-2, one Victor Airway, V16, and one Jet Route, J46, are within 10 mi (16 km) of the proposed site. Both V16 and J46 are 9.2 mi (14.8 km) wide. The centerline of

V16 is approximately 6.2 mi (10 km) south of the proposed facility and the nearest edge of this airway is 1.6 mi (2.6 km) from the proposed site, as given in PSAR Table 2.2-5. The proposed site lies beneath the Jet Route J46. The centerline of J46 runs 0.9 mi (1.5 km) north of the proposed site.

Based on its review of the information above as well as its independent review of the appropriate Federal Aviation Administration aeronautical chart, the staff finds that Kairos has appropriately identified the nearby airways for determining aircraft crash hazards to the proposed facility.

2.2.3.1.3 Effective Area of the Proposed Facility

As discussed in PSAR Section 2.2.2.2, Kairos calculated the total effective area of the proposed facility (for evaluating aircraft crash hazards) as the sum of effective fly-in area and effective skid area, following the formula given in DOE-STD-3014-2006. The facility dimensions Kairos used, as provided in PSAR Table 2.2-6, are 170 ft (51.8 m) length, 50 ft (15 m) width, and 42 ft (12.8 m) height. PSAR Table 2.2-6 also provides the characteristic dimensions of different types of aircraft to be used in determining the effective area of the proposed facility. Using the equations from DOE-STD-3014-2006, Kairos determined the effective area for each type of aircraft, and Kairos's calculated values are given in PSAR Table 2.2-7.

The staff reviewed the effective area calculations described in the PSAR, and finds that Kairos used appropriate assumptions that are consistent with the proposed Hermes facility and site, and that Kairos also used a methodology that is consistent with established practice from DOE-STD-3014-2006. Therefore, based on its review of the information above, the staff finds that Kairos appropriately calculated the estimated effective areas of the proposed facility for evaluating crash hazards from different types of aircraft flying in the vicinity of the proposed site.

2.2.3.1.4 Estimation of Aircraft Crash Hazards

As described in PSAR Section 2.2.2.2, Kairos used the four-factor formula provided in DOE-STD-3014-2006 to estimate the aircraft crash hazard at the proposed facility from general aviation operations at the future Oak Ridge Airport or from aircraft transiting either the V16 or J46 airways. The four-factor method estimates the annual frequency of aircraft crashes into a facility as a product of four factors N_j, P_j, $f_j(x,y)$, and A_j for the *j*-th type of aircraft. N_j is the estimated annual number of site-specific aircraft operations (i.e., takeoffs, landings, or flights in airways). P_j is the aircraft crash rate (per takeoff, per landing, or per airway flight, as applicable). The term $f_j(x,y)$ is the probability that the crash location is within a specific 1 mi^2 area given that a crash already occurred. A_j is the site-specific effective area of the facility.

Crash Hazard from Flights in Airways V16 and J46

As discussed in PSAR Section 2.2.2.2, for its analysis of airway crash hazards, Kairos assumed the $N_j P_j f_j(x,y)$ values for different aircraft types to be equal to the site-specific values given for ORNL from Tables B-14 and B-15 of DOE-STD-3014-2006. Kairos's estimated annual frequencies for aircraft crashes from aircraft flying in the V16 and J46 airways are presented in PSAR Table 2.2-9.

The staff finds that Kairos's approach for estimating airway crash hazards is reasonable and notes that the four-factor formula method is equivalent to the methods given in Section 3.5.1.6

of NUREG–0800, “Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition.” The staff notes that ORNL is approximately 8 km (5 mi) from the proposed site, and therefore the staff expects that the $N_j P_j f_j(x, y)$ values for the proposed site will not be much different from those at ORNL.

Crash Hazard from General Aviation Aircraft Operations at the Future Oak Ridge Airport

In PSAR Section 2.2.2.3, Kairos discusses the estimated annual aircraft crash frequency from general aviation aircraft operations (landings and takeoffs) at the future Oak Ridge Airport. Similar to its airway crash hazard analysis, Kairos used the DOE four-factor formula to estimate the annual crash frequency at the proposed facility due to general aviation operations at the Oak Ridge Airport. Table 2.5 of the DOE EA for the Oak Ridge Airport provides an estimated total of 48,222 annual general aviation operations (landings and takeoffs) at this airport. Table B-1 of DOE-STD-3014-2006 provides crash rates of general aviation aircraft, from which Kairos chose representative values for fixed wing general aviation operations. Kairos’s values of $f_j(x, y)$ for general aviation aircraft taking off and landing are taken from Tables B-4 and B-5 of DOE-STD-3014-2006. Assuming that half of the total annual general aviation operations are landings and the other half are takeoffs, Kairos estimated the annual crash frequencies at the Hermes facility from aircraft operations at the future Oak Ridge Airport to be 1.44E–5 per year for takeoffs and 2.42 E–5 per year for landings, as indicated by PSAR Tables 2.2-8 and 2.2-9.

The staff finds that Kairos’s approach of estimating the crash hazard from general aviation operations at Oak Ridge Airport using the methodology given in DOE-STD-3014-2006 is appropriate and consistent with established practice. The staff notes that the DOE-STD-3014-2006 methodology is similar to the methodology given in Section 3.5.1.6 of NUREG–0800 for airport operations. The staff also finds Kairos’s use of crash rates for general aviation aircraft from DOE-STD-3014-2006 to be reasonable because the crash rates are generic values.

Crash Hazard from Helicopter Flights

PSAR Section 2.2.2.3 also discusses Kairos’s analysis of crash hazards due to helicopter operations near the proposed site. PSAR Section 2.2.2.3 states that, according to the DOE EA for the Oak Ridge Airport, an estimated 3 percent of the annual flight operations at the future Oak Ridge Airport are expected to be attributed to helicopters. PSAR Section 2.2.2.3 also notes that according to Section 5.3 of DOE-STD-3014-2006, nonlocal helicopter flights contribute insignificant crash hazard to a facility; however, it is necessary to consider potential crash hazards due to local planned overflights associated with facility operations (e.g., security flights) and area operations (e.g., spraying flights). Therefore, Kairos used the variation of the four-factor formula given for helicopter flights in DOE-STD-3014-2006 to estimate the annual crash frequency of helicopters onto the proposed facility. Kairos used a helicopter crash rate from Table B-1 of DOE-STD-3014-2006. Kairos estimated the number of local helicopter flights per year to be 1,491, which is the number of annual helicopter flights at the future Oak Ridge Airport based on Table 2.5 of the DOE EA. Kairos assumed that the average length of helicopter flights at this future airport would be 37 mi (60 km) based on Table B-43 of DOE-STD-3014-2006. Kairos calculated that the annual crash frequency from helicopters would be 1.36E–6 per year, as indicated in PSAR Tables 2.2-8 and 2.2-9.

The staff notes that the value of the estimated average helicopter flight length could be imprecise because it is not based on the types of helicopter operations that may necessarily take place at the Oak Ridge Airport and near the proposed site. However, as discussed below, based on the estimated overall annual aircraft crash frequency at the Hermes site, a potential aircraft crash is considered to be a design-basis event for the proposed facility and Kairos states that the reactor building will be designed accordingly. Therefore, the staff finds that Kairos's approach of estimating the crash hazard from helicopter operations, using the methodology given in DOE-STD-3014-2006, is appropriate and its estimated helicopter crash hazard is reasonable.

2.2.3.1.5 Total Annual Crash Frequency

As discussed in PSAR Section 2.2.2.4 and given in PSAR Table 2.2-9, Kairos estimated the total crash frequency at the proposed facility to be 4.84E–5 per year, from all flights in airways, general aviation flights taking off and landing at the future Oak Ridge Airport, and nearby helicopter operations. In PSAR Section 2.2.2.4, Kairos states that, although NUREG-1537 does not provide an acceptance criterion to evaluate aircraft accident frequency, DOE-STD-3014-2006 provides a screening value of 1.00E–6 per year, where the risk of an aircraft accident is considered acceptable if the frequency is less than this value. Kairos notes that its total annual crash frequency of 4.84E–5, as well as its total annual airway crash frequency of 8.42E–6, and total local (Oak Ridge Airport and helicopter operations) crash frequency of 4.00E–5 per year exceed this screening value. However, Kairos notes that for all cases the criterion is exceeded due to general aviation aircraft and helicopter operations, and the risk from large aircraft is well below the screening value. Consequently, in PSAR Sections 2.2.2.4 and 3.5, Kairos states that the safety related portion of the reactor building will be designed to withstand the impact of small general aviation aircraft.

The staff reviewed the information above and finds that Kairos used several conservative assumptions to estimate the annual aircraft crash frequencies at the proposed facility. For example, the general aviation crash rate from Table B-1 of DOE-STD-3014-2006 was derived based on the general aviation aircraft crashes from 1986 through 1993, but the staff notes that the crash rate of general aviation aircraft has improved since that time. Additionally, the staff notes that Kairos's analysis uses the most conservative crash location probability values for general aviation aircraft takeoff and landing from Tables B4 and B5, respectively, of DOE-STD-3014-2006. Moreover, the staff notes that Hermes would be a non-power reactor with a 4-year licensed operating life, as stated in PSAR Section 1.3.3.2. Based on the preceding discussion, the staff expects that the realistic annual frequency of potential aircraft crashes into the proposed Hermes facility would likely be lower than that reported in PSAR Section 2.2.2.4 and PSAR Table 2.2-9, and the lifetime frequency would also be reduced due the relatively short expected operating lifetime for Hermes. Therefore, the staff finds that the threshold annual frequency of 1.00E–6 is reasonable for evaluation of risk from aircraft impacts at the proposed Hermes facility.

The staff also finds that although the frequency of small aircraft impacts exceeds the screening value in DOE-STD-3014-2006, the risk from larger aircraft is low and less than the screening value, and Kairos will design the safety related portion of the reactor building to withstand impacts from small general aviation aircraft. Regarding helicopters, the staff notes that they will only comprise about 3 percent of operations at the proposed Oak Ridge Airport based on the information in PSAR Table 2.2-8, and therefore the staff expects that the number of helicopters near the proposed site will be small compared to general aviation aircraft. In addition, potential general aviation aircraft impacts would likely bound helicopter impacts based on the relative speeds of the aircraft. The staff's review of the reactor building design for aircraft impact is discussed in SE Section 3.5. Based on the above, the staff finds that Kairos's calculated total annual crash frequency is acceptable.

2.2.3.2 Waterways

PSAR Section 2.2.1.2 describes the waterways near the proposed Hermes site and PSAR Section 2.2.3 assesses the potential hazards to the proposed facility from water transportation of hazardous materials. As discussed in PSAR Section 2.2.1.2, the Clinch River flows from Tazewell, Virginia, and joins the Tennessee River/Watts Bar reservoir at Kingston, Tennessee, just west of Knoxville, Tennessee. Significant waterborne transport near the proposed site is only possible on the Clinch River arm of the Watts Bar Reservoir. Kairos used the annual waterborne commerce data for 2001 through 2015, compiled by the U.S. Army Corps of Engineers (USACE) Waterborne Commerce Statistics Center, to determine the nature of hazardous cargoes transported. Kairos identified very few shipping cargoes on the Clinch River during this time period. The cargoes that were shipped were classified as machinery (not electrical), fabricated metal products, limestone, and wood in the rough. No hazardous materials (e.g., chemicals and related products, petroleum, or ordnance) that could pose a threat to the proposed Hermes site were transported. As a result, Kairos concluded that the waterborne traffic nearby does not require further consideration with respect to accidents that could pose a hazard to the proposed facility.

The staff finds that Kairos used a reliable government source, the database compiled by the USACE, to assess whether waterborne commerce on nearby waterways could pose a credible hazard to the proposed facility. Based on the absence of potential hazardous cargoes during a 15 year period (2001 through 2015) near the proposed site, as indicated in the database, the staff finds that the traffic in nearby waterways will not pose a credible hazard (e.g., from fires, explosions, or release of toxic chemicals) to the proposed facility.

2.2.3.3 Pipelines

PSAR Section 2.2.1.1 describes two East Tennessee Natural Gas pipelines within 5 mi (8 km) of the proposed site. Enbridge operates these two natural gas pipelines, Pipeline 1 and Pipeline 2. Pipeline 1 is 6 in. (15 cm) in diameter and was constructed in 1957. Pipeline 2 is closest to the proposed site, approximately 1 mi (1.6 km) to the north-northeast of the proposed site. Pipeline 2 has a diameter of 22 in. (56 cm) and was constructed in 1950. Both pipelines are buried at least 3 ft (0.9 m) below grade and operate at a maximum allowable operating pressure of 720 psig (5 MPa). Various isolation valves are located along the pipeline route and can be reached and operated within 1 hour of a notification.

The staff focused its review, discussed below, on hazards from a hypothetical pipeline rupture on Pipeline 2 since Pipeline 2 is closer to the proposed facility and has a larger diameter. As such, the effects of a postulated rupture of Pipeline 1 would be bounded by the effects from a rupture of Pipeline 2.

PSAR Section 2.2.3.1 states that for both pipelines, an unconfined release of natural gas resulting in an explosion (i.e., detonation, in which the flame front of the released material propagates at greater than speed of sound) is not a credible event. Ignition of natural gas near the release point would result in a jet fire or a deflagration (rapid burning of natural gas, but at less than the speed of sound). Detonation of the natural gas vapor cloud released from a ruptured pipeline could occur only if the vapor cloud becomes confined by migrating inside a building or a confined space. Kairos concluded that detonation of a natural gas vapor cloud released from a ruptured pipeline is not a credible hazard to the proposed facility.

In addition to reviewing the information presented by Kairos on the effects of a potential rupture of a pipeline, the staff reviewed literature including, for example, Gas Research Institute Report GRI-00/0189, “A Model for Sizing High Consequence Areas Associated with Natural Gas Pipelines,” for potential sequences of events that could progress after the rupture of a pipeline. In its assessment, the staff conservatively assumed that Pipeline 2 would suffer a full-bore rupture (guillotine break) at the closest point to the proposed site, approximately 1 mi (1.6 km) away. Using Google Maps, the staff determined that the hypothesized rupture point of Pipeline 2 (where it is the shortest distance from the proposed Hermes site) is in an open field with trees and a few roads. The staff notes that a potential rupture of a pressurized pipeline would release natural gas at high momentum, i.e., as a jet. As the time necessary for the operator to reach and operate the isolation valves could be 1 hour, a significant amount of natural gas would be released to the atmosphere from the pipe break.

The staff notes that if the release from a ruptured pipeline continues without ignition after the isolation valves are closed (within 1 hour after notification of the pipeline rupture), choked flow from the pipeline would no longer occur. The jet of released natural gas would transition from a momentum-driven turbulent discharge to a cloud dominated by buoyant forces, and the release of natural gas through the ruptured pipeline would decrease with time after the close of the isolation vales until the inventory in the pipeline is exhausted.

The staff’s assessments of scenarios (jet or trench fire, flash fire/fireball, and potential vapor cloud explosion) following a potential pipeline rupture and prior to closing of the isolation valves are discussed in the subsections below. The scenarios assessed by the staff are based on similar pipeline rupture events as those described in, for example, GRI-00/0189.

2.2.3.3.1 Jet or Trench Fire

The staff notes that a jet or a trench fire may develop after the full-bore rupture of a pipeline depending on whether the rupture creates a crater (trench). It is likely that a crater would form after a rupture of either of Pipelines 1 or 2 based on the depth of the pipelines below ground. The natural gas may trap air and form droplets as it escapes through the ruptured pipe in a high momentum jet. The heavier droplets of natural gas-air may rain out from the jet to form a pool of natural gas. In the presence of an ignition source, such as sparks generated by pipe fragments or rock pieces, a jet fire may start. The staff notes that in contrast to a jet fire, a flash fire or a fireball, discussed below, may start within seconds of pipeline rupture and would precede the jet fire. Flash fires generally have a short duration (a few seconds only) and can potentially start brush fires, but do not generate overpressure.

Kairos stated in PSAR Section 2.2.3.2 that, based on analysis presented in the Clinch River Site ESP SSAR, Revision 2, the safe distance beyond which the heat flux would be 5 kW/m^2 or less from a postulated jet fire at Pipelines 1 and 2 are 312 ft (95 m) and 1,203 ft (370 m), respectively. As the calculated distances are significantly less than 1 mi (1.6 km), the shortest distance between the proposed site and either pipeline, Kairos concludes in PSAR Section 2.2.3.2 that a jet fire after a rupture of either pipeline is not expected to adversely affect the operation or shutdown of the Hermes reactor at the proposed site.

The staff notes that a heat flux of 5 kW/m^2 is tolerable by humans and would not cause first-degree burns. Plastic will not melt at this heat flux.

The staff performed an independent calculation of a potential jet or trench fire using the formula given in 49 CFR Part 192, Subpart O, “Gas Transmission Pipeline Integrity Management,” to estimate the Potential Impact Radius (PIR) from a jet or a trench fire of released natural gas. The formula is used to calculate a PIR based on a heat flux of 15.8 kW/m^2. Using this formula, the staff determined that the effect of the jet or trench fire would not be significant on people or property beyond 407 ft (124 m). As Pipeline 2 is at least 1 mi (1.6 km) away from the proposed site, the staff’s calculation, similar to Kairos’s analysis, indicates that jet fire resulting from a rupture of Pipeline 2 would not be a credible hazard to the proposed facility.

The staff notes that natural gas in a pool, if formed near the pipe rupture location, would continually evaporate as it extracts heat from the air and the ground. In addition, with the ruptured location being in an open field, a significant amount of natural gas may seep into the soil. However, the staff notes that if the pool catches fire, the thermal radiation would not be able to affect the Hermes facility because of the significant separation distance (at least 1 mi (1.6 km)).

Based on the preceding discussion, the staff finds that a jet or trench fire, or any potential pool fire, at the near-most point of Pipeline 2 to the proposed site would not be credibly expected to cause any damage to safety related structures systems and components (SSCs) at the proposed facility.

2.2.3.3.2 Flash Fire

The staff notes that a plume of vapor (i.e., a vapor cloud) could form near the pipeline break. As the plume increases in size, small-scale turbulence within it mixes the natural gas-air mixture. The concentration of natural gas is at a maximum near the discharge point and decreases to the lower flammability limit near the cloud edges, both axially and laterally. The natural gas leaving the boundary of the cloud below its lower flammability limit does not contribute to any fire or explosion. The staff notes that if the plume meets an ignition source and portion of the cloud is within the flammability limits, a flash fire could occur without generating significant overpressure.

The staff also notes that if the natural gas cloud does not meet an ignition source, the cloud rises in the atmosphere because natural gas is lighter than air, and the cloud disperses. It cannot contribute to a fire and/or explosion if the concentration of natural gas drops below the lower flammability limit. The vapor cloud dispersion in the atmosphere is controlled by the prevalent meteorological and topographic conditions. Concentration of the natural gas within the plume decreases as the cloud is transported by the wind.

2.2.3.3.3 Potential Vapor Cloud Explosion

The staff notes that ignition of the vapor cloud could lead to a deflagration (rapid burning, but at less than speed of sound) of the natural gas vapor in the cloud. The deflagration may generate significant overpressure. Only in extremely rare circumstances would transition to detonation (combustion of the mixture propagates faster than the speed of sound) occur. The staff notes that according to Mercx, et al., “Vapour Cloud Explosions,” ignition energy needed to initiate a deflagration is on the order of 10E–4 Joules for common hydrocarbon-air mixtures; however, direct initiation of detonation requires approximately 10E6 Joules, an increase of 10 orders of magnitude. The staff notes that such a concentration of energy may be available from high explosives, but common ignition sources, such as sparking of electrical apparatuses, hot steam lines, open furnaces, heaters, and moving parts in machinery, do not generally possess such high energy concentration to directly initiate a detonation event.

Alternatively, a deflagration of the vapor cloud may transition to a detonation event if sufficient congestion or obstruction is present in the flame propagation path to mix the natural gas thoroughly with air in a confined area such that the natural gas vapor accumulates to the point that its concentration is within the upper and lower flammability limits (UFL and LFL). However, the staff notes that as the pipeline near the proposed facility traverses through an open field (an unconfined release scenario), there are no structures nearby that can provide the necessary confinement of the natural gas vapor cloud. As discussed above, the vapor cloud would rise due to the buoyancy of natural gas and disperse in the atmosphere without causing a fire and/or an explosion event that could affect the proposed facility.

2.2.3.3.4 Conclusions on Pipeline Hazards

Based on the preceding discussion, the staff notes that a hypothetical rupture of Pipeline 2 at the point closest to the proposed facility could release a significant amount of natural gas into the surrounding atmosphere. However, the staff finds that ignition of the resulting jet of natural gas released from the ruptured pipeline would not produce heat flux capable of damaging any safety related SSCs at the proposed facility due to the large distance from the proposed site. Similarly, heat flux from any pool fire would not have significant consequences to any safety related SSC. The staff notes that a flash or cloud fire would likely be of short duration, lasting only a few tens of seconds. The staff finds that thermal flux generated by a flash or cloud fire, as well as resulting overpressure, would be too small to cause damage to safety related SSCs at the proposed facility.

The staff also finds that it is highly unlikely that the natural gas plume resulting from a pipeline rupture would detonate upon ignition because the energy density necessary to directly initiate a detonation event is extremely large and would likely only be available from a high explosive source. The staff notes that as Pipeline 2 is in rural surroundings without any possible confinement, direct detonation of the natural gas cloud would be highly unlikely. The staff notes that, based on staff evaluation of maps of the local area, common ignition sources from industrial machineries are likely not available nearby. In addition, the terrain near the pipeline rupture point is in a topographic ridge structure with many trees. The staff notes that there is a significant possibility that even if a deflagration starts in the plume, somewhat confined within the trees, the terrain will reduce the overpressure experienced by the proposed facility. In addition, the staff finds that the distance of 1 mi (1.6 km) to the proposed site would reduce the peak overpressure significantly. Therefore, based on the preceding discussion, the staff finds that a potential explosion of the natural gas released from a rupture of Pipeline 2 is unlikely to cause damage to safety related SSCs at the proposed facility.

The staff further notes that a review of major vapor cloud incidents in the world, “Review of Vapour Cloud Explosion Incidents” (Atkinson, et al., 2017), commissioned by the U.S. Pipeline and Hazardous Materials Safety Administration (PHMSA) and the U.K. Health and Safety Executive, did not identify any historical records of vapor cloud explosions of liquefied natural gas or methane in open areas with sufficient severity to cause damage. In addition, as discussed in the “Report of the U.S. Nuclear Regulatory Commission Expert Evaluation Team on Concerns Pertaining to Gas Transmission Lines Near the Indian Point Nuclear Power Plant,” an NRC expert panel contacted PHMSA pipeline accident investigators in connection with potential rupture and associated consequences of natural gas pipelines near the Indian Point Energy Center nuclear power plant, and noted that these accident investigators have expressed a similar opinion to that expressed in the aforementioned review in that the investigators were unaware of any large natural gas (methane) delayed vapor cloud explosions resulting from a pipeline rupture. In addition, as discussed in the Indian Point report, the NRC expert panel did not find “any record of dense methane gas clouds … igniting or exploding at a location away from the initial pipe rupture.”

2.2.3.4 Highways

Kairos describes the highways nearby to the proposed site in PSAR Section 2.2.1.3. In addition, PSAR Section 2.2.3.1 discusses potential explosion hazards to the proposed facility from the accidental release of flammable materials being transported on these highways. PSAR Sections 2.2.3.2 and 2.2.3.4 discuss potential hazards from flammable vapor clouds and fires, respectively, to the proposed facility. PSAR Section 2.2.3.3 discusses potential hazards to the proposed facility from the accidental release of toxic chemicals on highways near the proposed site.

As discussed in PSAR Section 2.2.1.3, the interstate highway I-40, and four state highways, TN-58, TN-63, TN-95, and TN-327, are within 5 mi (8 km) of the proposed site. I-40 is the most significant highway and, as discussed in PSAR Sections 2.2.1.3 and 2.2.3.3, it is just under 5 mi (8 km) away at its closest point from the proposed site. As discussed in PSAR Section 2.2.3.3, TN-58 is approximately 1.2 mi (1.9 km) away at its closest distance from the safety related area of the proposed site. PSAR Section 2.2.3.1 states that TN-58 highway is used as a feeder highway to I-40. PSAR Section 2.2.1.3 states that, based on data from the Tennessee Department of Transportation, the annual average daily vehicle count on I-40 just east of its intersection with TN-58 was 44,470 in 2018.

PSAR Section 2.2.1.3 indicates that the closest state highway to the proposed site is TN-327, approximately 0.6 mi (1.0 km) away. Based on the data from the Tennessee Department of Transportation for 2018, the annual average daily vehicle count on TN-327 west of the intersection with TN-58 was 2,485, and the annual average daily vehicle count on TN-58 north of the intersection with TN-327 was 12,641.

In PSAR Section 2.2.1.3, Kairos identifies I-40 and TN-58 as those roads within 5 mi (8 km) of the proposed site on which chemicals may be transported. PSAR Table 2.2-4 identifies hazardous materials that could be transported on these roads and that could potentially impact the Hermes facility at the proposed site. For evaluation of potential impacts from flammable vapor clouds and toxic chemicals, Kairos used the assessment made in the Clinch River ESP SSAR using the Areal Locations of Hazardous Atmospheres (ALOHA) computer code.

2.2.3.4.1 Explosions

In PSAR Section 2.2.3.1, Kairos assessed the potential for detonation of high explosives and munitions, and deflagration of chemicals and liquid and gaseous fuels along nearby highway routes. Kairos evaluated each hazardous chemical listed in PSAR Table 2.2-4 with respect to its explosive potential using the assessment conducted for the Clinch River Site ESP application. Kairos assessed the effects of detonation and deflagration in terms of structural response to blast overpressure using NRC RG 1.91, “Evaluations of Explosions Postulated to Occur on Transportation Routes Near Nuclear Power Plants,” Revision 2. In addition, for Kairos’s assessment, trinitrotoluene (TNT) mass equivalents of chemicals are calculated using NUREG–1805, “Fire Dynamics Tools (FDTs) Quantitative Fire Hazard Analysis Methods for the U.S. Nuclear Regulatory Commission Fire Protection Inspection Program.”

As indicated in PSAR Table 2.2-10, Kairos identified the materials that may explode while being transported on nearby highways to include: (1) butane in 11,500 gal (43,532 L) tanker trucks, (2) gasoline in 8,500 gal (38,642 L) tanker trucks, and (3) hydrogen in tubes having capacity of 15,032 ft3 (426 m^3) per tube. PSAR Section 2.2.3.1 states that of these materials, butane has the longest minimum safe distance, 3,708 ft (1,130 m). PSAR Section 2.2.3.1 states that Kairos considered the minimum safe distance to be the distance at which the air overpressure would be 1 psi (6.9 kPa) from a potential explosion since RG 1.91 recommends 1 psi (6.9 kPa) as a conservative threshold for structural damage. The distance from the proposed site to either I-40 or TN-58 is greater than the minimum safe distance from a potential butane explosion, specified above. Therefore, Kairos concludes that hazardous materials transported on the nearby highways would not pose a credible explosion hazard to the proposed facility.

The staff reviewed Kairos's assessment and finds that Kairos followed appropriate guidance in RG 1.91 to assess the hazard from the potential explosion of hazardous chemicals transported on the nearby highways. The staff finds that Kairos conducted the assessment for three chemicals that may explode while being transported on highways, and, using guidance in RG 1.91, Kairos identified that the minimum safe distance for butane (the limiting chemical) would be smaller than the distance from I-40 or TN-58 to the proposed site. Therefore, the staff finds that potential explosion of hazardous chemicals being transported on nearby highways would not pose a credible hazard to the proposed facility.

2.2.3.4.2 Flammable Vapor Clouds

In PSAR Section 2.2.3.2, Kairos assessed the potential for a flash or cloud fire and a possible vapor cloud explosion (VCE) from flammable chemicals in both liquid and gaseous forms transported on the nearby roadways. PSAR Section 2.2.3.2 states that flammable chemicals could hypothetically form unconfined vapor clouds that could then drift toward the proposed facility under the prevailing atmospheric conditions before being ignited (delayed ignition). The portion of the cloud that is within the UFL and LFL of the released chemical could potentially ignite and burn if the cloud encounters an ignition source. The speed of this exothermic reaction's propagation through the vapor cloud determines whether it will be a deflagration (i.e., a VCE; slow burning) or a detonation event.

The staff notes that, similar to potential methane clouds released from natural gas pipelines as discussed above, detonation events involving other flammable vapor clouds, such as those that could be generated from flammable chemicals in liquid and gaseous form transported on highways or stored at nearby facilities, are also unlikely and would not be expected to pose a credible hazard to the proposed Hermes facility.

As discussed in PSAR Section 2.2.3.2, Kairos used the analyses conducted for the Clinch River Site ESP SSAR to assess the potential hazards posed by each chemical that may be transported on I-40 and TN-58. Kairos assessed both flash or cloud fire and VCE scenarios for each chemical. Kairos states that, in the Clinch River Site ESP SSAR, the dispersion model of the ALOHA code was used to determine the outer edge of the LFL limit, in order to identify the portion of the vapor cloud with flammable concentrations. Following the guidance in RG 1.91, Kairos assumed an overpressure threshold of 1 psi (6.9 kPa) to initiate damage to a safety related structure.

The staff notes that a flash fire exists for a very short duration and does not burn at a high temperature. Consequently, a structure must be within the burning cloud (portion of the cloud with concentration within the flammable range) to be significantly affected by thermal radiation.

As discussed in PSAR Section 2.2.3.2, Kairos states that the Clinch River Site ESP SSAR analysis identifies two chemicals potentially transported on I-40 and TN-58 that could be susceptible to delayed VCEs: (1) butane in 11,500 gal (43,532 L) tanker trucks and (2) gasoline in 8,500 gal (32,176 L) tanker trucks. Based on the assessment made in the Clinch River Nuclear Site ESP SSAR, Kairos states that butane has the longest safe distance (i.e., distance at which the overpressure generated by a VCE would exceed the 1 psi (6.9 kPa)), and this safe distance is 3,864 ft (1,178 m). The safe distance for gasoline is estimated to be 618 ft (188 m). Kairos states that these distances are less than the distance to either highway at the closest points to the proposed site. Additionally, PSAR Section 2.2.3.2 states that the distance to LFL for butane (which has the longest flammable plume of the analyzed chemicals) is 1,827 ft (557 m), which is less than the distance between either I-40 or TN-58 and the proposed site. Because the distance to the LFL is less than the distance of the proposed facility to both highways, and also because the safe distance for VCEs is less than the distance between the highways and the proposed site, Kairos concluded that potential ignition or VCEs from release of chemicals being transported on nearby highways would not pose a hazard to the proposed site.

The staff reviewed the information presented by Kairos and the analyses presented in the Clinch River Nuclear Site ESP SSAR as referenced by Kairos. The staff notes that the Clinch River SSAR analyses were previously approved by the NRC and finds that Kairos appropriately applied the analyses to the Hermes site considering the different location of the Hermes site and the Clinch River site. Based on its review, the staff finds that potential VCEs of chemicals transported on nearby highways would not pose a credible hazard to the proposed facility. Additionally, the staff finds that a vapor cloud would be diluted well below the LFL before reaching the proposed site. Therefore, the staff finds that a cloud or flash fire, or possible VCE, of the vapor cloud would not be expected to affect the safety related structures at the proposed facility and would not be a credible hazard.

2.2.3.4.3 Fires

PSAR Section 2.2.3.4 discusses the effects of potential fires associated with the chemicals being transported on the nearby highways I-40 and TN-58. Kairos states in PSAR Section 2.2.3.4 that based on the analyses from the Clinch River Nuclear Site ESP SSAR that are discussed in PSAR Sections 2.2.3.1 and 2.2.3.2, potential chemical fires from the vapor clouds due to accidents involving materials transported on highways I-40 and TN-58 would not affect the proposed facility.

The staff reviewed PSAR Section 2.2.3.4 as well as the relevant sections of the Clinch River Nuclear Site ESP SSAR as referenced by Kairos. Based on its review, and also consistent with its findings for flammable vapor clouds due to accidents involving materials transported on highways in the SE section above, the staff finds that any flash or cloud fire resulting from the transport of chemicals on I-40 or TN-58 would not be able to generate sufficient heat flux to cause damage to safety related structures because the distance at which the vapor cloud concentration decreases below the LFL is a significant distance away from the proposed facility.

PSAR Section 2.2.3.4 states that the potential effects of a brush fire or a forest fire on Hermes will be evaluated in an application for an OL.

2.2.3.4.4 Toxic Chemicals

In PSAR Section 2.2.3.3, Kairos evaluates the potential for toxic gas releases from highway sources within 5 mi (8 km) of the proposed site in order to assess the potential toxicity and ability to affect personnel in the Hermes Main Control Room. Kairos identifies the chemicals that may be transported on highways I-40 or TN-58 in PSAR Table 2.2-4. PSAR Section 2.2.3.3 states that the safety related area of the proposed facility is located approximately 4.8 mi (7.7 km) from I-40 and 1.2 mi (1.9 km) from TN-58. To support its assessment of potential toxic chemical releases from highway sources, Kairos references the assessment of toxic chemicals made in the Clinch River ESP SSAR, which uses the ALOHA computer code. Kairos evaluated potential mobile sources of hazardous chemicals (selected based on the chemicals listed in PSAR Table 2.2-4) that could impact the Main Control Room. Table 2.2-11 of the Clinch River ESP SSAR gives the minimum safe distance for various chemicals transported on I-40, where the minimum safe distance is the distance from a release point beyond which the concentration of the released chemical drops below its respective Immediately Dangerous to Life or Health (IDLH) value. Kairos used the information in Table 2.2-11 of the Clinch River ESP SSAR to assess whether chemicals being transported on I-40 and TN-58 could pose a hazard to safe operation of the Hermes facility.

Based on the results given in Table 2.2-11 of the Clinch River ESP SSAR, Kairos determined the chemicals listed in PSAR Table 2.2-4 would not pose a hazard for transportation on I-40 because the minimum safe distances are less than the distance between I-40 and the Main Control Room. However, Kairos determined that transportation of anhydrous ammonia and chlorine on highway TN-58, which runs significantly closer to the proposed site, could potentially produce a concentration hazardous to life or health at the proposed site because the minimum safe distance exceeds the distance between TN-58 and the Main Control Room. Consequently, in PSAR Sections 2.2.3.3 and 7.4, Kairos states that it will design the Main Control Room with ammonia and chlorine detectors in the ventilation system.

The staff reviewed the information in PSAR Section 2.2.3.3 and the assessment presented in Table 2.2-11 of the Clinch River ESP SSAR as they pertain to toxic chemical releases that could affect the Hermes Main Control Room. The staff notes that, as discussed in PSAR Section 2.2.3.3, analyses of airborne dispersion of released chemicals in the Clinch River ESP SSAR were conducted using the ALOHA computer code with the worst-case wind direction and a temperature and a wind speed having an annual exceedance probability of 5 percent. As the distance of the proposed site from the Clinch River Nuclear Site is only 3.6 mi (5.8 km), the staff expects that the temperature and the wind speed at 5 percent annual exceedance probability would be similar for estimating the airborne concentration of chemicals at the Hermes site. Based on the review, including reviews of the estimated minimum safe distances for highway-transported chemicals provided in the Clinch River ESP SSAR and referenced in the PSAR, the staff finds that Kairos appropriately identified anhydrous ammonia and chlorine as chemicals that could affect the Hermes Main Control Room at the proposed site. The staff also finds that Kairos plans to install ammonia and chlorine detectors in the ventilation system for the Hermes Main Control Room. Therefore, the staff finds that Kairos has appropriately identified and addressed the potential for any toxic chemicals being transported on nearby highways to affect the Hermes facility.

2.2.3.5 Railways

PSAR Section 2.2.1.4 describes the railway lines near the proposed site and assesses the potential hazards to the proposed site from an accidental release of hazardous materials being transported on these railroads. Norfolk Southern operates the two major railway lines near the proposed site. One line runs parallel to state highway TN-61, from Harriman, Tennessee, toward Clinton, Tennessee. At its closet point, this line is 3.3 mi (5.3 km) from the proposed site. The other line runs through Loudon, Tennessee, to Knoxville, Tennessee. The line at its closest point is approximately 12 mi (19.3 km) away from the proposed site. Kairos states that due to the complex terrain (valleys and wooded ridges) between the site and these railway lines, and also due to the distance between the site and the railways, it did not evaluate any accident scenarios for these railways.

PSAR Section 2.2.1.4 also identifies a minor rail line, owned and operated by Energy*Solutions* LLC, that runs close to the proposed site. This rail line connects the Blair Interchange of the Norfolk Southern main line north of the site to the Heritage Center Industrial Park. Kairos states that this rail line transports mostly solid, low-level radioactive waste, and approximately 121 railcars were moved over this line in fiscal year 2020. PSAR Section 2.2.1.4 states that because solids have a sufficiently low vapor pressure, formation of a vapor cloud is an unlikely event. Additionally, the solid waste materials are not considered explosive. Therefore, Kairos concludes that accidents involving transport of these solid waste materials on this minor rail line would not pose a significant threat to the proposed facility.

The staff reviewed the information presented in PSAR Section 2.2.1.4. The staff notes that, according to Google Maps, there are several valleys and wooded ridges in proximity to both the major railway lines and the proposed site. The staff finds that, as a result of this terrain, the magnitude of the pressure waves from any immediate detonation of released chemicals from a potential accident on these major rail lines would be significantly reduced when they reach the proposed site. In addition, the staff finds that the thermal radiation from a potential fire due to an accidental release of hazardous chemicals being transported on the major rail lines would not directly affect any safety related SSCs at the proposed facility because the intervening distance is too large. The staff also finds that the concentration of the plume of the released chemicals would be significantly diluted when the proposed plume reaches the site. Therefore, due to the large distance combined with the complex intervening terrain (with wooded ridges and valleys), the staff finds that a release of toxic chemicals from an accident on these major rail lines would not pose a credible hazard to the proposed site. Regarding the minor rail line which transports primarily low-level radioactive waste, the staff finds that these low-level waste materials do not pose a significant threat to the proposed facility due to their physical properties. Based on the above, the staff finds that the transportation of hazardous materials by rail would not pose a credible hazard to the proposed site.

2.2.3.6 Nearby Facilities

In PSAR Section 2.2.3, Kairos assessed 15 facilities near the proposed site to determine whether an accident at any of these facilities could affect the proposed reactor facility. These 15 facilities are within 20 mi (32 km) of the proposed site and are listed in PSAR Table 2.2-1. The list in PSAR Table 2.2-1 includes the proposed Clinch River Nuclear Site, the Energy*Solutions* LLC Bear Creek Facility, the K1251 Barge Docking Facility, ORNL (including ORNL-Battelle and ORNL-URS, which are counted together for the purpose of PSAR Table 2.2-1), the proposed Oak Ridge Airport, the proposed Coqui Pharmaceutical facility, two water treatment facilities, two TVA fossil fuel power plants, technology/industrial parks, and the White Oak Dam. Based on the activities conducted at these facilities, Kairos screened out nine of the facilities as not having significant impact on the proposed reactor facility. These nine facilities are listed in PSAR Table 2.2-2.

Additionally, as indicated in PSAR Table 2.2-1, three of the other facilities listed in PSAR Table 2.2-1, the Clinch River Nuclear Site, Coqui Pharmaceutical, and the Oak Ridge Airport, are proposed facilities and construction of these facilities has not yet started. Consequently, Kairos states that it was unable to assess the specific hazards from these three facilities. However, Kairos states that it expects the operations at the Coqui Pharmaceutical facility to be similar to the SHINE Medical Technologies LLC (SHINE) facility in Janesville, Wisconsin, and the radiological effects during routine operations and accidents from this radiopharmaceutical production facility would be within the NRC's regulatory dose limits. In addition, Kairos states that SHINE has shown in its SHINE Medical Isotope Production Facility PSAR that a release of on-site chemicals would not be a hazard to personnel in the control room of its facility. Based on this, Kairos states that it expects that chemicals stored on site at the proposed Coqui Pharmaceutical facility would not pose a hazard to the proposed Hermes facility. In addition, Kairos states that the future Oak Ridge Airport is considered in the Hermes PSAR on the basis of estimated information. Kairos references the DOE EA for the Oak Ridge Airport which describes a fuel farm with two tanks, each having a capacity of 10,000 gal (37,855 L) of aviation fuel, to be constructed at the proposed airport.

PSAR Section 2.2.3 states that the Clinch River Nuclear Site ESP SSAR provides an analysis to demonstrate that the offsite radiological impact from routine operations and accidents at one or more reactors on the Clinch River site would be within the regulatory limits. Additionally, although the proposed Hermes site would be within the LPZ of the Clinch River Site reactor(s), the proposed Hermes site would not be within the EPZ for reactor(s) on the Clinch River Nuclear Site. As appropriate, the staff will assess the potential hazards from an accident at the Clinch River Nuclear Site, Coqui Pharmaceutical, and Oak Ridge Airport (including the fuel farm) on the proposed reactor facility further during an operating license (OL) application review.

Kairos states that it assessed the remaining three (currently existing) facilities for the potential effects on the proposed Hermes facility based on their design parameters or associated physical phenomena considering the guidance in NUREG-1537, as well as NRC RG 1.78, "Evaluating the Habitability of a Nuclear Power Plant Control Room During a Postulated Hazardous Chemical Release," Revision 1; NRC RG 1.91, "Evaluations of Explosions Postulated To Occur on Transportation Routes Near Nuclear Power Plants," Revision 2; and NRC RG 4.7, "General Site Suitability Criteria for Nuclear Power Stations," Revision 3. These three facilities are ORNL (including ORNL-Battelle and ORNL-URS), the TVA Kingston Fossil Plant (a coal-fired electric generation facility), and the TVA Bull Run Fossil Plant (a coal-fired electric generation facility).

Although Kairos generally excluded the two nearby water treatment facilities, the Oak Ridge and Hallsdale Water Treatment Plants (WTPs), from consideration of potential impacts on the proposed Hermes site due to their distance from the site and included these two facilities in PSAR Table 2.2-2, the staff notes that Kairos did consider these two facilities in evaluating the potential for releases of toxic chemicals from nearby facilities as discussed below.

2.2.3.6.1 *Explosions*

In PSAR Section 2.2.3.1, Kairos assesses the potential for detonation of high explosives and munitions, chemicals, and liquid and gaseous fuels at nearby facilities to affect the Hermes facility at the proposed site. Kairos assessed the effects of detonation and deflagration in terms of structural response to blast overpressure using the guidance in NRC RG 1.91, Revision 2. For Kairos's assessment, TNT mass equivalents of chemicals are calculated using the guidance in NUREG–1805, "Fire Dynamics Tools (FDT[s]) Quantitative Fire Hazard Analysis Methods for the U.S. Nuclear Regulatory Commission Fire Protection Inspection Program."

Kairos assessed the effects of explosions at ORNL-Battelle and the nearby Kingston and Bull Run Fossil Plant facilities based on information in the Clinch River ESP SSAR. The staff notes that Table 2.2-2 of the Clinch River ESP SSAR and Hermes PSAR Table 2.2-3 indicate that flammable chemicals are stored at these three facilities. PSAR Section 2.2.3.1 states that ORNL-Battelle is approximately 5 mi (8 km) east of the proposed Hermes site. The TVA Kingston Fossil Plant is approximately 7 mi (11.2 km) from the proposed Hermes site and the TVA Bull Run Fossil Plant is approximately 15 mi (24.1 km) from the proposed Hermes site.

Kairos lists chemicals being stored at ORNL-Battelle, along with quantities, in PSAR Tables 2.2-3 and 2.2-10. Kairos used the assessment conducted in the Clinch River ESP SSAR (see SSAR Tables 2.2-2 and 2.2-5) to identify potentially explosive materials stored in each facility (ORNL-Battelle and TVA Kingston Fossil Plant and TVA Bull Run Fossil Plant) and to determine the minimum safe distance from an explosion. The safe distances are given in SSAR Table 2.2-9 and are based on the TNT-equivalent methodology given in NRC RG 1.91, Revision 2. Kairos concludes that based on these calculated minimum safe distances (i.e., the distance from the explosion where overpressure is 1 psi (6.9 kPa)) for each chemical stored in these three facilities, the distance between each facility and the proposed Hermes site exceeds the calculated minimum safe distances. Kairos provides the minimum safe distances for chemicals at ORNL-Battelle, which bound those for chemicals at the Kingston and Bull Run Fossil Plants, in PSAR Table 2.2-10.

The staff reviewed the information in PSAR Section 2.2.3.1 and in the Clinch River ESP SSAR referenced by Kairos. The staff finds that the SSAR analyses, which Kairos references in PSAR Section 2.2.3.1 and which are reported in SSAR Table 2.2-9 (and reproduced for ORNL-Battelle in PSAR Table 2.2-10), appropriately applied guidance in RG 1.91 to assess the minimum safe distances for each flammable chemical stored at ORNL-Battelle and the TVA Kingston fossil plant and the TVA Bull Run fossil plant. The staff also notes that the NRC previously approved the SSAR analyses for issuance of the Clinch River ESP. Therefore, the staff finds that it is appropriate that Kairos rely on the SSAR analyses for evaluation of minimum safe distances for flammable chemicals near the proposed Hermes site. The staff also finds that the calculated minimum safe distance for each flammable chemical is significantly smaller than the distances of these facilities from the proposed Hermes site. Therefore, the staff finds that a potential explosion of stored chemicals at the nearby facilities would not present a credible hazard to the proposed Hermes site.

As discussed above, Kairos also evaluated potential hazards from the planned Oak Ridge Airport based on available information. Specifically, in PSAR Section 2.2.3.1, Kairos discusses the potential explosion of the jet fuel tanks at the proposed airport. In PSAR Section 2.2.3.1, Kairos references an analysis in the SHINE PSAR that determined a potential explosion of a tank containing 500,000 lb (226,796 kg) (approximately 75,000 gal (340,957 L)) of jet fuel would result in an overpressure of 1 psi (6.9 kPa) at a distance of 1,162 ft (354 m) from the explosion. Kairos concluded, based on the analysis conducted in the SHINE PSAR, that a potential explosion of one or both of the 10,000 gal (37,854 L) tanks proposed for the future Oak Ridge Airport would not pose a credible hazard to the proposed Hermes site based on the smaller size of the Oak Ridge Airport tanks and because the Oak Ridge Airport tanks would be more than 1,162 ft (354 m) away from the Hermes site.

The staff reviewed the information in PSAR Section 2.2.3.1 regarding a potential explosion of fuel tanks at the future Oak Ridge Airport, and also reviewed the relevant information in SHINE PSAR Section 2.2.3.1.1.5. The staff notes that the assessment in the SHINE PSAR, which was previously approved by the NRC, shows that the overpressure generated from the explosion of a 75,000 gal (340,957 L) jet fuel tank would be 1 psi (6.9 kPa) at a distance of 1,162 ft (354 m). The staff finds that, because the capacity of each tank at the proposed Oak Ridge Airport would be 10,000 gal (37,854 L), a potential explosion of both tanks would create significantly less overpressure at a distance of 1,162 (354 m). As the proposed site is more than 1,162 (354 m) from the identified location of the tanks at the Oak Ridge Airport, the staff finds that a potential explosion of one or both tanks would not pose a credible hazard to the Hermes facility at the proposed site.

2.2.3.6.2 Flammable Vapor Clouds

In PSAR Section 2.2.3.2, Kairos presents an assessment of potential VCEs of flammable chemicals stored at the three nearby facilities ORNL-Battelle, TVA Kingston Fossil Plant, and TVA Bull Run Fossil Plant, from delayed ignition of a chemical cloud after an accidental release. Kairos states that its assessment is based on the results of analyses provided in the Clinch River ESP SSAR, which used the ALOHA computer code for dispersion modeling. The staff notes that these results are presented in SSAR Table 2.2-10. Kairos states that the results indicate that both the distances to the LFL boundaries of vapor clouds and the minimum safe distances at which the incident air overpressure is 1 psi (6.9 kPa) from a potential VCE, for potential releases of each of the stored flammable chemicals at these three nearby facilities, are smaller than the distance between these facilities and the proposed Hermes site. Therefore, Kairos concludes that a flammable vapor cloud from a release of stored chemicals at these nearby facilities would not adversely affect the safe operation of the Hermes facility at the proposed site.

The staff reviewed the discussion presented in PSAR Section 2.2.3.2 and the results in Table 2.2-10 of the Clinch River ESP SSAR referenced by Kairos. Based on its review, the staff finds that the flammable chemicals stored in the three nearby facilities would not pose a credible flash/cloud fire and overpressure hazard to the proposed facility because the distance from each of the three nearby facilities to the proposed Hermes site is greater than the calculated minimum safe distance for a VCE, and because the chemical concentrations in the vapor clouds would be diluted below the LFL before reaching the proposed Hermes site.

In PSAR Section 2.2.3.1, Kairos also assessed the potential damage from a Boiling Liquid Expanding Vapor Explosion (BLEVE) event occurring at one or both of the fuel tanks at the future Oak Ridge Airport. Kairos states in PSAR Section 2.2.3.1 that for its assessment, it assumes that one tank will contain 10,000 gal (37,855 L) of jet fuel (Jet A) and the other will hold 10,000 gal (37,855 L) of aviation gasoline (AvGas).

The staff notes that, in a BLEVE, flammable liquids in these tanks would be released into the atmosphere due to sudden loss of confinement, such as a major structural failure of the storage tanks due to mechanical failure or engulfing fire. The staff notes that the amount of flammable chemical released needs to be significant to form a BLEVE. During a BLEVE, sudden release of flammable chemicals and subsequent ignition can generate a pressure wave. In addition, tank fragments may form missiles. A fireball can result that travels upward while burning.

As discussed in PSAR Section 2.2.3.1, Kairos estimated that, assuming only one tank undergoes a BLEVE, the impact radius (where the air overpressure would be 1 psi (6.9 kPa)) would be 0.40 mi (0.64 km) for jet fuel and 0.38 mi (0.61 km) for aviation fuel. Were both tanks to undergo a BLEVE event simultaneously, the impact radius would be 0.49 mi (0.80 km). As the distance between the proposed Hermes site and the future Oak Ridge Airport would be more than 1.0 mi (1.6 km), Kairos concluded that a BLEVE of the fuel tanks would not have an impact on the Hermes facility at the proposed site.

The staff reviewed the BLEVE information in PSAR Section 2.2.3.1. In addition, the staff reviewed "Guidelines for Vapor Cloud Explosion, Pressure Vessel Burst, BLEVE, and Flash Fire Hazards," Chapter 8, "Basic Principles of BLEVES," (Center for Chemical Process Safety, 2010) and "SFPE Handbook of Fire Protection Engineering," Chapter 71, "BLEVES and Fireballs" (Ibarreta, 2016). The staff notes that, as stated in PSAR Section 2.2.3.1, the future Oak Ridge Airport tanks would either be of double-walled construction or would have other means of secondary containment, and in addition, spill response equipment would readily be available. The staff also notes that, as stated in PSAR Section 2.2.3.1, these tanks may be equipped with vapor control devices. Therefore, the staff expects that a BLEVE of these storage tanks would be unlikely. The staff also finds that, even if a BLEVE were to occur, the estimated impact radius is smaller than the distance between the tanks and the proposed Hermes facility. The staff further finds that the ensuing fireball from a BLEVE would likely consume the entirety of the fuel released before a fireball could reach the proposed Hermes site because of the distance between the tanks and the site. Additionally, the staff finds that because of the large distance, any tank fragments acting as missiles would not have enough kinetic energy to cause damage to the safety related structures at the proposed site.

Based on the preceding discussion, the staff finds that it is unlikely that a BLEVE of the fuel storage tanks at the future Oak Ridge Airport would pose a credible hazard to the proposed Hermes facility. As detailed information about the design and exact locations of these proposed storage tanks at the future Oak Ridge Airport is not currently known, the staff will review the potential hazards these tanks may pose to the proposed facility further during its review of a Hermes OL application, as appropriate.

2.2.3.6.3 Fires

In PSAR Section 2.2.3.4, Kairos discusses the potential hazard from fires to the proposed Hermes facility due to flammable chemicals stored in nearby facilities (or transported on nearby transportation routes), and references analyses in previous PSAR sections. As discussed in preceding PSAR sections including PSAR Section 2.2.3.2, a vapor cloud from an accidental release of flammable chemicals stored in nearby facilities (or in transit on nearby transportation routes) would be significantly diluted below the LFL before reaching the proposed Hermes site. Therefore, as stated in PSAR Section 2.2.3.2, Kairos concludes that vapor clouds associated with the flammable chemicals stored at nearby facilities would not pose a credible hazard to the proposed facility. PSAR Section 2.2.3.4 states that the potential effects of a brush fire or a forest fire on Hermes will be evaluated in an application for an OL.

The staff finds that because vapor clouds from any chemical releases from nearby facilities would be diluted well below the LFL before reaching the proposed Hermes site, such releases would not pose a significant fire risk to the proposed site. In addition, the staff finds that large intervening distances between nearby facilities and the proposed Hermes site preclude safety related structures at the proposed Hermes facility from being affected by the direct heat flux of a fire at the nearby facilities. Based on the preceding discussion, the staff finds that an accidental fire due to activities at nearby facilities would not pose a credible hazard to the proposed reactor facility. The staff will review Kairos's assessment of hazards associated with a brush or a forest fire during its review of an OL application, as appropriate.

2.2.3.6.4 Toxic Chemicals

In PSAR Section 2.2.3.3., Kairos evaluated the potential for toxic gas releases within 5 mi (8 km) of the proposed site to affect the personnel in the Hermes Main Control Room. Kairos considered both stationary sources at nearby facilities and frequent mobile sources on highways, waterways, and rail lines (Kairos defines frequent shipments as more than 10 chemical shipments per year for truck traffic on highways or 30 shipments each year for rail traffic; the staff notes that this definition is consistent with the definition given in NRC RG 1.78, Revision 1). Potential toxic gas releases from highway, waterway, and railway mobile sources are discussed and evaluated in the SE sections above.

In its analyses of toxic chemical releases, Kairos only considered chemicals with vapor pressure greater than 10 torr (1.3 kPa). The staff notes that chemicals with lower vapor pressure are unlikely to develop sufficient vapor to be transported by the prevailing atmospheric conditions for a considerable distance and still have the potential to cause a danger to human life or health.

In PSAR Section 2.2.3.3, Toxic Chemicals, Kairos states that the locations and quantities of chemicals to be stored at the proposed Hermes facility are not yet determined. Therefore, Kairos states that it will evaluate any potential hazards from stored on site chemicals in a Hermes OL application. The staff will review the locations and quantities of specific chemicals that will be stored on site, and Kairos's associated hazard assessment, during review of an OL application, as appropriate.

In PSAR Section 2.2.3.3, Kairos identifies six facilities (counting ORNL–Battelle and ORNL–URS separately) near the proposed Hermes site for which release of a toxic chemical could potentially affect the Hermes Main Control Room. Kairos assessed the potential hazards based on the analysis presented in the Clinch River ESP SSAR and stated that the Hermes Main Control Room would have a similar air exchange rate to the 1.2 exchanges per hour assumed in the Clinch River Nuclear Site ESP SSAR. Identified chemicals and quantities stored at each of the six sites are presented in SSAR Table 2.2-11. The SSAR analysis uses the ALOHA code dispersion model to determine the distance from each of the six facilities at which the IDLH/asphyxiating or other determined toxicity limits for each identified chemical at these facilities could be exceeded due to a release. SSAR Table 2.2-11 lists the calculated distance to IDLH for each chemical stored at the nearby facilities. The six facilities are:

- TVA Bull Run Fossil Plant, approximately 15 mi (24.1 km) away from the proposed Hermes site
- TVA Kingston Fossil Plant, approximately 7mi (11.2 km) away from the proposed Hermes site
- ORNL–Battelle, approximately 5 mi (8 km) away from the proposed Hermes site
- ORNL–URS, approximately 5 mi (8 km) away from the proposed Hermes site
- Hallsdale Powell Utility District Melton Hill WTP, approximately 18 mi (29 km) away from the proposed Hermes site
- Oak Ridge WTP, approximately 9.5 mi (15 km) away from the proposed Hermes site

Based on the information in SSAR Table 2.2-11, anhydrous ammonia has the longest distance to IDLH for the TVA Bull Run and Kingston fossil plants. These distances are 4.1 mi (6.6 km) and 1.2 mi (1.9 km), respectively, for the 2 plants. For ORNL-Battelle, sulfur hexafluoride has the longest IDLH distance, 2 mi (3.2 km), and for ORNL-URS, nitric acid has the longest IDLH distance, 2.9 mi (4.7 km). For release of the entire quantity of chlorine stored at the Hallsdale Powell Utility District Melton Hill WTP and Oak Ridge WTP, the IDLH distances are 3.8 mi (6.1 km) and 2.9 mi (4.7 km), respectively. As the calculated minimum safe distances for the stored chemicals at these six facilities are smaller than the intervening distances to the proposed Hermes site, Kairos concludes in PSAR Section 2.2.3.3 that an accidental toxic chemical release from these facilities would not cause a toxicity limit to be exceeded at the proposed Hermes site.

The staff reviewed the information on toxic chemical releases from nearby facilities in PSAR Section 2.2.3.3. In addition, the staff reviewed information in Clinch River ESP SSAR Section 2.2.3.1.3.1 and SSAR Table 2.2-11. The staff notes that the SSAR analyses assume the entire quantity of a toxic chemical at a facility listed in SSAR Table 2.2-11 is accidentally released. The staff finds that the IDLH distance for each toxic chemical in each of the six facilities, presented in SSAR Table 2.2-11, is less than the distance between each facility and the proposed Hermes site, based on the distances given in PSAR Table 2.2-1. Based on the above, the staff finds that accidental releases of toxic chemicals stored in these nearby facilities would not pose a credible hazard to the proposed Hermes facility.

2.2.3.7 Technical Evaluation Summary

The staff evaluated the sufficiency of the proposed site characteristics regarding nearby industrial, transportation, and military facility descriptions, as described in Hermes PSAR Section 2.2, using the guidance and acceptance criteria from Section 2.2 of NUREG-1537, Parts 1 and 2. The staff also used other NRC guidance documents, as needed and as described above, to supplement NUREG-1537.

In summary, the staff finds that Kairos adequately described the facilities, installations, and transportation routes near the proposed site and evaluated the potential hazards posed by them to the proposed Hermes facility. The staff finds that Kairos has adequately evaluated the potential human-induced hazards from operations at the nearby airports, transportation routes, and facilities to establish the site parameters such that the proposed reactor facility can accommodate the commonly occurring hazards (e.g., explosions, fires, and flammable and toxic vapor clouds) and any consequences of such hazards would be bounded by the accidents considered in PSAR Chapter 13. The staff notes that Kairos will design the reactor building to withstand a small aircraft crash due to the proximity to the future Oak Ridge Airport; the staff's evaluation of the reactor building is discussed in SE Section 3.5. The staff also notes that Kairos plans to install ammonia and chlorine detectors in the ventilation system for the Hermes Main Control Room due to transportation of those chemicals on highways near the proposed Hermes site.

Based on its review, the staff determined that the level of detail and analyses provided on nearby industrial facilities, transportation routes, and military facilities demonstrate an adequate design basis and satisfy the applicable acceptance criteria of NUREG–1537, Part 2, Section 2.2, allowing the staff to find that:

- The information in the PSAR is sufficiently detailed to provide an accurate description of the nearby facilities and transportation routes and hazards to the proposed facility posed by them.
- The description of the hazards and their assessments are adequate to determine potential radiological impact on the public resulting from the siting and operation of the proposed reactor facility.
- Potential hazards associated with nearby transportation routes and industrial and military facilities will pose no undue risk to the proposed facility as the facility is either designed against it (e.g., aircraft crash hazard) or the hazard is not a credible hazard to the proposed facility.

2.2.4 Conclusion

Based on its findings above, the staff concludes the information on nearby industrial, military, and transportation facilities in Hermes PSAR Section 2.2 is sufficient and meets the applicable guidance and regulatory requirements identified in this SE section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40.

2.3 Meteorology

2.3.1 Introduction

PSAR Section 2.3, “Meteorology,” provides a description of the general climate of the region around the proposed Hermes site and meteorological conditions relevant to the design and operation of the Hermes facility. PSAR Section 2.3 also provides data and information used to determine the atmospheric dispersion conditions in the vicinity of the site. This information includes local and regional airflow and meteorological measurements used for dispersion estimates.

2.3.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of the Hermes site meteorology are as follows:

- 10 CFR 50.34, “Contents of applications; technical information,” paragraph (a), “Preliminary safety analysis report,” including 10 CFR 50.34(a)(1)(i), which requires that the PSAR include “A description and safety assessment of the site on which the facility is to be located, with appropriate attention to features affecting facility design. Special attention should be directed to the site evaluation factors identified in [10 CFR Part 100]…”.
- 10 CFR 50.35, “Issuance of construction permits.”
- 10 CFR 50.40, “Common standards.”
- 10 CFR 100.10, “Factors to be considered when evaluating sites,” paragraph (c)(2), which requires that in considering the acceptability of a site for a test reactor, “Meteorological conditions at the site and in the surrounding area should be considered” by the NRC.

The applicable guidance for the evaluation of the Hermes site meteorology is as follows:

- NUREG-1537, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors," Part 1, "Format and Content," and Part 2, "Standard Review Plan and Acceptance Criteria," Section 2.3, "Meteorology."

2.3.3 Technical Evaluation

2.3.3.1 Regional Climatology

In PSAR Section 2.3.1, Kairos provides information regarding regional climatic conditions and the occurrence of meteorological phenomena (including both averages and extremes) that could potentially affect the design and operating bases of Hermes SSCs at the proposed site. Kairos provides detailed information about the climate region as it relates to the topics of the following 13 subsections of this SE, which correspond to the topics of PSAR Sections 2.3.1.2 through 2.3.1.14.

In PSAR Section 2.3.1.1, Kairos states that since the design of safety related SSCs may need to consider severe weather phenomena, Kairos has obtained statistics on the severe weather phenomena discussed in the application from historical data. Kairos states that most data are taken from the National Climatic Data Center (NCDC) Storm Events Database.

In PSAR Section 3.2, Kairos describes the approach it used to translate the relevant design basis meteorological parameters into loads used in the design of Hermes SSCs; the staff's review of this information in discussed in Chapter 3 of this SE.

2.3.3.1.1 Thunderstorms

As discussed in PSAR Section 2.3.1.2, Kairos used data collected at ORNL to examine the thunderstorm activity in the region of the proposed Hermes site. The period of data used was collected for the years 2001 through 2020. Kairos states that thunderstorms are common in the Oak Ridge region with a normal range of 34 to 65 days with thunderstorms during the year. The greatest frequency of thunderstorms is during the summer months, with a range of 18 to 40 days with thunderstorms during May through August.

The staff reviewed the information on thunderstorms in the region of the proposed Hermes site and, based on its review, including verification that Kairos obtained the information from appropriate sources and that the information is consistent with other available data and appears reasonable for the geographic area, the staff finds that Kairos's assessment is sufficient for evaluation of potential thunderstorm impacts on Hermes to inform design bases for the Hermes facility. Therefore, the staff finds that Kairos's assessment of thunderstorms is acceptable.

2.3.3.1.2 Hail

As discussed in PSAR Section 2.3.1.3, Kairos used data taken from the NCDC Storm Events Database to assess severe hail activity in the region. Kairos states that in Roane County, Tennessee, severe hail, which is defined as hail with 0.75 inch (1.9 cm) or larger diameter, has been reported only 36 times during the period from 1950 through 2020. During the same period, surrounding counties, Loudon and Knox, reported severe hail 50 and 93 times, respectively.

The staff reviewed the information on hail in the region of the proposed Hermes site and, based on its review, including verification that Kairos obtained the information from appropriate sources and that the information is consistent with other available data and appears reasonable for the geographic area, the staff finds that Kairos's assessment is sufficient for evaluation of potential hail impacts on Hermes to inform design bases for the Hermes facility. Therefore, the staff finds that Kairos's assessment of hail is acceptable.

2.3.3.1.3 Lightning

In PSAR Section 2.3.1.4, Kairos states that the proposed Hermes site averages four to eight cloud-to-ground lightning flashes per square kilometer annually, based on the 26-year period from 1993 through 2018. Kairos states that a review of cloud-to-ground lightning strike data collected at ORNL over the 10-year period from 2011 through 2019 indicates that three of the 10 years had a lightning strike occurring within a few hundred feet of the site.

The staff reviewed the information on lightning in the region of the proposed Hermes site and, based on its review, including verification that Kairos obtained the information from appropriate sources and that the information is consistent with other available data and appears reasonable for the geographic area, the staff finds that Kairos's assessment is sufficient for evaluation of potential lightning impacts on Hermes to inform design bases for the Hermes facility. Therefore, the staff finds that Kairos's assessment of lightning is acceptable.

2.3.3.1.4 Extreme Winds

In PSAR Section 2.3.1.5, Kairos states that windstorms at the proposed Hermes site are relatively infrequent but may occur several times a year, usually in association with thunderstorms. Kairos states that the strong winds are usually associated with lines of thunderstorms along or ahead of cold fronts and are more probable in the late winter and spring than any other time of the year. Kairos notes that brief, strong gusts of wind due to downdrafts and outflow from individual thunderstorms can occur but are generally limited to the large, intense thunderstorms that develop in the spring and summer.

Kairos states that it estimated extreme winds based on NCDC climatological data for Oak Ridge and Knoxville, Tennessee, as well as hourly observations from the ORR's meteorological Tower J and Tower L. The data analyzed for Oak Ridge and Knoxville, Tennessee, covered 1999 through 2020, and 1981 through 2020, respectively. The data analyzed for ORR Tower J and Tower L covered 2018 through 2020, and 2016 through 2020, respectively. Kairos states that the maximum hourly average wind speed for the three years of data analyzed at ORR Tower J is 24.8 mph (11.1 m/s) at the 20-meter (66-foot) level. The maximum hourly average wind speed for the five years of data analyzed at ORR Tower L is 21.4 mph (9.6 m/s) at the 10- or 15-meter (33- or 49-foot) level and 24.4 mph (10.9 m/s) at the 30-meter (98-foot) level. In comparison, based on NCDC data, Oak Ridge, Tennessee, has a maximum hourly average wind speed of 29.0 mph (13.0 m/s), and Knoxville, Tennessee, has a maximum hourly average wind speed of 60 mph (27 m/s). Regarding peak wind speeds, ORR Tower L recorded peak wind speeds of 78.3 mph (35.0 m/s) at the 15-meter (49-foot) level and 84.5 mph (37.8 m/s) at the 30-meter (98-foot) level. Based on the NCDC data, Oak Ridge, Tennessee, recorded a peak wind speed of 53 mph (24 m/s), and Knoxville, Tennessee, recorded a peak wind speed of 68 mph (30 m/s). Kairos additionally states that based on data for a 100-year return period, the fastest wind in the Hermes site area is approximately 90 mph (40 m/s).

The staff reviewed the information on extreme winds in the region of the proposed Hermes site and, based on its review, including verification that Kairos obtained the information from appropriate sources and that the information is consistent with other available data and appears reasonable for the geographic area, the staff finds that Kairos's assessment is sufficient for evaluation of potential impacts from extreme winds on Hermes to inform design bases for the Hermes facility. Therefore, the staff finds that Kairos's assessment of extreme winds is acceptable.

2.3.3.1.5 Precipitation Extremes

In PSAR Section 2.3.1.6, Kairos states that it obtained historical precipitation data from several National Weather Service (NWS) and TVA sites surrounding the proposed Hermes site. Kairos summarized these data in PSAR Table 2.3-1. The table indicates that the normal annual precipitation is in the range of 47 to 53 in (119 to 135 cm). Kairos also states in PSAR Section 2.3.1.6 that the maximum 24-hour rainfall is less than 10 in (25 cm), and the maximum monthly rainfall is less than 20 in (51 cm). In addition, Kairos states that the average annual snowfall is less than 12 in (30 cm). Kairos states that droughts are uncommon in the vicinity of the site, with records indicating that only 16 episodes of severe drought have occurred in the past 200 years.

The staff reviewed the information on precipitation extremes in the region of the Hermes site and, based on its review, including verification that Kairos obtained the information from appropriate sources and that the information is consistent with other available data and appears reasonable for the geographic area, the staff finds that Kairos's assessment is sufficient for evaluation of potential impacts from extreme precipitation on Hermes to inform design bases for the Hermes facility. Therefore, the staff finds that Kairos's assessment of precipitation extremes is acceptable.

2.3.3.1.6 Tornadoes

As discussed in PSAR Section 2.3.1.7, Kairos used the NWS Morristown Tornado Database and the NCDC Storm Events Database to assess the probability of a tornado occurring at the proposed Hermes site. Kairos states that the probability is low based on records from the 71-year period from 1950 through 2020, during which only five tornadoes were reported within 10 mi (16 km) of the site. PSAR Table 2.3-2 lists these tornado reports. The intensities of the five tornadoes ranged from F0/EF0 to F3/EF3.

Kairos used the tornado strike probabilities presented in NUREG/CR-4461, "Tornado Climatology of the Contiguous United States," Revision 2, to estimate the number of tornado events from 1950 through August 2003 within a 2-degree latitude and longitude box surrounding the Hermes site. Kairos's estimated number of tornado events is 226, which corresponds to an annual average of four tornado events striking somewhere within the 2-degree box.

The staff reviewed the information on tornadoes in the region of the proposed Hermes site and, based on its review, including verification that Kairos obtained the information from appropriate sources and that the information is consistent with other available data and appears reasonable for the geographic area, the staff finds that Kairos's assessment is sufficient for evaluation of potential impacts from tornadoes on Hermes to inform design bases for the Hermes facility. Therefore, the staff finds that Kairos's assessment of tornadoes is acceptable.

2.3.3.1.7 Hurricanes

In PSAR Section 2.3.1.8, Kairos states that hurricane winds are mainly a concern for coastal locations and should not be a concern for the proposed Hermes site, based on the wind speed contours presented in RG 1.221, "Design-Basis Hurricane and Hurricane Missiles for Nuclear

Power Plants," and NUREG/CR-7005, "Technical Basis for Regulatory Guidance on Design-Basis Hurricane Wind Speeds for Nuclear Power Plants." Kairos notes that while RG 1.221 provides guidance for power reactors, it also provides a useful reference for hurricane wind speeds. Kairos also states that a review of the NCDC Storm Events Database for the period of 1950 through 2020 shows that there was only one tropical storm near Roane County, TN, on September 16, 2004, which caused minimal damage.

The staff reviewed the information on hurricanes in the region of the proposed Hermes site and, based on its review, including verification that Kairos obtained the information from appropriate sources and that the information is consistent with other available data and appears reasonable for the geographic area, the staff finds that Kairos's assessment is sufficient for evaluation of potential impacts from hurricanes on Hermes to inform design bases for the Hermes facility. Therefore, the staff finds that Kairos's assessment of hurricanes is acceptable.

2.3.3.1.8 Winter Storm Events

In PSAR Section 2.3.1.9, Kairos states that the maximum reported 24-hour snowfall depth at the NWS Knoxville station during the 61-year period of record, was 23.3 in (59.2 cm) in February 1960. Kairos states that snowfall records for other stations around the site show a maximum 24-hour snowfall of 20 in (51 cm) at the NWS Chattanooga station in March 1993. Snowfall records for these stations are listed in PSAR Table 2.3-1.

Kairos states that frost penetration depth is important for protection of water lines and other buried structural features that are subject to freeze damage. Kairos notes the extreme depth of frost penetration at the site is slightly less than 19.6 inches (49.8 cm), based on Figure 13 in National Oceanic and Atmospheric Administration (NOAA) Manual NOS NGS 1, "Geodetic Bench Marks."

The staff reviewed the information on winter storm events in the region of the proposed Hermes site and, based on its review, including verification that Kairos obtained the information from appropriate sources and that the information is consistent with other available data and appears reasonable for the geographic area, the staff finds that Kairos's assessment is sufficient for evaluation of potential impacts from winter storm events on Hermes to inform design bases for the Hermes facility. Therefore, the staff finds that Kairos's assessment of winter storm events is acceptable.

2.3.3.1.9 Ice Storms

In PSAR Section 2.3.1.10, Kairos discusses the estimations of regional glaze probabilities made by Tattelman and Gringorten in "Estimated Glaze Ice and Wind Loads at the Earth's Surface for the Contiguous United States." Kairos states that for Region V, which contains Tennessee, ice storms with greater than or equal to 1 in (2.5 cm) of ice occurred five times in 50 years and storms with ice greater than or equal to 2 inches (5.1 cm) of ice occurred two times in 50 years. Kairos also states that for ice storms with wind gusts greater than or equal to 44.7 mph (20.0 m/s), the estimated ice thickness is less than 1 in (2.5 cm) for 25- and 50-year return periods, and 1.4 in (3.6 cm) for a 100-year return period.

Kairos notes that based on the data provided in Figure 10-2 of American Society of Civil Engineers (ASCE) Standard No. 7-10, "Minimum Design Loads for Buildings and Other Structures," the specification for calculating the ice load on a structural element is the 50-year mean recurrence interval of uniform ice thickness due to freezing rain with a concurrent 3-

second wind gust. Kairos states that for Roane County, TN, that thickness is 0.75 in (1.9 cm) for a 30 mph (13 m/s) gust.

Kairos states that for glaze ice, the point probabilities for ice thicknesses are about 0.20 for greater than or equal to 0.5 in (1.3 cm) of ice, and 0.36 for greater than or equal to 0.25 in (0.63 cm) of ice. Kairos states that these probabilities correspond to recurrence intervals of once in 5 years and once in 3 years, respectively.

The staff reviewed the information on ice storms in the region of the proposed Hermes site and, based on its review, including verification that Kairos obtained the information from appropriate sources and that the information is consistent with other available data and appears reasonable for the geographic area, the staff finds that Kairos's assessment is sufficient for evaluation of potential impacts from ice storms on Hermes to inform design bases for the Hermes facility. Therefore, the staff finds that Kairos's assessment of ice storms is acceptable.

2.3.3.1.10 Normal and Extreme Winter Precipitation Events

In PSAR Section 2.3.1.11, Kairos states that it defines snowpack, as used in PSAR section 2.3.1.11, as a layer of snow and/or ice on the ground surface. Kairos notes that snowpack is usually reported daily, in inches, by the NWS at all first-order weather stations. Kairos developed historical snowpack and snowfall values by reviewing data from first-order NWS stations and the cooperative network. Kairos determined the 50-year mean recurrence interval snowpack for the Oak Ridge area to be 10 pounds per square foot (psf) (49 kg/m^2) based on Figure 7-1 of ASCE Standard No. 7-10. Using the 1.22 adjustment factor presented in Table C7-3 of ASCE Standard No. 7-10, Kairos then converted this to a 100-year return period snowpack value of 12.2 psf (59.6 kg/m^2).

Kairos reviewed NWS data to find that the greatest snow depth reported during the 77-year period of record (1938 through 2014) for Chattanooga, Tennessee, was 19 in (48 cm) in March 1993. Kairos states that this was the highest snow depth reported among NWS stations near the Hermes site. Kairos then used the methodology in the NRC Interim Staff Guidance (ISG) DC/COL-ISG-7, "Interim Staff Guidance on Assessment of Normal and Extreme Winter Precipitation Loads on the Roofs of Seismic Category I Structures," to convert the historical maximum snowpack depth to a ground snow load. Using the 19-in (48-cm) snow depth for Chattanooga, Kairos calculated a snow load of 15.3 psf (74.7 kg/m^2) for the maximum historical snowpack.

Kairos determined based on NCDC data that the 48-hour 100-year return snowfall event for Oak Ridge, Tennessee, is the 15.7 in (39.9 cm) of snow that occurred during a March 1960 snowstorm. For Knoxville, Tennessee, the 48-hour 100-year return snowfall event is the 18.8 in (47.8 cm) of snow during a February 13–14, 1960, snowstorm. Kairos determined the historical maximum snowfall event for a 48-hour period for the Tennessee River Basin to be the 28 in (71 cm) of snow recorded in Westbourne, Tennessee, on February 19–21, 1960. Kairos used the methodology from DC/COL-ISG-7 to determine the snow load due to the maximum 48-hour 100-year return period snowfall event, as well as due to the historical maximum snowfall event. For the maximum 100-year return snowfall event (18.8 in (47.8 cm)), Kairos calculated a snow load of 14.7 psf (71.8 kg/m^2). For the historical maximum snowfall event for a 48-hour period (28 inches), Kairos calculated a snow load of 21.9 psf (107 kg/m^2).

Kairos stated that it determined the loading from both the Normal Winter Precipitation Event, and the Extreme Frozen Winter Precipitation Event, as defined in PSAR Section 2.3.1.11, to be 21.9 psf (107 kg/m^2).

Kairos used logarithmic interpretation of information in the NOAA "Hydrometeorological Report HMR-53, Seasonal Variation of 10-Square-Mile Probable Maximum Precipitation Estimates, United States East of the 105th Meridian," to estimate the 48-hour Probable Maximum Winter Precipitation (PMWP) (January through March) for a 10 mi^2 (26 km^2) area to be 23.5 in (59.7 cm). Kairos states that it utilized the March PMWP for this estimate since the historically highest snowpack occurred in March 1993 (see discussion above).

The staff reviewed the information on the normal and extreme winter precipitation events in the region of the proposed Hermes site and, based on its review, including verification that Kairos obtained the information from appropriate sources and that the information is consistent with other available data and appears reasonable for the geographic area, the staff finds that Kairos's assessment is sufficient for evaluation of potential impacts from normal and extreme winter precipitation events on Hermes to inform design bases for the Hermes facility. Therefore, the staff finds that Kairos's assessment of normal and extreme winter precipitation events is acceptable.

2.3.3.1.11 Design Basis Dry- and Wet-Bulb Temperatures

In PSAR Section 2.3.1.12, Kairos provides ambient temperature and humidity statistics to establish heat loads for the Hermes design (e.g., for cooling systems).

As discussed in PSAR Section 2.3.1.12, Kairos determined the following parameters:

- Maximum dry-bulb temperatures at 0.4 percent, 2 percent, and 5 percent annual exceedance levels;
- Mean coincident wet-bulb temperatures at 0.4 percent, 2 percent, and 5 percent annual
- exceedance levels;
- Maximum non-coincident wet-bulb temperature at 0.4 percent annual exceedance levels;
- Minimum dry-bulb temperature at 0.4 percent, 1 percent, and 2 percent annual exceedance levels; and
- 100-year return maximum dry-bulb, mean coincident wet-bulb, maximum non-coincident wet-bulb, and minimum dry-bulb temperatures.

Kairos states that it used meteorological data from the NCDC for the Chattanooga Lovell Airport for determining the parameters (i.e., extreme values) listed above. Kairos states that it obtained 66 years of raw climatological data and used this data to calculate the various exceedance temperatures. The results of Kairos's ambient design temperature analyses are presented in PSAR Tables 2.3-3 (maximum dry-bulb and mean coincident wet-bulb temperatures), 2.3-4 (maximum non-coincident wet-bulb temperatures), and 2.3-5 (minimum dry-bulb temperatures). Kairos states that it performed similar evaluations using the NCDC data for Knoxville but, because the Chattanooga data produced more conservative (i.e., higher temperature) results, Kairos used these results as the design basis for Hermes.

Kairos states that, in addition, it obtained monthly climate data (monthly design dry-bulb and wet-bulb temperatures) for the Chattanooga Lovell Airport and for the Oak Ridge Automated

Surface Observing System station from the "2017 ASHRAE [American Society of Heating, Refrigerating, and Air Conditioning Engineers] Handbook – Fundamentals." Kairos presented both the monthly design dry-bulb temperatures with mean coincident wet-bulb temperatures as well as the monthly design wet-bulb temperatures, for Chattanooga and Oak Ridge in PSAR Tables 2.3-6, 2.3-7, 2.3-8, and 2.3-9. Kairos states that the Chattanooga data produces slightly more conservative results than the Oak Ridge data, but noted both datasets are very similar, so Kairos used the Chattanooga data as the design basis for Hermes.

The staff reviewed the information on dry- and wet-bulb temperatures in the region of the proposed Hermes site and, based on its review, including verification that Kairos obtained the information from appropriate sources and that the information is consistent with other available data and appears reasonable for the geographic area, the staff finds that Kairos's assessment is sufficient for evaluation of expected conditions at the proposed Hermes site to inform design bases for the Hermes facility. Therefore, the staff finds that Kairos's assessment of design basis dry- and wet-bulb temperatures is acceptable.

2.3.3.1.12 Meteorological Data for Evaluating Ultimate Heat Sink

In PSAR Section 2.3.1.13, Kairos states that Hermes does not rely on an external water source as its ultimate heat sink (UHS), but rather uses direct to air heat rejection. Therefore, Kairos states that considerations of evaporation and drift loss of water, minimum water cooling, and the potential for water freezing in a UHS water storage facility are not applicable.

The staff reviewed the information above and finds that because Hermes does not use an external water source as an UHS, Kairos's determination that analyses of meteorological data for evaluating a UHS are not applicable to Hermes is reasonable.

2.3.3.1.13 Climate Change

In PSAR Section 2.3.1.14, Kairos states that even the most extreme projected climate changes are for time scales much longer than the approximate 4-year planned operation period for Hermes. Kairos notes that the long-term climate trend from multiple sources indicates a moderate increase in the average temperature and possibility of extreme precipitation events through the end of the 21st century. However, Kairos states that the time scale of the Hermes licensing period is a small fraction of this projection period.

The staff reviewed the information above and finds that Kairos's assessments of climate information to inform design bases for Hermes are suitably valid given the 4-year planned operation period for Hermes and because the staff does not expect climate changes over a 4-year period to significantly impact Hermes operation or design bases.

2.3.3.2 Local Meteorology

In PSAR Section 2.3.2, Kairos provides information regarding local meteorology of the proposed site. Kairos provides detailed information about the local meteorology in PSAR Sections 2.3.2.1 through 2.3.2.11, whose topics correspond to the following 11 subsections of this SE.

As discussed in PSAR Section 2.3.2.1, local meteorology data provide detailed information regarding wind flow patterns and other factors to determine dispersion of potential radiological releases in the Oak Ridge, Tennessee, area, including from the proposed Hermes site. PSAR Sections 2.3.4 and 2.3.5 discuss atmospheric dispersion modeling and analyses for accidental and routine radiological releases from Hermes; these analyses are based on local meteorological data. As discussed in PSAR Section 2.3.2.2, local meteorology data are also useful to help verify that site-specific conditions are consistent with regional climatology information discussed previously.

2.3.3.2.1 Local Meteorological Data Overview

In PSAR Section 2.3.2.1, Kairos provides an overview of the meteorology for the proposed Hermes site. Kairos provides a description of the site, discusses the period of record for the data, and describes meteorological towers used to record the data. Kairos includes discussion of the topography and geography of the site and describes the affect that both have on the meteorological conditions.

The staff reviewed Kairos's overview of the local meteorological data for the region of the proposed Hermes site. The staff finds that this information helps demonstrate the suitability of local meteorological data described in PSAR Section 2.3.2 for evaluating conditions at the proposed Hermes site because, for example, the meteorological towers are located in appropriate proximity to the proposed site such that they should be expected to produce data that is representative of the proposed site and because the towers collect an appropriate range of data consistent with typical practice. Therefore, the staff finds Kairos's overview of local meteorological data to be acceptable.

2.3.3.2.2 Normal and Extreme Values of Meteorological Parameters

In PSAR Section 2.3.2.2, Kairos discusses its review of long-term temperature and wind data from regional stations to determine if data collected near the site are consistent with regional conditions, both spatially and temporally.

Kairos notes that historical studies from 1953 and 2011 referenced in PSAR Section 2.3.2.1 indicate basic flow patterns that have been in place during the recorded weather history of the ORR area. Therefore, Kairos concludes that meteorological characteristics for the Hermes site have not changed significantly over time and should also not change over the life span of the Hermes project.

Kairos also notes that data taken from ORR Towers J, L, and D for the 2-year period including calendar years 2018 and 2019 show generally good agreement between these local towers and regional offsite locations for the average values. Kairos states that these comparisons indicate that data from the site is consistent with overall meteorological conditions in the Oak Ridge/Knoxville, Tennessee area.

The staff reviewed Kairos's assessment of normal and extreme values of meteorological parameters, discussed above. The staff finds that Kairos's assessment helps demonstrate the consistency of meteorological data as well as suitability of both local and regional meteorological data collected over time for evaluating conditions at the proposed Hermes site and, therefore, the staff finds Kairos's assessment to be acceptable.

2.3.3.2.3 Winds

In PSAR Section 2.3.2.3, Kairos describes the configuration of the three ORR site Towers J, L, and D during a data collection period consisting of calendar years 2018 and 2019 and then discusses the data from the towers during this period.

Average Wind Direction and Wind Speed Conditions

In PSAR Figures 2.3-12 through 2.3-17, Kairos presents the tower data for the three Towers J, L, and D near the proposed Hermes site as wind roses. For comparison, Kairos also presents regional wind roses for Chattanooga and Oak Ridge, Tennessee, based on 10 years of data (2000 through 2009), in PSAR Figures 2.3-18 and 2.3-19, respectively. Kairos also outlines the wind speeds at the ORR meteorological towers near the Hermes site during 2018 and 2019 in PSAR Table 2.3-11. In PSAR Section 2.3.2.3, Kairos describes the local terrain around the proposed Hermes site and the effect that the geographic orientation of the ridges and valleys generally has on the wind speed and wind directions. Kairos states that the local wind patterns are influenced by the complex terrain, with up-valley (SSW-WSW) /down-valley (NE-ENE) flow patterns common, and stable conditions with light winds frequently observed, as seen at all measurement height levels of all three meteorological towers. Kairos states that these flow patterns influence the dispersion around the proposed Hermes site.

Wind Direction Persistence

In PSAR Section 2.3.2.3, Kairos notes that, generally, the longer the winds blow in the same direction, the lower the dilution potential because effluent is not dispersing significantly from the persistent wind sector. Kairos states that, as outlined in PSAR Table 2.3-12, the maximum persistence at the 15-meter (49-foot) height for Tower L for the 2018 to 2019 time period is 19 hours with wind from NE for the same sector; 39 hours with wind from W-NW for ± 1 sector; and 69 hours with wind from WSW-NNW for ± 2 sectors. Kairos states that the wind data show a consistent pattern of wind directions with predominant winds from the SSW-SW, with a second maximum of persistent winds from the opposite direction (i.e., from the NE-ENE). Kairos notes that there is seasonal variation in this pattern as illustrated in PSAR Figure 2.3-20, which shows Tower L wind directions by quarter. In addition, Kairos notes that there is also a diurnal pattern with the winds as illustrated by PSAR Figures 2.3-21 and 2.3-22 which show daytime and nighttime wind roses, respectively. Kairos notes that during the day the winds show the predominant patterns of winds from the SSW-SW and NE-ENE, but during the night the wind flow comes off the terrain to the south and east.

Staff Review of Information on Winds

The staff reviewed the information on winds, including average wind direction, wind speed conditions, and wind direction persistence in the region of the proposed Hermes site. Based on its review, including verification that Kairos obtained the information from appropriate sources and that the information is consistent with other available data and appears reasonable for the geographic area, the staff finds that Kairos's assessment is sufficient for characterization of winds at the site to inform analyses for the Hermes facility. Therefore, the staff finds that Kairos's assessment of winds is acceptable.

2.3.3.2.4 Air Temperature

Kairos presents NCDC temperature data for Knoxville and Oak Ridge, Tennessee, in PSAR Tables 2.3-13 and 2.3-14, respectively, and discusses this data in PSAR Section 2.3.2.4. Kairos states that PSAR Tables 2.3-13 and 2.3-14 show the normal temperatures (in °F) ranged from the upper 30 s in the winter to the upper 70 s in the summer at both locations. Normal daily maximum temperatures ranged from about 47 °F (8 °C) in mid-winter to about 88 °F (31 °C) in mid-summer. The normal daily minimum temperatures ranged from about 29 °F (-2 °C) in mid-winter to about 69 °F (21 °C) in mid-summer. The extreme daily maxima recorded were 105 °F (41 °C) (June and July 2012) at Knoxville and also 105 °F (41 °C) (July 1952 and June 2012) at Oak Ridge, while the extreme daily minima (during January 1985) were -24 °F (-31 °C) and -17 °F (-27 °C), at Knoxville and Oak Ridge, respectively.

In PSAR Table 2.3-15, Kairos lists the temperatures measured by Tower L for 2018 and 2019, and Kairos also discusses this data in PSAR Section 2.3.2.4. Kairos states that the data for Tower L show a similar pattern of daily average temperatures (in °F) ranging from the mid-20 s in winter to the upper 70 s in summer. Normal daily maximum temperatures ranged from about 59.0 °F (15.0 °C) in mid-winter to about 79.1 °F (26.2 °C) in mid-summer. The normal daily minimum temperatures ranged from about 25.3 °F (-3.7 °C) in mid-winter to about 71.5 °F (21.9 °C) in mid-summer. A maximum temperature of 96.2 °F (35.7 °C) and a minimum temperature of 0.5 °F (-17.5 °C) were recorded over the 2-year period.

The staff reviewed the information on air temperature in the region of the proposed Hermes site. Based on its review, including verification that Kairos obtained the information from appropriate sources and that the information is consistent with other available data and appears reasonable for the geographic area, the staff finds that Kairos's assessment is sufficient for characterization of air temperature at the site to inform analyses for the Hermes facility. Therefore, the staff finds that Kairos's assessment of air temperature is acceptable.

2.3.3.2.5 Atmospheric Moisture

PSAR Table 2.3-16 presents long-term relative humidity and absolute humidity data for Knoxville and Oak Ridge, Tennessee. PSAR Table 2.3-17 summarizes short term humidity data based on measurements at the ORR meteorological Tower L. In PSAR Section 2.3.2.5, Kairos notes that PSAR Tables 2.3-16 and 2.3-17 allow for comparison of the humidity data between the Knoxville, Oak Ridge, and Tower L locations. Kairos states that the Tower L site data (for 2018 and 2019) are comparable to the long-term data for Knoxville and Oak Ridge, although Kairos notes that the dew points and humidity data are slightly higher for the 2018 and 2019 Tower L data compared to the longer-term Knoxville and Oak Ridge data.

The staff reviewed the information on atmospheric moisture in the region of the proposed Hermes site. Based on its review, including verification that Kairos obtained the information from appropriate sources and that the information is consistent with other available data and appears reasonable for the geographic area, the staff finds that Kairos's assessment is sufficient for characterization of atmospheric moisture at the site to inform analyses for the Hermes facility. Therefore, the staff finds that Kairos's assessment of atmospheric moisture is acceptable.

2.3.3.2.6 Precipitation

In PSAR Section 2.3.2.6, Kairos discusses its assessment of precipitation in the region of the proposed Hermes site. Kairos notes that the information provided in PSAR Section 2.3.2.6 is taken in large part from documents pertaining to the Clinch River site due the proximity of the Clinch River site to the proposed Hermes site.

Rain

In PSAR Section 2.3.2.6, Kairos states that hourly precipitation observations are available from the Oak Ridge NWS station. PSAR Table 2.3-18 presents long-term observations from the historical precipitation data for Oak Ridge. Kairos states that precipitation falls an average of about 125 days per year, and the normal annual precipitation is nearly 51 in (130 cm). The historical maximum monthly precipitation for each of the 12 months of the year ranged from about 7 in (18 cm) to just over 19 in (48 cm). The minimum monthly amount was a trace in October 1963. The maximum precipitation in 24 hours was 7.48 in (19.0 cm) in August 1960. Kairos states that except for late-summer/early-autumn, which are slightly drier periods, precipitation generally has a uniform distribution throughout the year. July and March are normally the wettest months of the year.

PSAR Table 2.3-19 presents precipitation data from Towers J and L and indicates greater than average precipitation during 2018 and 2019. PSAR Table 2.3-20 presents data taken from NOAA Atlas 14 that show the maximum rainfall, estimated by statistical analysis of regional precipitation data, for return periods of 1 to 100 years and for rainfall durations from 5 minutes to 10 days.

In PSAR Section 2.3.2.6, Kairos states that the probable maximum precipitation (PMP), sometimes called maximum possible precipitation, "for a given area and duration is the depth that is expected to possibly be reached, but not exceeded, based on historical meteorological observations." Kairos states in PSAR Section 2.3.2.6 that the PMP values for the proposed Hermes site area, using a 100-year return period, for 6, 12, 24, and 48 hours are 4.7, 5.7, 6.8, and 8.3 in (11.9, 14.5, 17.2, and 21.1 cm), respectively. PSAR Table 2.3-18 indicates thunderstorm activity for the proposed Hermes site area and indicates that approximately 49 thunderstorms occur in a typical year. Kairos notes in PSAR Section 2.3.2.6 that thunderstorm activity is most predominant in the spring and summer seasons, and the maximum frequency of thunderstorm days is normally in July.

Snow

In PSAR Section 2.3.2.6, Kairos states that appreciable snowfall is relatively infrequent in the area. PSAR Table 2.3-21 summarizes snowfall data for Knoxville and Oak Ridge, Tennessee. Kairos states that normal annual snowfall has ranged from about 6.5 in (16.5 cm) at Knoxville to about 11 in (28 cm) at Oak Ridge. Generally, significant snowfalls are limited to December through March. Respective 24-hour maximum snowfalls have been 18 and 12 in (46 and 30 cm) at Knoxville and Oak Ridge.

Precipitation Wind Roses

PSAR Figure 2.3-23 shows composite precipitation and wind direction (vector) data from Tower L for 2018 and 2019. In PSAR Section 2.3.2.6, Kairos states that precipitation conditions are most often associated with wind blowing from the SSW-SW directions, corresponding to the predominant wind flow direction sectors for all conditions. Kairos states that there is a secondary maximum for precipitation conditions with wind blowing from the NE-ENE directions.

Staff Review of Information on Precipitation

The staff reviewed the information on precipitation in the region of the proposed Hermes site. Based on its review, including verification that Kairos obtained the information from appropriate sources and that the information is consistent with other available data and appears reasonable for the geographic area, the staff finds that Kairos's assessment is sufficient for characterization of precipitation at the site to inform analyses for the Hermes facility. Therefore, the staff finds that Kairos's assessment of precipitation is acceptable.

2.3.3.2.7 *Fog*

PSAR Table 2.3-22 presents fog data for Knoxville and Oak Ridge. In PSAR Section 2.3.2.7, Kairos states that these data indicate that heavy fog (reducing visibility to less than or equal to 0.25 mi (0.40 km)) occurs about 30 days per year at Knoxville and 52 days per year at Oak Ridge, with the autumn normally the foggiest season. Kairos states that the proposed Hermes site has conditions more similar to Oak Ridge due its proximity to Oak Ridge.

The staff reviewed the information on fog in the region of the proposed Hermes site. Based on its review, including verification that Kairos obtained the information from appropriate sources and that the information is consistent with other available data and appears reasonable for the geographic area, the staff finds that Kairos's assessment is sufficient for characterization of fog at the site to inform analyses for the Hermes facility. Therefore, the staff finds that Kairos's assessment of fog is acceptable.

2.3.3.2.8 *Atmospheric Stability*

PSAR Table 2.3-23 lists the frequency of occurrence of Pasquill atmospheric stability classes A through G (i.e., the percentage of time each stability class occurs) as determined by ORR Tower L for the 2-year period of calendar years 2018 and 2019. The classes are determined based on the vertical temperature difference at the tower, as shown in PSAR Table 2.3-25. In PSAR Section 2.3.2.8, Kairos states that while the atmosphere at the tower location for the 2 years analyzed appears to be almost equally stable, neutral, and unstable, the stable lapse conditions (i.e., inversions, which are represented by classes E, F, and G) occur most of the time (42 percent). However, Kairos notes that the majority of the stable lapse conditions, occurring 27 percent of the time, are only slightly stable (class E). The most stable class (class G) occurs approximately 5.5 percent of the time while neutral lapse conditions (class D) occur approximately 27 percent of the time. Unstable classes (A, B, and C) occur approximately 31 percent of the time.

The staff reviewed the information on atmospheric stability in the region of the proposed Hermes site. Based on its review, including verification that Kairos obtained the information from appropriate sources and that the information is consistent with other available data and appears reasonable for the geographic area, the staff finds that Kairos's assessment is sufficient for characterization of atmospheric stability at the site to inform analyses for the Hermes facility. Therefore, the staff finds that Kairos's assessment of atmospheric stability is acceptable.

2.3.3.2.9 *Inversion Persistence*

PSAR Table 2.3-24 presents a summary of inversion persistence data, with a breakdown by stability class, for ORR Tower L for 2018 and 2019. In PSAR Section 2.3.2.9, Kairos states that inversion persistence is defined as "two or more consecutive hours of a single stable class (or combination of stable classes)." Kairos states that the longest contiguous period of inversion conditions during the 2-year period analyzed for Tower L lasted 215 hours.

The staff reviewed the information on inversion persistence in the region of the proposed Hermes site. Based on its review, including verification that Kairos obtained the information from appropriate sources and that the information is consistent with other available data and appears reasonable for the geographic area, the staff finds that Kairos's assessment is sufficient for characterization of inversion persistence at the site to inform analyses for the Hermes facility. Therefore, the staff finds that Kairos's assessment of inversion persistence is acceptable.

2.3.3.2.10 Mixing Heights

In PSAR Section 2.3.2.10, Kairos lists the estimated mean maximum heights from the surface up to which atmospheric mixing is occurring (i.e., mixing heights) for the NWS upper air site at Nashville, Tennessee, based on data from Holzworth, "Mixing Heights, Wind Speeds, And Potential for Urban Air Pollution Throughout the Contiguous United States." Kairos provides seasonal and annual estimates of rural mixing heights for the proposed Hermes site as follows:

- Winter (December, January, February) – 563 m (1,847 ft) (morning), 1,123 m (3,684 ft) (afternoon)
- Spring (March, April, May) – 606 m (1,988 ft) (morning), 1,783 m (5,850 ft) (afternoon)
- Summer (June, July, August) – 441 m (1,447 ft) (morning), 1,874 m (6,148 ft) (afternoon)
- Autumn (September, October, November) – 357 m (1,171 ft) (morning), 1,473 m (4,833 ft) (afternoon)
- Annual – 492 m (1,614 ft) (morning), 1,563 m (5,128 ft) (afternoon)

The staff reviewed the information on mixing heights in the region of the proposed Hermes site. Based on its review, including verification that Kairos obtained the information from appropriate sources and that the information is consistent with other available data and appears reasonable for the geographic area, the staff finds that Kairos's assessment is sufficient for characterization of mixing heights at the site to inform analyses for the Hermes facility. Therefore, the staff finds that Kairos's assessment of mixing heights is acceptable.

2.3.3.2.11 Potential Influence of the Plant and Its Facilities on Local Meteorology

In PSAR Section 2.3.2.11, Kairos states that the proposed Hermes plant systems have a limited potential to noticeably affect local meteorology. Kairos notes that Hermes would utilize air-cooling as the primary heat sink, which would limit emission of water droplets or water vapor or aerosol. Kairos states that the decay heat removal system utilizes low-pressure evaporative cooling, so while there would be some steam plumes due to heat rejection exhaust, these would be hot exhaust streams that would rapidly evaporate when mixed with ambient air. Kairos notes that there would be some minor air quality and visibility impacts during Hermes construction, but the impacts would be localized and due to near-ground-level releases of non-radioactive particulate related to the construction activities.

The staff reviewed Kairos's information on the potential influence of Hermes on local meteorology in the region of the proposed Hermes site. The staff finds that, based on the Hermes design, including the design of systems for cooling the reactor discussed above, Hermes plant systems would be unlikely to noticeably affect local meteorology. Therefore, the staff finds that Kairos's assessment of the potential influence of Hermes on local meteorology is acceptable.

2.3.3.3 Meteorological Monitoring Program

In PSAR Section 2.3.3, Kairos states that the Hermes facility uses meteorological monitoring and measurements taken within the ORR. Kairos provided data from measurements taken at Tower L for 2 complete calendar years 2018 and 2019. Kairos states that Tower L is the closest multiple-level tower in the vicinity of the site. Kairos describes the location of the tower and presents the instrumentation list. The measurement levels are 15-m (49-ft) and 30-m (98-ft).

Kairos used the 2 years of data to support dispersion analyses for postulated airborne releases at the proposed site.

Kairos states that while Tower L was permanently shut down on May 6, 2021, other available sources of meteorological data include Tower J for measurements of wind and temperature and Tower D for measurements of temperature and stability class. The locations and measurements taken at these towers are also outlined in the PSAR. Kairos states that validated data from all of the ORR meteorological towers is available at ORNL's ORR Meteorology website.

The staff reviewed Kairos's information on the meteorological monitoring program for the proposed Hermes site and finds that Kairos provided meteorological data that is representative of the proposed site and sufficient to support dispersion analyses. The staff also finds that Kairos identified the towers and data measurements for its continuing onsite measurements program and identified where the data could be found. Therefore, the staff finds Kairos's meteorological monitoring program to be acceptable.

2.3.3.4 Short Term Atmospheric Dispersion Modeling for Accidental Releases

In PSAR Section 2.3.4, Kairos addresses the short term dispersion modeling approaches for assessing the atmospheric dispersion factors (χ/Q) to evaluate dose consequence of postulated releases resulting from accidents. Kairos states in PSAR Section 2.3.4 that the short term dispersion modeling uses the ARCON96 code with the atmospheric dispersion methodology as outlined in Kairos topical report KP-TR-012-NP-A, "KP-FHR Mechanistic Source Term Topical Report," Revision 3, which was previously reviewed and approved by the staff.

By letter dated February 3, 2022, Kairos provided its ARCON96 input and output files. These files contained the site-specific inputs and assumptions used in the dispersion modeling. In the PSAR, Kairos uses ARCON96 to calculate short term dispersion factors for the EAB, which is at a distance of 250 m (820 ft) from the proposed facility, and the outer boundary of the LPZ which is at a distance of 800 m (2,625 ft) from the proposed facility. Kairos provides these χ/Q values in PSAR Table 13.2-1.

In PSAR Section 2.3.4, Kairos states that the hourly meteorological data input to ARCON96 consists of the wind direction and speed from two measurement levels (15 m (49 ft) and 30 m (98 ft)), and the stability class. The hourly meteorological data used is from ORR Tower L for 2018 and 2019 and constitutes two complete annual cycles.

In its February 3, 2022, letter, Kairos stated that it had identified a formatting error in the meteorology data and an error in the chronological order the files were listed in for the ARCON96 run. Kairos stated that the dispersion calculation would be updated in a future revision of the calculation. By letter dated March 1, 2022, Kairos submitted a PSAR change package reflecting updated site-specific χ/Q values.

The staff reviewed the methodology, data, inputs, and assumptions used by Kairos in its short term atmospheric dispersion analysis. The staff finds that Kairos's methodology, data, inputs, and assumptions appropriately reflect the conditions of the proposed Hermes site and that Kairos's use of the ARCON96 code is also appropriate and consistent with established practice. The staff also performed a confirmatory analysis of atmospheric dispersion for Hermes using ARCON96, the atmospheric dispersion methodology as outlined in KP-TR-012-NP-A, Revision 3, and meteorological data provided by Kairos and obtained similar results to Kairos. Therefore, based on its review of Kairos's analysis as well as the results of the staff's confirmatory analysis, the staff finds Kairos's short term atmospheric dispersion analysis and calculated dispersion factors for the EAB and LPZ boundary acceptable.

2.3.3.5 Long-Term Atmospheric Dispersion Estimates for Routine Releases

In PSAR Section 2.3.5, Kairos states that details regarding long-term dispersion modeling (i.e., modeling for routine releases), including the modeling inputs and the interpretation of the modeling results, will be provided in an OL application. The staff will review this information as part its review of an OL application.

2.3.3.6 Technical Evaluation Summary

The staff evaluated the proposed Hermes site meteorology, including the description of the general climate of the region and local meteorological conditions relevant to the design and operation of the facility, as described in Hermes PSAR Section 2.3, using the guidance and acceptance criteria from Section 2.3 of NUREG-1537, Parts 1 and 2. Consistent with the review procedures of NUREG-1537, Part 2, Section 2.3, the staff confirmed that the information presented in the PSAR was obtained from sources of adequate credibility and is consistent with other available data. The staff also reviewed how that information was used in assessing the general climate of the region and meteorological conditions relevant to the design and operation of the facility. In addition, the staff reviewed Kairos's atmospheric dispersion analysis for the site.

In summary, the staff finds that the site characteristics associated with meteorology, including general and local climatology, are acceptable and reasonably representative of the region of the proposed Hermes site. The staff finds that the data resources (e.g., meteorological data sources) Kairos used to prepare PSAR Section 2.3 are appropriate. The staff finds, based on the review of the application, as supplemented, as well as the results of the staff's confirmatory analyses, that Kairos's analyses of meteorological hazards and atmospheric dispersion are sufficient and acceptable. The staff finds that the proposed Hermes site is not located where catastrophic meteorological events are likely, that Kairos considered credible meteorological events in developing the design basis parameters for the proposed facility, and that Kairos provided an adequate description of site characteristics needed to evaluate the potential uncontrolled release of radioactive materials.

Based on its review, the staff finds that the level of detail and analyses provided on Hermes site meteorology demonstrates an adequate design basis and satisfies the applicable acceptance criteria of NUREG–1537, Part 2, Section 2.3, allowing the staff to find that:

- The meteorological history and projections for the proposed site have been prepared in an acceptable form.
- These projections have been factored into the choice of facility location, as well as the design (as discussed in SE Section 3.2), sufficiently to provide assurance that no weather-related event is likely to cause damage to the reactor facility during its lifetime that could result in the uncontrolled release of radioactive material to the unrestricted area.
- The meteorological information is sufficient for analyses applicable to and commensurate with the risks of the dispersion of accidental airborne releases of radioactive material in the unrestricted environment at the proposed site.

2.3.4 Conclusion

Based on its findings above, the staff concludes the information on meteorology in Hermes PSAR Section 2.3, as supplemented, is sufficient and meets the applicable guidance and regulatory requirements identified in this SE section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Further information on meteorology, e.g., details regarding long-term dispersion modeling, can reasonably be left for later consideration in the final safety analysis report (FSAR) since this information is not necessary to be provided as part of a CP application.

2.4 <u>Hydrology</u>

2.4.1 Introduction

PSAR Section 2.4, "Hydrology," provides a description of hydrological information that includes postulated hydrological events and potential flood hazards for the proposed Hermes site. Kairos references hydrological information from several flood hazard study reports. Kairos states that information in PSAR Section 2.4 supports the analyses and evaluations of the consequences of potential uncontrolled releases of radioactive material.

2.4.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of the Hermes site hydrology are as follows:

- 10 CFR 50.34, "Contents of applications; technical information," paragraph (a), "Preliminary safety analysis report," including 10 CFR 50.34(a)(1)(i), which requires that the PSAR include "A description and safety assessment of the site on which the facility is to be located, with appropriate attention to features affecting facility design. Special attention should be directed to the site evaluation factors identified in [10 CFR Part 100]…".
- 10 CFR 50.35, "Issuance of construction permits."
- 10 CFR 50.40, "Common standards."
- 10 CFR 100.10, "Factors to be considered in evaluating sites," paragraph (c)(3), which requires that in determining the acceptability of a test reactor site, the NRC should consider that: "Geological and hydrological characteristics of the proposed site may have a bearing on the consequences of an escape of radioactive material from the facility. Special precautions should be planned if a reactor is to be located at a site where a significant quantity of radioactive effluent might accidentally flow into nearby streams or rivers or might find ready access to underground water tables."

The applicable guidance for the evaluation of the Hermes site hydrology is as follows:

- NUREG-1537, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors," Part 1, "Format and Content," and Part 2, "Standard Review Plan and Acceptance Criteria," Section 2.4, "Hydrology."

2.4.3 Technical Evaluation

The SE subsections below discuss the staff's review of the hydrological description of the site, including the flood record for the site; the design basis flood for the site; hypothetical dam failures that could affect the site; and groundwater at the site, including the potential for groundwater contamination.

2.4.3.1 Hydrological Description and Flood Record

As described in PSAR Section 2.4, the proposed Hermes site is approximately 3.5 mi (5.6 km) from the Clinch River site. Kairos indicated that the hydrological information included in the Clinch River ESP SSAR has been previously approved by the NRC, and its regional hydrological information is applicable to the Hermes site due to its close proximity. Therefore, Kairos referenced Section 2.4.1 of the Clinch River ESP SSAR and did not repeat details of the hydrosphere information in PSAR Section 2.4.

The staff reviewed the hydrosphere information provided in the Clinch River ESP SSAR. Since the Hermes site is not far from the Clinch River site and both sites are in the same hydrological region, the staff finds that the hydrosphere information of the Clinch River site is similar and relevant to the regional hydrology for the Hermes site. Therefore, the staff finds that Kairos's referenced hydrosphere information is acceptable and sufficient for the staff's hydrological evaluation.

In addition to the regional hydrology, Kairos provided a description of the local hydrology that affects the Hermes site. As described in PSAR Section 2.4.1, the Hermes site is in the ETTP just west of Poplar Creek and it is located approximately 3 mi (5 km) upstream of the confluence of Poplar Creek with the Clinch River. Another nearby confluence is that of Poplar Creek and East Fork Poplar Creek, and that confluence is at a flow distance approximately 5.5 mi (8.9 km) from the confluence of Poplar Creek and the Clinch River.

The staff used the U.S. Geological Survey (USGS) Elverton, Tennessee, Quadrangle Map to verify the neighboring stream flow confluences near the test reactor site. The staff finds that the local hydrological descriptions in Section 2.4.1 of the PSAR are sufficient because Kairos provided the hydrological descriptions of Poplar Creek, East Fork Poplar Creek, Clinch River, and the Tennessee River, which all have hydrological impacts on the test reactor site.

As described in PSAR Section 2.4.1, the Hermes site is within the approximately 40-acre footprint of the former K-33 building. The grade elevation of the site is approximately 765 ft (233 m) above the USGS vertical datum, North American Vertical Datum of 1988 (NAVD88). Kairos reported that the elevations used in the PSAR are in different vertical datums, including Mean Sea Level, National Geodetic Vertical Datum of 1929 (NGVD29), and NAVD88. The differences among those datums are within a few inches. The grade elevation is 21 ft (6.4 m) above Poplar Creek's normal flow elevation and 24 ft (7.3 m) above the Clinch River's normal flow elevation.

The staff used the USGS Elverton, Tennessee, Quadrangle Map to confirm that the average site grade elevation is 765 ft (233 m) above the USGS vertical datum, NAVD88. Based on the map and TVA's operational reservoir level of Watts Bar Lake for the Clinch River shown in PSAR Table 2.4-1, the staff confirmed that the normal flow elevations of Poplar Creek and the Clinch River are below the Hermes site grade as described in PSAR Section 2.4.1.

For the local hydrology study, Kairos references four flood study reports in PSAR Section 2.4.1:the Federal Emergency Management Agency (FEMA) Flood Insurance Study (FIS) for Roane County, Tennessee, November 2009; Barge, Waggoner, Summer, and Cannon, Inc., "Probabilistic Flood Hazard Assessment for Y-12 (Bear Creek) and K-25 (Poplar Creek)," 2015 Update (included as an attachment to a letter from Kairos dated February 8, 2022); TVA, "Flood Analyses for Department of Energy Y-12, ORNL and K-25 Plants," 1991 (also included as an attachment to the letter from Kairos dated February 8, 2022); and the Clinch River ESP SSAR. These studies are related to Poplar Creek, East Fork Poplar Creek, and the Clinch River, as well as other creeks and rivers that are not near the proposed Hermes site. Kairos presents the flood elevations for various exceedance probabilities (taken from the FEMA FIS for Roane County) at the Poplar Creek outlet to the Clinch River in PSAR Table 2.4-2. Kairos projects these flood elevations to the Hermes site. The estimated flood elevations indicate no flooding at the Hermes site. In PSAR Table 2.4-3, Kairos also presents the updated flood elevations (projected from a 2015 study) for various flood conditions at the Hermes site. Kairos provided a detailed description of the updated flood elevations in a letter dated February 8, 2022. PSAR Table 2.4-3 shows that the updated flood elevations do not exceed 765 ft (233 m) (the site grade elevation), except for one of the predicted flood events with an extremely low annual exceedance probability (0.001 percent).

The staff reviewed FEMA's 2009 flood elevations shown in PSAR Table 2.4-2 and the updated 2015 flood elevations shown in PSAR Table 2.4-3. Comparing the two studies, the staff notes that the flood elevations have small differences resulting from different locations of stream cross-sections and different hydrological modeling.

The staff notes that the flood elevations shown in PSAR Table 2.4-2 were originally developed for the Clinch River at the outlet of Poplar Creek. Kairos projected those flood elevations to the Hermes site. Since they are based on flood frequency analysis and river hydraulic modeling without including river hydraulic parameters of Poplar Creek, the staff notes that the flood elevations projected from the Poplar Creek outlet to the test reactor site are surrogate flood elevations. The flood elevations shown in PSAR Table 2.4-3 are computed to be directly applicable to the test reactor site and are based on the 2015 river hydraulic simulation for Poplar Creek.

Based on a comparison between the information in the 2015 study and the 2009 FEMA report, the staff notes that the backwater effect from the confluence to the Hermes site dominates the flow conditions in Poplar Creek and affects the flood elevation at the Hermes site. The staff finds that the computed flood elevations given in PSAR Table 2.4-3 for the Hermes site are acceptable because these flood elevations were computed for Poplar Creek and include the backwater from the Clinch River.

In PSAR Section 2.4.1, Kairos references information from the FEMA FIS report to provide the historical flood record for the local hydrology study. Kairos states that, based on the FEMA study, the most severe flood event that affected the local area is the 1928 Poplar Creek flood event which was associated with a recorded peak flow rate of 17,000 cubic feet per second (cfs) (481,386 L/s) at the stream gauge station at mile 13.8 of Poplar Creek (roughly 10 mi (16 km) upstream of the Hermes site). This flood has an average recurrence interval of 40 years. The highest flood elevation, at the gauge station of mile 13.94 of Poplar Creek, was recorded in 1973 and was 770.6 ft (234.9 m) above the USGS vertical datum, NGVD29. In the East Fork Poplar Creek, a gauge station at 3.3 mi (5.3 km) upstream from the confluence with Poplar Creek (roughly 5.8 mi (9.3 km) upstream of the Hermes site) recorded a flood elevation of 770.2 ft (234.8 m) (NGVD29) in the 1973 flood event and also in 1977; this flood has a recurrence of approximately 30 years. Kairos indicates that this flood, with an elevation of 770.2 ft (234.8 m) at the gauge station, had no impact on the Hermes site, based on Kairos's comparison to the computational results for a 100-year flood given in the 1991 TVA report "Flood Analyses for Department of Energy Y-12, ORNL and K-25 Plants."

The staff reviewed the local hydrological description in PSAR Section 2.4.1, as well as the FEMA FIS referenced in the PSAR. The staff finds that the local hydrological description in PSAR Section 2.4.1 contains sufficient and appropriate information on the flood record because the descriptions are supported by the FEMA FIS report and include the flood elevations and recurrences of the recorded severe flood events.

The staff extended the most severe flood event recorded in the 1970s from the gauge station at mile 13.94 of Poplar Creek and from the gauge station at mile 3.3 of East Fork Poplar Creek to independently estimate the flood elevations at the Hermes site. The staff's estimation for the site flooding was consistent with Kairos's statement that the recorded severe flood events in the 1970s did not inundate the Hermes site.

Based on the discussion above, the staff finds that Kairos included in the PSAR a sufficient site description and information on historical flood records and studies for analyzing various flood hazards. The staff finds that Kairos appropriately considered the Hermes site's location adjacent to a stream and flood plain. Based on the above, the staff finds that Kairos appropriately evaluated the suitability of the site location for withstanding hydrologic events.

2.4.3.2 Design Basis Flood

As discussed in PSAR Section 2.4.2, Kairos quotes the flood elevations from river hydraulic modeling results in Barge, Waggoner, Summer, and Cannon, Inc., "Probabilistic Flood Hazard Assessment for Y-12 (Bear Creek) and K-25 (Poplar Creek)" (2015), related to the test reactor site and summarizes the flood elevations for various predicted flood events in PSAR Table 2.4-3. Kairos indicates that the flood elevations shown in PSAR Table 2.4-3 are the results generated by the USACE Hydraulic Engineering Centers River Analysis System (HEC-RAS) river hydraulic computational software. The simulated flood elevations for the Hermes site shown in PSAR Table 2.4-3 include the backwater effect from the Poplar Creek outlet at the Clinch River. Kairos selected the flood elevation of 759.9 ft (231.6 m) (NAVD88) in PSAR Table 2.4-3 as the design basis flood elevation corresponding to a credible hydrological event. Kairos indicates in PSAR Table 2.4-3 that the design basis flood elevation has an annual exceedance probability of 4E-5, which is equivalent to a recurrence interval of 25,000 years. As discussed in Kairos's letter dated February 8, 2022, this probability value is based on an interpolation using a Log-Pearson Type III flood frequency curve.

The staff finds that the computed flood elevation of 759.9 ft (231.6 m) (from the 2015 "Probabilistic Flood Hazard Assessment for Y-12 (Bear Creek) and K-25 (Poplar Creek)" report) is the most current computational result of the flood elevation for the test reactor site. The staff notes that the computational model (HEC-RAS) employed by the 2015 report is commonly used in flood profile simulations. Therefore, the staff finds that Kairos's use of the model is adequate for simulating the flood flow at the Hermes site. Based on the above findings, the staff also finds that the design basis flood elevation of 759.9 ft (231.6 m) (NAVD88) shown in Section 2.4.3.1 and in Table 2.4-3 of the PSAR is acceptable. The staff notes that this design basis flood elevation is approximately 5 ft (1.5 m) below the site grade elevation, and 7 ft (2.1 m) higher than the 752.7 ft (229.4 m) 500-year flood elevation shown on Table 2.4-3 of the PSAR. Since the design basis flood elevation is approximately 5 ft (1.5 m) below the grade elevation, the staff finds that the safety margin for flooding is sufficient to ensure the safe operation and shutdown of the Hermes reactor at the site, as well as to help ensure that any potential release of radioactive material due to the design basis flood would be bounded by the MHA as described in PSAR Chapter 13.

The staff notes that the Barge, Waggoner, Summer, and Cannon, Inc. report, “Probabilistic Flood Hazard Assessment for Y-12 (Bear Creek) and K-25 (Poplar Creek)” (2015), and the TVA report “Flood Analyses for Department of Energy Y-12, ORNL and K-25 Plants,” provide flood elevations resulting from a PMP, or a hypothetical sunny-day dam failure, that exceed the Hermes grade elevation. However, based on Kairos’s results of these hydrologic analyses and the staff’s estimation, the staff finds that extreme flood events causing inundation of the site are unlikely during the planned 4-year Hermes operational lifetime.

In addition to providing the probability for the design basis flood elevation from the 2015 “Probabilistic Flood Hazard Assessment for Y-12 (Bear Creek) and K-25 (Poplar Creek)” report in PSAR Table 2.4-3, Kairos also provided probabilities for occurrence of other flood events (i.e., flood events at other elevations) in PSAR Table 2.4-3. Kairos obtained these additional probabilities from the 1991 TVA report “Flood Analyses for Department of Energy Y-12, ORNL and K-25 Plants.” In this TVA report, probabilities of the PMP and the probable maximum flood (PMF) are set to be equal. For the Hermes site, Kairos indicates in PSAR Section 2.4.2.1 that the TVA report provides rainfall frequency study results that include studies of the PMP event and other smaller storm events. The TVA report also assumes that the probability of a storm is equal to the probability of its resulting flood (e.g., a TVA PMP event and its resulting flood, a TVA PMF event, have the same probability). In PSAR Section 2.4.3, Kairos indicates that the PMF is not used in the design bases of Hermes SSCs. Kairos states that the site-specific PMF analysis, including its selection of a PMF, will be discussed in a Hermes OL application.

Kairos indicates in PSAR Section 2.4 that potential releases of radioactive material due to credible hydrological events are bounded by postulated events analyzed in Chapter 13 of the PSAR. The staff finds that Kairos provides a sufficient safety margin against a credible hydrological event because the design basis flood elevation resulting from a credible hydrological event is 759.9 ft (231.6 m) and this is below the site grade elevation of 765 ft (233 m). Because safety related SSCs in the Hermes reactor building are above the design basis flood elevation, the staff finds that preliminary facility design bases adequately consider predicted hydrologic events which helps ensure that such hydrologic events would not preclude safe operation and shutdown of the reactor.

In PSAR Section 2.4, Kairos indicates that additional information relevant to stream blockage and stream diversion in Poplar Creek will be provided in a Hermes OL application.

As discussed in PSAR Sections 2.4, 2.4.2.2, and 2.4.2.3, Kairos considered other potential flood hazards that could be induced by dam failure, landslide, tsunami, surge, seiche, standing water, or a distant or locally generated “sea wave.” However, Kairos determined that the causes of those potential flood hazards are either unlikely or not applicable to the site.

In addition to the stream flood events, the staff evaluated the other flood events that could be caused by dam failure, landslide, tsunami, surge, seiche, or a distant or locally generated “sea wave.” Since the Hermes site is not near sea or lake shorelines, the staff finds that “sea wave,” tsunami, surge, and seiche are not applicable to the site. The staff also finds that any landslide-induced water waves in the Watts Bar Reservoir would have a minimal impact on the reservoir level as described in the NRC-approved Clinch River ESP SSAR. The staff notes that the Clinch River site is upstream of the reservoir and near the Hermes site. Therefore, the staff finds that a landslide would have no impact on the Hermes site. As discussed below, there is a low risk of potential upstream dam failures that may cause a flood at the Hermes site.

2.4.3.3 Hypothetical Dam Failures

In Section 2.4.1.1 of the PSAR, Kairos states that the release flows from Norris Dam and Melton Hill Dam on the Clinch River, as well as Watts Bar and Fort Loudoun Dams on the Tennessee River, can influence the proposed Hermes site. The four dams are owned and operated by TVA. Section 2.4.2.2 of the PSAR describes the hypothetical dam failures of Norris and Melton Hill Dams. Kairos describes the failures as being hypothetical and indicates that TVA has a dam safety program to inspect and maintain the dams in a safe condition. Kairos also indicates that TVA has installed instruments to monitor the integrity of the dams.

The staff reviewed the PSAR Section 2.4.1.1 descriptions of the four reservoirs retained by the Norris, Melton Hill, Watts Bar, and Fort Loudoun Dams as well as the characteristics of the reservoirs shown in PSAR Table 2.4-1. The staff reviewed the distance from each dam to the Hermes site, each reservoir storage volume, and the age of each dam. The staff finds that a hypothetical Norris Dam failure is the critical case that has the most potential influence on the Hermes site if it fails and releases uncontrolled outflows. The staff's determination of a Norris Dam failure to be the most critical case is based on the following: (1) the Norris Dam is the oldest dam, built in 1936; (2) the Norris Dam impounds the largest storage volume; and (3) the Norris Dam maintains the highest operational reservoir level. The staff notes that Melton Hill Dam is downstream of Norris Dam and its flood storage volume is negligible as indicated in PSAR Table 2.4-1. Therefore, the staff finds that an individual Melton Hill Dam failure is not a credible threat to the Hermes site even though the dam is the closest distance to the site when compared to the other dams.

The staff notes that it is reasonable to expect that a Melton Hill Dam failure due to an overtopping flow caused by a Norris Dam failure could occur in conjunction with a Norris Dam failure because Melton Hill Dam has negligible storage volume for retaining any upstream dam breach outflows from Norris Dam. Since the hypothetical dam failure of Norris Dam plus the overtopping failure of Melton Hill Dam on the Clinch River is more critical to the Hermes site than the other two dam failures on the Tennessee River, the staff did not evaluate potential failures of the Fort Loudoun and Watts Bar Dams. PSAR Section 2.4.2.2 states that TVA reanalyzed the stability of Norris Dam in 2014 and determined that the concrete sections and the earthen embankment were stable under seismic loading conditions. The controlling seismic event producing the highest elevations on Watts Bar reservoir was used for the seismic postulated failure evaluation, and the evaluation included a postulated failure of Melton Hill Dam. As part of the TVA studies, a potential "sunny-day" failure of Norris Dam was evaluated and reported in "Probabilistic Flood Hazard Assessment for Y-12 (Bear Creek) and K-25 (Poplar Creek)." This report provides the flood elevations for various locations of the hypothetical "sunny-day" dam failure.

The staff finds that Kairos provided adequate flooding analysis for a hypothetical "sunny-day" dam failure, since the analysis included unsteady flow simulation with dam breach outflow and used reasonable dam breach assumptions. As discussed above in the Design Basis Flood subsection of SE Section 2.4, the staff notes that potential flood elevations for the hypothetical "sunny-day" dam failure could exceed the Hermes grade elevation but finds that such extreme flood events causing inundation of the site are unlikely during the planned 4-year period of Hermes operation. In addition, because TVA owns and operates the dams discussed above and regularly inspects the dams based on its dam safety program, the staff estimates that the probability of dam failures is low. Based on the low probability of dam failure, the staff finds that the Hermes site is at low risk of flooding caused by dam failure. Based on the above, supported by the staff's review of Hermes facility design features to prevent water damage, which is discussed in SE Section 3.3, the staff finds that Hermes would be located and designed to withstand flooding induced by credible dam failures.

2.4.3.4 Groundwater

Kairos states in PSAR Sections 2.4.4 and 2.4.1.2 that the groundwater table is about 10 ft (3 m) below the site grade. Kairos also states that there is no need for groundwater extraction and injection to operate Hermes. The staff confirmed that the groundwater table is approximately 10 ft (3 m) below the site grade, based on the indications of the groundwater table shown in Figures 2.5-2, 2.5-3, and 2.5-22 of the PSAR. In PSAR Section 2.4.4, Kairos indicates that it will address the seasonal variation of the groundwater table in a Hermes OL application.

Kairos states in PSAR Section 2.4.5 that a small amount of tritiated water migration in secondary support systems, including the Decay Heat Removal System and the Component Cooling Water System, may occur. Kairos states that these systems are monitored through periodic sampling. The Tritium Management System (TMS) maintains a level of overall tritium capture capacity to minimize tritium releases from the Hermes facility. Section 9.1.3 of the PSAR describes the TMS, and the staff reviewed the TMS as discussed in SE Section 9.1.3. Kairos states in PSAR Section 2.4.5 that the tritium inventory is monitored to comply with the inventory limits set by the MHA assumptions and accident dose limits in 10 CFR 100.11. The staff notes that the Pebble Handling and Storage System (PHSS) described in PSAR Section 9.3 includes a spent fuel cooling pool; PSAR Section 3.5 states that the PHSS is located in the safety related portion of the Hermes reactor building. Section 11.1.7 of the PSAR identifies an environmental monitoring program to demonstrate compliance with regulatory dose limits. As discussed in PSAR Section 11.1.7, Kairos will provide the environmental monitoring program in a Hermes OL application.

The staff notes that, because TRISO fuel particles serve as containment for fission products, tritium is the primary radionuclide of interest to monitor and confine. As Kairos has described in the PSAR, tritium will be captured and tritium content in the plant air and water systems will be monitored. Kairos will also have an environmental monitoring program to detect any potential radiological releases beyond normal operational releases. Because of the measures identified in this and the preceding paragraph, the staff finds that the Hermes preliminary design contains adequate provisions to mitigate or prevent uncontrolled release of radioactive material to groundwater.

PSAR section 1.5.2.1 states that the Hermes primary coolant is a molten salt with a high freezing temperature. Accordingly, the staff expects that any primary coolant leakage would solidify within the Hermes facility and could not contaminate groundwater. Because of the shielding afforded by the reactor building and the groundwater table being roughly 10 ft (3 m) below grade, the staff expects that neutron activation of groundwater will also be insignificant. Because the design basis flood elevation is below the site grade elevation, the staff finds that the design basis flood is not a factor in the potential release of radioactive material to surface water. The staff also notes that the TMS and the Reactor Building Heating, Ventilation and Air Conditioning System described in PSAR Chapter 9 limit the release of airborne radioactive material and the potential for deposition of radioactive material in surface water. Based on these features, the staff finds that groundwater contamination by primary coolant is unlikely, neutron activation of groundwater will be minimal, and release of airborne radioactive material with the potential for deposition in surface water will be controlled and monitored.

2.4.3.5 Technical Evaluation Summary

The staff evaluated the hydrologic characteristics for the proposed Hermes site, as described in PSAR Section 2.4, using the guidance and acceptance criteria from Section 2.4 of NUREG-1537, Parts 1 and 2. Consistent with the review procedures of NUREG-1537, Part 2, Section 2.4, the staff verified that the site has been selected with due consideration of potential hydrologic events and consequences. In addition, the staff ascertained that the design bases incorporated into the facility design will minimize potential radioactive contamination of ground or surface waters.

In summary, based on its technical evaluation discussed above, and supported by its review of Hermes design features in SE Section 3.3, the staff finds that the Hermes facility will be located and designed to withstand credible hydrologic events. The staff finds that potential events at the site that could cause nearby hydrological consequences are shown by PSAR analyses not to present significant risk to the facility. The staff also finds that facility design bases are derived sufficiently from predicted hydrologic events to help ensure that such events would not preclude safe operation and shutdown of Hermes. In addition, the staff finds that the facility design bases contain provisions to mitigate or prevent uncontrolled release of radioactive material in the event of a predicted hydrologic occurrence; potential consequences of such events are bounded by accidents analyzed in PSAR Chapter 13. Furthermore, the staff finds that facility design bases appropriately consider leakage or loss of reactor coolant to groundwater, neutron activation of groundwater, and deposition of released airborne radioactive material in surface water.

Based on its review, the staff finds that the level of detail and analyses provided on Hermes site hydrology demonstrates an adequate design basis and satisfies the applicable acceptance criteria of NUREG-1537, Part 2, Section 2.4, allowing the staff to find that:

- Kairos considered hydrologic events of credible frequency and consequence in selecting the proposed Hermes site, and the site is not located where catastrophic hydrologic events are credible.
- Kairos considered credible hydrologic events in developing the design bases for Hermes such that safe operation and shutdown of the reactor would not be precluded by a hydrologic event.
- Hermes's combination of site characteristics and design bases provide reasonable assurance that uncontrolled release of radioactive materials due to a credible hydrologic occurrence would be bounded by the accidents analyzed in PSAR Chapter 13.
- The Hermes design bases give reasonable assurance, for a CP, that any contamination of ground or surface waters at the site from Hermes operation or accidents would not exceed applicable 10 CFR Part 20 limits.

2.4.4 Conclusion

Based on its findings above, the staff concludes that the information on hydrology in PSAR Section 2.4, as supplemented, is sufficient and meets the applicable guidance and regulatory requirements identified in this SE section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Further information on hydrology can reasonably be left for later consideration in the FSAR since this information is not necessary to be provided as part of a CP application.

2.5 Geology, Seismology, and Geotechnical Engineering

2.5.1 Introduction

PSAR Section 2.5, "Geology, Seismology, and Geotechnical Engineering," describes the geologic, geophysical, seismic, and geotechnical characteristics of the proposed Hermes site and the surrounding region.

2.5.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of geology, seismology, and geotechnical engineering are as follows:

- 10 CFR 50.34, "Contents of applications; technical information," paragraph (a), "Preliminary safety analysis report," including 10 CFR 50.34(a)(1)(i), which requires that the PSAR include "A description and safety assessment of the site on which the facility is to be located, with appropriate attention to features affecting facility design. Special attention should be directed to the site evaluation factors identified in [10 CFR Part 100]…".
- 10 CFR 50.35, "Issuance of construction permits."
- 10 CFR 50.40, "Common standards."
- 10 CFR 100.10, "Factors to be considered when evaluating sites," paragraph (c), which requires that in considering the acceptability of a site for a test reactor, physical characteristics of the site, including seismology and geology, should be considered by the NRC.

The applicable guidance for the evaluation of geology, seismology, and geotechnical engineering is as follows:

- NUREG-1537, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors," Part 1, "Format and Content," and Part 2, "Standard Review Plan and Acceptance Criteria," Section 2.5, "Geology, Seismology, and Geotechnical Engineering."

2.5.3 Technical Evaluation

The staff notes that the proposed Hermes site is located less than four miles from the TVA Clinch River site, for which the NRC issued an ESP in 2019. In PSAR Section 2.5, Kairos cites information in the NRC-approved Clinch River ESP SSAR as also representative of the regional geology at the Hermes site due to its proximity to the Clinch River site. The staff finds that because of the proximity between the proposed Hermes site and the NRC-approved Clinch River site, the regional geologic history of the Clinch River site is also applicable to the proposed Hermes site. The staff's review and approval of the geologic, seismic, and geotechnical engineering characteristics of the Clinch River site, including a staff confirmatory analysis of the site seismic ground motion, is documented in the Clinch River ESP SER.

The Hermes SE subsections below discuss the staff's reviews of the proposed Hermes site geology (regional and local geology, and surface deformation), seismology (vibratory ground motion), and geotechnical engineering (stability of subsurface materials).

2.5.3.1 Regional and Local Geology

In PSAR Section 2.5.2, Kairos describes the proposed Hermes site as underlain by three distinct bedrock formations: the Mascot Dolomite, Murfreesboro Limestone, and Pond Springs Limestone Formations. Each of these formations (i.e., bedrock units) trends northeast to southwest parallel to the regional trend of the Appalachian Valley and Ridge Physiographic Province. The formations are, to some degree, calcareous as discussed in PSAR Section 2.5.2. As discussed in PSAR Sections 2.5.2.2 and 2.5.2.3, Kairos developed the subsurface stratigraphy from the geotechnical boring program at the site. Kairos provided updated site profiles in a letter dated February 9, 2022. As discussed in PSAR Section 2.5.2.3, the geotechnical investigations of the proposed Hermes site included soil borings and observation trenches, as well as laboratory testing.

Kairos states in PSAR Section 2.5.2.3.2 that the site subsurface includes fill, alluvial soils and residual soils above the bedrock units. PSAR Figures 2.5-2 and 2.5-3 illustrate the subsurface geologic profiles for the Hermes site. During the site characteristics audit (ML23115A480), Kairos confirmed that these profiles differ slightly from the geologic profile presented in Hermes Environmental Report Figure 3.3-3 in that the PSAR figures are based on detailed site-specific information and are the best representation of the site subsurface based on the actual boreholes at the selected site.

The staff reviewed Kairos's information in the PSAR characterizing the regional and local geology at the proposed Hermes site. Based on its review, the staff finds that Kairos provided an adequate description of the regional and local geology to sufficiently characterize the proposed site to support development of applicable design criteria for the Hermes facility, and therefore, the staff finds that Kairos's geology characterization is acceptable.

2.5.3.2 Surface Deformation

PSAR Section 2.5.4 addresses subsurface deformation at the proposed site. With respect to surface faulting as a potential cause for subsurface deformation, Kairos states that it will provide information on this topic in a Hermes OL application.

PSAR Section 2.5.2.1 discusses indications of karst activity that Kairos discovered during the geotechnical investigations, at depth, at the proposed Hermes site. Although the geotechnical investigations encountered evidence of karst activity at depth, Kairos indicates that there was no evidence of sinkhole activity encountered at the surface. Kairos also addresses karst in PSAR Section 2.5.4.3, in which Kairos states that the Hermes reactor building foundation will be located at a depth at which no karstic dissolution is encountered. In a letter dated February 9, 2022, Kairos clarifies how it intends to determine that the foundation rock shows no signs of karstic dissolution. Kairos states that the overburden soils and weathered rock will be removed to a depth of 30 ft (9 m) and the exposed bedrock will be inspected (prior to the foundation preparation with either an engineered crushed stone or lean concrete fill) to ensure the foundation rock has no evidence of karstic dissolution.

In order to confirm that the exposed bedrock does not show signs of karstic dissolution when the excavations are complete and before the foundation is prepared, and to provide reasonable assurance that regulatory requirements and license commitments are adequately addressed during the construction of the Hermes facility, the staff recommends that the CP include the following condition:

> Kairos shall perform detailed geologic mapping of excavations for safety related engineered structures; examine and evaluate geologic features discovered in those excavations; and notify the Director of the Office of Nuclear Reactor Regulation, or the Director's designee, as specified in 10 CFR 50.4, once excavations for safety related structures are open for examination by Staff.

The staff notes that following receipt of notification from Kairos, the staff would make a determination whether direct examination of open excavations are necessary as part of the NRC construction inspection program.

The staff reviewed Kairos's information in the PSAR characterizing the potential for surface deformation at the proposed Hermes site. Based on its review, because Kairos plans to remove the upper 30 feet of overburden soils and weathered rock and to ensure the foundation rock shows no evidence of karstic dissolution subject to the condition referenced above, the staff finds that the surface deformation is sufficiently characterized to support development of applicable design criteria for the Hermes facility and, therefore, the staff finds that Kairos's characterization of surface deformation potential is acceptable.

2.5.3.3 Vibratory Ground Motion

PSAR Section 2.5.3 addresses vibratory ground motion at the proposed Hermes site. Kairos states that, consistent with the intent of the guidance in NUREG-1537, it used seismic hazard information for the Clinch River site for developing its base rock probabilistic seismic hazard analysis (PSHA). In its letter dated February 9, 2022, Kairos stated that the PSAR reflects the assumption that the PSHA (based on an earthquake catalog ending in 2013) remains valid, and an updated earthquake catalog will be used for a Hermes OL application.

The staff reviewed the information above as well as the USGS earthquake catalog for the years 2013 through 2021. The staff finds that the changes in earthquake rates relative to the catalog used in the Clinch River ESP SSAR are minimal and unlikely to result in significant increases in seismic hazard at the proposed Hermes site.

In PSAR Section 2.5.3, Kairos compares its estimated subsurface seismic profiles to those developed by TVA in the Clinch River ESP SSAR. Kairos determined that the uniform hazard response spectra at the base of the proposed Clinch River facility are applicable at the foundation level of the proposed Hermes facility because the baserock lithology at both sites is similar and the results of the site response analysis at the Clinch River site are essentially linear. Kairos states that the Hermes site PSHA, used to develop the design response spectrum (DRS) for Hermes, will be updated to incorporate a Hermes site response analysis, which captures the rock dynamic properties for the proposed Hermes site, in a Hermes OL application.

Based on the similarities of the rock types and proximity of the Clinch River site to the proposed Hermes site, the staff finds that Kairos's use of the Clinch River ground motion response spectrum as the site-specific DRS for the Hermes test reactor is appropriate at the CP stage.

In PSAR Section 2.5.3, Kairos states that in developing its DRS, it considered the Hermes reactor and surrounding safety related structures to be Seismic Design Category 3 (SDC-3) and applied the guidance in ASCE 43-19, "Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities." To account for uncertainties in the PSHA, Kairos states that it considered potential impacts from the USGS National Seismic Hazard Mapping Project and the Pacific Earthquake Engineering Research Center (PEER) report, "Central and Eastern North

American Ground-Motion Characterization, NGA-East Final Report," in developing its preliminary site-specific DRS. Kairos provided its DRS in PSAR Figure 2.5-16 and PSAR Table 2.5-3.

The staff reviewed Kairos's approach for developing the DRS used in the PSAR. Based on Kairos's use of Staff-approved seismic source and ground motion models, which characterize both the regional and local seismic activity and the expected ground motions from these seismic sources, the staff finds that Kairos's approach ensures that the ground motions resulting from seismic activity affecting the Hermes site is sufficiently characterized to support development of applicable design criteria for the Hermes facility.

2.5.3.4 Stability of Subsurface Materials

The staff's review of Kairos's excavation plans and the proposed site subsurface properties, including the properties of the proposed foundation bedrock, is discussed in the following subsections.

PSAR Section 2.5.4.2 states that because the Hermes facility will be founded on bedrock, liquefaction will not be an issue at the proposed Hermes site. A detailed discussion of the staff's review of liquefaction potential at the proposed site is included below.

2.5.3.4.1 Subsurface Stratigraphy

PSAR Section 2.5.2, as supplemented by Kairos's letter dated February 9, 2022, describes the six boreholes (B-1 through B-6) and six observation trenches (OT-1 through OT-6) used to explore subsurface conditions at the proposed Hermes site. These boreholes and trenches are illustrated in PSAR Figure 2.5-1. PSAR Section 2.5.2.3 describes the methods used by Kairos to develop the boreholes, conduct the standard penetration tests (SPTs), and sample the soil. PSAR Section 2.5.2.3.1 states that Kairos constructed the trenches (except OT-3) adjacent to a remnant foundation from the previous K-33 gaseous diffusion facility. Kairos characterized the fractures (joints) present in the bedrock at the proposed site using the Rock Quality Designation (RQD) values measured at the boreholes; these values are presented in PSAR Table 2.5-1. The staff notes that the RQD measure is widely used to characterize fractured rock masses.

Based on its review of the information in PSAR Section 2.5.2 and Kairos's letter dated February 9, 2022, the staff finds that Kairos followed nationally recognized standards (for example, the American Society for Testing and Materials International (ASTM) standards) to identify and describe the soil types present in the subsurface of the proposed Hermes site, to sample the soil from the boreholes, and to measure the SPT blow counts. Therefore, the staff finds that Kairos's subsurface stratigraphy methodology is appropriate.

PSAR Figures 2.5-23 and 2.5-24 illustrate the subsurface profiles at the proposed Hermes site based on information from the boreholes and observation trenches. These figures also show the SPT N-values at various depths as measured in each borehole. As discussed in PSAR Section 2.5.2.3, Kairos states that it completed basic index tests for site characterization to classify the soils at the proposed site. Kairos states that it will perform a more comprehensive evaluation of the subsurface geotechnical properties in a Hermes OL application.

In PSAR Section 2.5.2.3.2, Kairos describes the different soil strata overlying the bed rock strata found at the proposed Hermes site based on the observations in the six boreholes and six trenches. PSAR Table 2.5-1 summarizes the subsurface stratigraphy present at the proposed Hermes site.

Based on the preceding information and discussion, and because Kairos used an appropriate subsurface stratigraphy methodology as discussed above, the staff finds that Kairos's evaluation of the proposed Hermes site's geotechnical characteristics is sufficient to support development of applicable design criteria for the Hermes facility and to assess the support required for the stability of Hermes structures. Therefore, the staff finds that Kairos's evaluation is acceptable for a CP application.

2.5.3.4.2 Karst Features

In PSAR Sections 2.5.2.1 and 2.5.4.3, Kairos discusses the karst features observed at the proposed Hermes site during subsurface characterization. Kairos states that the indications of karstic activities observed at the proposed site include an open void in Boring B-5 and at the bedrock/overburden interface near Boring B-1. However, Kairos states that the location of the reactor would be approximately 100 ft (31 m) north of Boring B-5 and more than 1,200 ft (365 m) from Boring B-1. As discussed earlier in this SE section, Kairos states in its letter dated February 9, 2022, that the overburden soils and weathered rock would be excavated to a depth of approximately 30 ft (9 m), exposing the surface of the foundation rock to allow for inspection and surface preparation. As also discussed earlier in this SE section, Kairos will be subject to a CP condition requiring it to inspect the exposed bedrock and perform detailed geologic mapping to ensure that the bedrock under the foundation of the reactor does not show signs of karstic dissolution. In PSAR Section 2.5.2.1, Kairos also states that it will provide a detailed site characterization with respect to potential karst features in a Hermes OL application.

Based on the preceding discussion of Kairos's preliminary investigations of karst features, and its findings earlier in this SE section with respect to Kairos's evaluations of the subsurface (including karst activity) and geotechnical characteristics, and subject to the CP condition referenced above, the staff finds that Kairos appropriately characterized the proposed Hermes site with regard to identifying potential karst features for a CP application. Kairos will be required to perform additional investigation of karst features by the CP condition and the staff would also review additional information during its review of a Hermes OL application.

2.5.3.4.3 Bearing Capacity and Settlements

Kairos discusses the stability of the proposed Hermes reactor foundation at the proposed site in PSAR Section 2.5.5.

In PSAR Section 2.5.5, Kairos states that the foundation layout for the Hermes reactor and its auxiliary facilities was selected based on the subsurface conditions determined from both historical documentation and subsurface borings at the proposed site. PSAR Figure 2.5-11 shows the proposed location of the Hermes reactor at the southeast corner of the site. PSAR Section 2.5.5.2 states that the bedrock interface is just above the depth of the reactor foundation at this site location, which reduces the amount of hard rock to be excavated. Kairos states that if weathered zones of the bedrock are encountered at the foundation location, they will be over-excavated and backfilled with concrete to develop an adequate foundation for the reactor. As shown in PSAR Figure 2.5-22, engineered backfill will be placed over the foundation bedrock to construct the non-safety related structures.

As also illustrated in PSAR Figure 2.5-22, the Hermes reactor building (safety related portion) will be placed on a below grade mat foundation supported by the Murfreesboro limestone. As indicated in PSAR Section 2.5.2.3.2 and PSAR Table 2.5-1, this limestone is light gray in color and medium bedded. It is also close jointed. PSAR Section 2.5.2.3.2 states that this limestone has approximately 3 ft (1 m) of weathered layer on top, and PSAR Table 2.5-1 indicates that it has a Rock Quality Designation for the intact limestone of 80 percent. As discussed in PSAR Section 2.5.5.2.1, as the reactor and the associated safety related structures will be placed on bedrock, Kairos expects that the bearing capacity provided by the bedrock will be adequate. In addition, the staff notes that the rock fracture characteristics of the bedrock at the reactor footprint location are needed to estimate the ultimate bearing capacity of the foundation. In PSAR Section 2.5.5.2.1, Kairos states that additional details regarding characterization of the bedrock in the vicinity of the selected reactor location will be provided in a Hermes OL application.

Kairos states in PSAR Section 2.5.5.2.1 that the settlement of the foundation due to placement of the reactor and associated safety and non-safety related structures would be limited only to immediate (or elastic) settlement. As the immediate settlement is a function of the subsurface stiffness, Kairos states that the settlement of the non-safety related structure can be controlled by selecting the engineered backfill with appropriate stiffness properties.

The staff finds that reactor foundation settlement will be limited only to immediate settlement because the foundation will be on rock and, therefore, the consolidation-related and secondary settlements will be negligible, if any. The staff also finds that Kairos can control settlement of non-safety related structures through the use of engineered backfill because it can control the stiffness properties of the engineered backfill.

The staff also notes that the foundations of the safety and non-safety related portions of the building are different. The safety related portion will be placed on a concrete mat over the bedrock. The non-safety related portion will have engineered fill over the bedrock to support this lighter portion of the structure. The staff notes that a differential settlement between the safety and the non-safety portion of the reactor building would be expected due to different stiffness properties of the engineered fill and the concrete. As discussed in PSAR Section 3.5.1, Kairos will provide a “moat” in the design of the reactor building between the safety and the non-safety portions to accommodate the differential settlement in addition to displacement during design basis seismic events.

Based on the preceding discussion, the staff finds that Kairos adequately described the foundation of the proposed reactor and qualitatively discussed the expected bearing capacity and immediate settlement. The staff also finds that Kairos described adequately for the CP stage the subsurface geology that the reactor foundation is expected to encounter. As discussed, Kairos will provide detailed information on site characterization along with the calculations to demonstrate that adequate bearing capacity is available in a Hermes OL application.

2.5.3.4.4 Liquefaction

Kairos discusses the potential for liquefaction in PSAR Section 2.5.4.2. Kairos states that liquefaction is not an issue at the proposed site for the Hermes reactor and associated safety related components because the safety related reactor foundation basemat will be over bedrock. The surrounding non-safety portion of the structure will rest over engineered backfill.

Kairos states in PSAR Section 2.5.4.2 that the effects of potential liquefaction on the foundation of the non-safety related structure will be addressed in the OL application.

The staff finds that there is no liquefaction potential for the safety related portion of the reactor building because this portion of the building will be over bedrock. As the characteristics of the engineered backfill will be controlled by Kairos, the staff will review the fill characteristics in a Hermes OL application along with Kairos's assessment of potential liquefaction under the non-safety related portion of the reactor building to ensure that the selected fill materials are not susceptible to liquefaction.

Based on the preceding discussion, the staff finds that Kairos has appropriately described, characterized, and assessed the site with respect to potential liquefaction that could affect the safety of the proposed Hermes reactor facility. The staff also finds that Kairos has characterized the rock layers under the safety related portions of Hermes to determine that the ground under safety related portions of the facility will not be susceptible to liquefaction in an earthquake.

2.5.3.4.5 Stability of Slopes

The PSAR does not discuss the potential for slope instability at the proposed site. However, in Section 3.3.2 of the Hermes Environmental Report, Kairos states that the former industrial site is generally flat, having a slope between 0 to 5 percent with elevations ranging between almost 860 ft (262 m) above mean sea level (amsl) in the northeast portion of the site to almost 740 ft (226 m) amsl on the shore of Poplar Creek. The staff notes that PSAR Figure 2.5-1 also indicates that the site is flat.

Based on the above discussion, the staff finds that Kairos adequately considered the topography of the site to assess and describe the stability of slopes at the proposed site, and because the site is flat, there is no slope instability problem at the proposed Hermes site.

2.5.3.5 Technical Evaluation Summary

The staff evaluated the geology, seismology, and geotechnical characteristics for the proposed Hermes site, as described in Hermes PSAR Section 2.5, using the guidance and acceptance criteria from Section 2.5 of NUREG-1537, Parts 1 and 2. Consistent with the review procedures of NUREG-1537, Part 2, Section 2.5, the staff confirmed that the information presented in the Hermes PSAR was obtained from sources of adequate credibility and is consistent with other available data, such as data from the USGS or in the Clinch River ESP SSAR for a nearby nuclear power plant site. The staff also evaluated whether the seismic characteristics of the site are considered in the design bases of structures, systems, and other facility features discussed in PSAR Chapter 3, "Design of Structures, Systems, and Components."

In summary, the staff finds that the preliminary information provided by Kairos in the PSAR demonstrates that the geologic features, both underlying and in the region surrounding the proposed Hermes site, are sufficient to provide the stable support required for reactor structures. In addition, the seismic source and ground motion models used by Kairos adequately capture the seismic activity in the site region, including the possibility for ground motions from large earthquakes. In conclusion, the staff finds that Kairos sufficiently characterized the seismic hazard in development of the site-specific DRS to support development of applicable design criteria for Hermes structures for a CP application.

Based on its review, the staff finds that the level of detail and analyses provided on Hermes site geology, seismology, and geotechnical characteristics demonstrates an adequate design basis and satisfies the applicable acceptance criteria of NUREG-1537, Part 2, Section 2.5, allowing the staff to find, subject to the CP condition discussed above, that:

- Information on the geologic features and the potential seismic activity at the proposed Hermes site has been provided in sufficient detail and in a form to be integrated acceptably into design bases for structures, systems, and other features of the reactor.
- Information in the PSAR indicates that damaging seismic ground motions at the proposed Hermes site during the Hermes operating lifetime are very unlikely. Furthermore, if seismic activity were to occur, any radiological consequences are bounded by analyses in Chapter 13 of the PSAR.
- The PSAR shows that there is no significant likelihood that the public would be subject to undue radiological risk following seismic activity; therefore, the potential for earthquakes does not make the proposed Hermes site unsuitable for the proposed facility.

2.5.4 Conclusion

Based on its findings above, the staff concludes that the information on geology, seismology, and geotechnical characteristics in Hermes PSAR Section 2.5, as supplemented, is sufficient and meets the applicable guidance and regulatory requirements identified in this SE section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40.

2.6 Summary and Conclusions on Site Characteristics

The staff evaluated the descriptions and discussions of the proposed Hermes site characteristics, as described in Chapter 2 of the Hermes PSAR, as supplemented, and finds that the information on Hermes site characteristics: (1) provides reasonable assurance that the final design will conform to the design basis, (2) meets all applicable regulatory requirements, and (3) meets the applicable acceptance criteria in NUREG-1537, Part 2. Based on these findings and subject to the condition referenced above, the staff makes the following conclusions for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40:

- Kairos described the proposed design of the facility, including, but not limited to, the principal architectural and engineering criteria for the design, and has identified the major features or components incorporated therein for the protection of the health and safety of the public.
- Such further technical or design information as may be required to complete the safety analysis of the site characteristics, and which can reasonably be left for later consideration, will be supplied in the FSAR.
- There is reasonable assurance that, taking into consideration the site criteria contained in 10 CFR Part 100, the proposed facility can be constructed and operated at the proposed location without undue risk to the health and safety of the public.
- The issuance of a permit for the construction of the facility would not be inimical to the common defense and security or to the health and safety of the public.

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3 DESIGN OF STRUCTURES, SYSTEMS, AND COMPONENTS

The purpose of the Hermes non-power test reactor's structures, systems, and components (SSCs) is to ensure the safety of the facility and the health and safety of the public. The material presented in Chapter 3, "Design of Structures, Systems, and Components," of the Hermes preliminary safety analysis report (PSAR) Revision 2 discusses the safety and protective functions and related design features of the SSCs that help provide protection against uncontrolled releases of radioactive material and related exposures. The bases for the design criteria for some of the SSCs discussed in this chapter may be developed in other chapters of the PSAR.

This chapter of the Hermes construction permit (CP) safety evaluation (SE) describes the U.S. Nuclear Regulatory Commission (NRC) staff's (the staff) technical review and evaluation of the preliminary design of the Hermes SSCs as presented in Chapter 3.0 of the Hermes PSAR. The Hermes CP application is for a non-power reactor facility whose purpose is to test and demonstrate the key technologies, design features, and safety functions of the Kairos Power fluoride salt-cooled high temperature reactor (KP-FHR) technology and its SSCs. The facility will also provide data and insights for the safety analysis tools and computational methodologies used for the design and licensing of a KP-FHR commercial power reactor. The Hermes reactor uses tristructural isotropic (TRISO) fuel, molten salt as a coolant, graphite as a moderator and dissipates heat generated by the TRISO fuel to the atmosphere through a primary heat transfer system and the decay heat removal system (DHRS).

The staff's findings and conclusions in this SE are limited to whether the Hermes reactor satisfies the Title 10, *Code of Federal Regulations* (10 CFR) Part 50 requirements for the issuance of a CP. The principal design criteria (PDC) for the facility SSCs are described in Section 3.1 of the PSAR. The PDC are based on the NRC-approved Kairos Power Topical Report (TR), KP-TR-003-NP-A, "Principal Design Criteria for the Kairos Power Fluoride Salt-Cooled, High Temperature Reactor, Revision 1," (PDC TR) dated May 22, 2020. Each of the sections below identify the applicable PDC for the SSCs being evaluated.

3.1 Design Criteria

3.1.1 Introduction

The PDC for the Hermes reactor are based on the PDC developed for the KP-FHR submitted to the NRC as TR KP-TR-003-NP-A, "Principal Design Criteria for the Kairos Power Fluoride Salt-Cooled, High Temperature Reactor," Revision 1. Hermes PSAR Table 3.1-3, "Principal Design Criteria," identifies the PDC from KP-TR-003 that are applicable to the Hermes reactor and the PSAR sections that discuss how the PDCs are met. In this chapter, the staff considered whether the four limitations and conditions identified in the PDC TR are satisfied. The staff evaluated the preliminary design information for Hermes to determine whether the Hermes design is consistent with the design aspects of the KP-FHR noted in the PDC TR, and that any deviations from the TR will lead to operation of the Hermes reactor without undue risk to the health and safety of the public.

3.1.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of the Hermes SSC design criteria are as follows:

- 10 CFR 50.34, “Contents of applications; technical information,” paragraph (a), “Preliminary safety analysis report.”
    - 10 CFR 50.34(a)(3)(i), which requires that each application for a CP include in the PSAR the PDC for the facility.
- 10 CFR 50.35, “Issuance of construction permits.”
- 10 CFR 50.40, “Common standards.”

For its evaluation of the Hermes design criteria, the staff used the following applicable guidance:

- NUREG-1537, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors,” Parts 1 and 2, Section 3.1, “Design Criteria.”
- Regulatory Guide (RG) 1.232, “Guidance for Developing Principal Design Criteria for Non-Light Water Reactors,” Revision 0, describes the staff’s proposed guidance on how the general design criteria in 10 CFR 50, Appendix A may be adapted for non-light-water reactor (non-LWR) designs.

3.1.3 Technical Evaluation

The staff evaluated the Hermes design criteria using the guidance and acceptance criteria in Section 3.1 of NUREG-1537, 10 CFR 50.34(a)(3)(i) requirements on design criteria, and relevant guidance in RG 1.232. The objective of the staff’s review of PSAR Section 3.1 is to determine whether:

- The design criteria are based on applicable standards, guides, codes, and criteria and provide reasonable assurance that the facility SSCs can be built and will function as required by the analyses in the PSAR.
- The design criteria provide reasonable assurance that the public will be protected from radiological risks resulting from operation of the reactor facility.

In Table 3.1-1, “Design Related 10 CFR Regulations Applicable to the Design,” of the PSAR, Kairos lists the design-related regulations applicable to Hermes addressed in the PSAR. The staff notes that the staff approved Kairos TR, KP-TR-004-NP-A, Revision 3, “Regulatory Analysis for the Kairos Power Salt-Cooled, High Temperature Reactor,” in its SE dated May 26, 2022. In its SE for KP-TR-004-NP-A, the staff found that the regulations identified in the TR generally encompass the regulations a KP-FHR power or test reactor must address. The staff’s SE also recognized that the spectrum of regulations that apply to a given application, whether a power or test reactor, will differ based on the scope of approval requested and specific applicability to the prospective application types identified in the tables in the TR appendixes. While some regulations listed in PSAR Table 3.1-1 are consistent with those identified in KP-TR-004-NP-A as applicable to a KP-FHR test reactor, the staff did not review Table 3.1-1 as a comprehensive list of all regulations applicable to the Hermes design. Rather, each section of this SE identifies the applicable regulations for that review area as part of the regulatory evaluation of the staff’s review of the CP application.

The Hermes PDCs, as listed in PSAR Table 3.1-3, “Principal Design Criteria,” are based on the PDC TR, with appropriate modifications as discussed below. The staff evaluated the limitations and conditions identified in the PDC TR to confirm the limitations and conditions were either met or evaluated as part of the PSAR. The staff's SE for the PDC TR imposed the following limitations and conditions:

1. As presented in the TR, there are key design features without which the proposed PDC would not be applicable or encompass the full set of necessary design criteria. Therefore, a KP-FHR design referencing the TR must have the following:

    - A "chemically stable molten fluoride salt mixture" coolant.
    - TRISO fuel particles and fuel pebbles that, combined with other design features as applicable, demonstrate functional containment performance criteria consistent with SECY-18-0096 and applicable regulatory dose requirements.
    - An intermediate coolant loop using a coolant that is compatible with reactor coolant, and that is demonstrated not to have a safety significant impact on the primary system.
    - "Near-atmospheric" primary coolant pressures.
    - The ability to ensure core cooling by maintaining coverage of the fuel within the reactor core with coolant.

    If other key design features are identified by the applicant that could necessitate additional PDCs, those PDCs would be subject to the staff's review, independent of the TR.

2. The proposed scope of a manufacturing license that would reference the TR and how the proposed PDC would be applicable is not sufficiently clear. As such, any use of the TR in a ML [Manufacturing License] application would be conditional on a related license application with a clear scope (a CP, COL, or DC application).

3. The development of this SE was informed by guidance in DG-1353, "Guidance for a Technology-Inclusive, Risk-Informed, and Performance-Based Methodology to Inform the Licensing Basis and Content of Applications for Licenses, Certifications, and Approvals for Non-Light-Water Reactors," April 2019, and NEI 18-04, "Risk-Informed Performance-Based Technology-Inclusive Guidance for Non-Light Water Reactor Licensing Basis Development," Revision 1. However, use of this guidance is not yet approved by the NRC. Further, the methodology described in NEI 18-04 is an integral process that requires a full understanding of all plant SSCs and their role in the probabilistic risk assessment and would need to appropriately consider all aspects of plant safety. Therefore, use of the TR by an applicant is conditional on the NRC's approval of the guidance in DG-1353 and NEI 18-04, with or without modification, and staff's further approval of any deviations from the approved guidance requested by the applicant.

4. Use of the term "safety related" as described in the TR is narrowly applicable to the context discussed herein and must include SSCs designated as safety related as defined in NEI 18-04 and endorsed by the NRC in DG-1353 as well as any SSCs that meet the definition of 10 CFR 50.2 as applicable to the broader future application referencing the TR.

Limitation and condition 1 in the PDC TR is based on the KP-FHR design, which includes an intermediate coolant loop not present in the Hermes design. Instead, the Hermes design uses a heat rejection pathway directly from the primary coolant to air. Although the preliminary Hermes design does not include an intermediate salt loop, the staff evaluated the underlying concern related to the potential of the heat rejection pathway design to have a safety significant effect on the primary heat transport system. In order to address this Hermes design feature, the staff evaluated the Hermes preliminary design to consider the potential for an air ingress event to affect the primary heat transport system and found that structural integrity of the system will likely be maintained following an air ingress event until such time the ingress is terminated, or the fuel has been removed from the reactor. All other aspects of the Hermes design (e.g., chemically stable molten fluoride salt, TRISO fuel particles and fuel pebbles) are consistent with the KP-FHR design and hence the PDCs associated with those items remain valid. The lack of an intermediate loop in the Hermes design is evaluated in Section 5.1 of this SE.

PDC TR limitation and condition number 2 is not applicable to the Hermes CP application because the application is not related to a manufacturing license.

PDC TR limitation and condition number 3 conditioned use of the PDC TR on the NRC's approval of the probabilistic risk assessment-centric methodology described in NEI 18-04, which had not been endorsed by the staff at the time the staff reviewed the PDC TR. Since the issuance of the PDC TR SE, the staff endorsed the approach in NEI 18-04 in RG 1.233, "Guidance for a Technology-Inclusive, Risk-Informed, and Performance-Based Methodology to Inform the Licensing Basis and Content of Applications for Licenses, Certifications, and Approvals for Non-Light Water Reactors," Revision 0.

However, the Hermes licensing methodology uses the non-power reactor licensing framework of NUREG-1537 and does not use the NEI 18-04 probabilistic approach for identification of licensing basis events, SSC classification and special treatment, and evaluation of defense-in-depth (DID). Kairos instead uses deterministic evaluations for postulated events, the single failure criterion, and the maximum hypothetical accident of NUREG-1537 to evaluate plant safety and classify SSCs.

NUREG-1537 provides the design basis event hazards that safety related SSCs are required to withstand. PDC 2 for Hermes also addresses the need to design SSCs to withstand the effects of external events, including seismic events. Kairos employs an approach which is different from the probabilistic approach of NEI 18-04 but that is accepted by the staff and is documented in NUREG-1537. Therefore, based on the above discussion, the staff finds that an acceptable approach to address limitation and condition 3 has been used in the Hermes application for selection of licensing basis events, classification and special treatments of SSCs, and assessment of DID because it is consistent with the approach described in NUREG-1537.

PDC TR limitation and condition number 4 is related to the definition of "safety related." As stated in condition 4, the term safety related must include SSCs designated as safety related as defined in NEI 18-04 as well as any SSCs that meet the definition of 10 CFR 50.2. Kairos defines safety related SSCs solely using the definition of 10 CFR 50.2 as the probabilistic approach of NEI 18-04 is not used. Since Hermes uses the term "safety related" consistent with 10 CFR 50.2 except for a departure from the use of the term "reactor coolant pressure boundary" as discussed below, the staff finds the portion of limitation and condition 4 applicable to the Hermes NUREG-1537 licensing approach is met.

In the Hermes design, the reactor coolant boundary, except for the reactor vessel, is not credited for fission product retention like the reactor coolant pressure boundary in current LWRs. The vessel is credited indirectly for fission product retention by maintaining the Flibe coolant above the fuel pebbles in the reactor core to support residual heat removal. As such, the vessel is classified as safety related while the remainder of the reactor coolant boundary is classified as non-safety related. The staff finds the classification of the ex-vessel reactor coolant boundary as non-safety related, except for the reactor vessel, to be acceptable, as the coolant boundary is not credited for fission product retention.

Based on its assessment described above, the staff has determined that Kairos has adequately addressed the limitations and conditions on use of the PDC TR, with modifications necessary to address the Hermes design and use of the deterministic licensing framework of NUREG-1537.

Kairos has proposed departures from the PDC TR for the Hermes PDC. The Hermes PSAR Section 1.2.3, “Design Features and Design Bases,” states that the term “safety related” will be substituted for the term “safety significant” in the PDC developed in the PDC TR. The Hermes test reactor has SSCs that are relied upon to mitigate the postulated events. There are only two SSC classifications used in the safety analysis report: “safety related” and “non-safety related.” This classification does not depend on a significance determination. The term “safety related” is defined in Section 1.2.3 of the Hermes PSAR and is consistent with the definition used in 10 CFR 50.2 for safety related SSCs, except for the limitation applied to the reactor coolant boundary that was evaluated above. Therefore, since the definition of “safety related” is consistent with NRC regulations and the SSC classification is not dependent upon a significance determination, the staff finds that substitution of the term “safety related” for “safety significant” in the PDC is acceptable and the PSAR’s preliminary information regarding the methodology of determining safety related classification provides a basis for the staff to find that the methodology will comply with applicable requirements.

The Hermes PSAR also explains that the term “postulated events” is substituted for “anticipated operational occurrences” and “accidents” in the PDC applicable to the Hermes reactor as there is no need to distinguish event frequencies as they are evaluated regardless of their frequency of occurrence. This is a departure from the PDC TR which relies on frequency-based licensing basis event categorization and uses corresponding terminology to classify these events. Therefore, the staff finds that substitution of “postulated events” for “operational occurrences” and “accidents” in the PDC for the Hermes reactor is acceptable. The staff also finds that the PSAR’s preliminary information regarding the use of the term “postulated events” provides a basis for the staff to find that the safety analysis is consistent with guidance in NUREG-1537. The staff finds that the Hermes PDC, as either approved in the PDC TR or modified where necessary as described in the PSAR, are acceptable and meet the requirements in 10 CFR 50.34(a)(3)(i).

3.1.4 Conclusion

The staff finds that the above information provides the basis to conclude the design criteria are consistent with guidance in RG 1.232 on the development of non-LWR design criteria and meet the acceptance criteria of NUREG-1537, Part 2, Section 3.1 and therefore that the facility SSCs can be built and will function as designed consistent with the analyses in the PSAR. Accordingly, the staff finds that design criteria provide reasonable assurance that the public will be protected from radiological risks resulting from operation of the reactor facility.

Based on its findings above, the staff concludes the information on design criteria in Hermes PSAR Section 3.1 is sufficient and meets the applicable guidance and regulatory requirements identified in this section for the issuance of a construction permit in accordance with 10 CFR 50.35 and 50.40.

3.2 <u>Meteorological Damage</u>

3.2.1 Introduction

Hermes PSAR Section 3.2, “Meteorological Damage,” describes the approach used to translate site meteorological parameters (e.g., normal wind speed, precipitation) into design loads used in the design of the safety related SSCs. Section 3.2 of the PSAR summarizes the methods for determining wind loads, including loads from hurricanes and tornadoes, and precipitation loads, including snow and ice loads. Relevant consensus design codes and design equations are identified, along with relevant NRC guidance.

3.2.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of the Hermes SSCs for meteorological damage are as follows:

- 10 CFR 50.34, “Contents of applications; technical information,” paragraph (a), “Preliminary safety analysis report.”
    - 10 CFR 50.34(a)(3)(iii), which requires that each application for a CP include in the PSAR information relative to materials of construction, general arrangement, and approximate dimensions, sufficient to provide reasonable assurance that the final design will conform to the design bases with adequate margin for safety.
    - 10 CFR 50.34(a)(4), which requires that each applicant for a CP include “[a] preliminary analysis and evaluation of the design and performance of [SSCs] of the facility with the objective of assessing the risk to public health and safety resulting from operation of the facility and including determination of the margins of safety during normal operations and transient conditions anticipated during the life of the facility, and the adequacy of [SSCs], provided for the prevention of accidents and the mitigation of the consequences of accidents…”
- 10 CFR 50.35, “Issuance of construction permits.”
- 10 CFR 50.40, “Common standards.”

For its evaluation of the Hermes meteorological damage the staff used the following applicable guidance:

- NUREG-1537, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors,” Part 2, Section 3.2, “Meteorological Damage.”

3.2.3 Technical Evaluation

The staff evaluated the sufficiency of the facility design features to cope with meteorological damage, as described in PSAR Section 3.2, using the guidance and acceptance criteria from Section 3.2, “Meteorological Damage,” of NUREG-1537, Part 2. Consistent with the review procedures of NUREG-1537, Part 2, Section 3.2, the staff considered the description of the site meteorology to ensure that all SSCs that could suffer meteorological damage are considered, as presented in PSAR Sections 3.2 and 3.5, “Systems and Components.” The staff also reviewed the design criteria to ensure they are compatible with local architectural and building codes for similar structures.

In its review of SSCs considered for meteorological damage, the staff noted that PSAR Section 3.2 describes the methodology and parameters used for determining the meteorological loads on the safety related portion of the reactor building. The structural loads are determined in accordance with the local building code, which references American Society of Civil Engineers (ASCE)/SEI 7-10, "Minimum Design Loads for Buildings and Other Structures," while tornado and hurricane wind speeds are taken from RG 1.76, "Design-Basis Tornado and Tornado Missiles for Nuclear Power Plants," Revision 1, and RG 1.221, "Design-Basis Hurricane and Hurricane Missiles for Nuclear Power Plants," respectively. PSAR Section 3.2.4, "Precipitation Loads," notes that the final design will have a sloped roof, so structural loads due to rain accumulation are minimal and will be enveloped by the snow load.

During its review of Section 3.2, the staff noted that several subsections, equations, and associated variables from ASCE/SEI 7-10 were called out and explicitly defined in the PSAR. However, other relevant sections of the code (e.g., Sections 7.9, "Sliding Snow," and 7.10, "Rain-on-Snow Surcharge Load") were not mentioned. The staff finds this approach acceptable for the CP because it is clear from PSAR Section 3.2 that Kairos intends to follow all applicable portions of ASCE/SEI 7-10. Many of the sections and variables that are not explicitly identified are dependent on the final structural design, such as roof height or slope. Once this information is known, it can be incorporated into the Final Safety Analysis Report (FSAR), as necessary, and reviewed by the staff during the operating license (OL) application review.

PSAR Section 3.2.3.2, "Determination of Applied Forces," notes that the maximum hurricane wind speed, V, is 130 miles per hour (mph), in accordance with RG 1.221. The Hermes site is located near Oak Ridge, TN in the northeastern portion of Roane County. The staff reviewed Figure 2, "Design-Basis Hurricane Windspeeds …" in RG 1.221 and noted that the Hermes location is below the 130-mph wind speed contour line and in the 140-mph zone. However, the proposed site is very close to the 130-mph line and the guidance in RG 1.221 notes that linear interpolation between two wind contour lines is permitted. If the maximum hurricane wind speed were increased by one or two mph (based on interpolation), it would have a negligible impact on the overall design of the structure; therefore, the staff finds it reasonable for 130-mph to be used as the hurricane wind speed.

Based on the information provided in PSAR Section 3.2, the staff finds that, consistent with the applicable acceptance criteria in NUREG-1537, Part 2, Section 3.2, the design, methodology and parameters used are consistent with local applicable architectural and building codes for similar structures and are compatible with the requirements of the structures to perform their safety functions throughout the predicted meteorological conditions.

3.2.4 Conclusion

On the basis of its review, the staff has determined that the level of detail provided on meteorological damage is adequate for the preliminary design and satisfies the applicable acceptance criteria of NUREG-1537, Part 2, Section 3.2. The staff concludes that the design criteria and design for the protection from meteorological damage conditions are based on applicable local building codes, standards, and criteria that provides assurance that SSCs will continue to perform their safety functions as specified in the PSAR. Therefore, the staff finds that the facility design features for coping with meteorological damage meet the applicable guidance and regulatory requirements identified in this section for issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Further technical or design information required to complete the safety analysis may reasonably be left for later consideration. The staff will confirm that the final design conforms to this design basis during the evaluation of the Hermes FSAR.

3.3 Water Damage

3.3.1 Introduction

Hermes PSAR Sections 3.3, “Water damage,” and 3.5.3.2, “Conformance with PDC 2 for Internal and External Flooding,” describe the approach taken to establish loads on the safety related portion of the reactor building due to postulated internal and external flooding events. PSAR Section 3.5.3.1, “Conformance with PDC 2 for Meteorological Events,” notes that the safety related portion of the reactor building is designed in accordance with industry codes and standards, including the American Concrete Institute (ACI) 349 and the American Institute of Steel Construction (AISC) N690. Section 3.5.3.2 of the PSAR notes that the facility is a passively dry site and that the basemat of the safety related portion of the structure is at grade level. Safety related SSCs that are vulnerable to water damage from internal floods are elevated above the floor and water is directed away from SSCs via sloped floors and curbs.

3.3.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of the Hermes SSCs for water damage are as follows:

- 10 CFR 50.34, “Contents of applications; technical information,” paragraph (a), “Preliminary safety analysis report.”
    - 10 CFR 50.34(a)(3)(iii), which requires that each application for a CP include in the PSAR information relative to materials of construction, general arrangement, and approximate dimensions, sufficient to provide reasonable assurance that the final design will conform to the design bases with adequate margin for safety.
    - 10 CFR 50.34(a)(4), which requires that each applicant for a CP include “[a] preliminary analysis and evaluation of the design and performance of [SSCs] of the facility with the objective of assessing the risk to public health and safety resulting from operation of the facility and including determination of the margins of safety during normal operations and transient conditions anticipated during the life of the facility, and the adequacy of [SSCs], provided for the prevention of accidents and the mitigation of the consequences of accidents…”
- 10 CFR 50.35, “Issuance of construction permits.”
- 10 CFR 50.40, “Common standards.”

For its evaluation of the potential Hermes water damage, the staff used the following applicable guidance:

- NUREG-1537, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non—Power Reactors,” Part 2, Section 3.3, “Water Damage.”

3.3.3 Technical Evaluation

The PDC applicable to Hermes water damage are as follows:

- PDC 2, Design Bases for Protection Against Natural Phenomena

The staff evaluated the sufficiency of the facility design features to cope with water damage, as described in PSAR Sections 3.3 and 3.5.3.2, using the guidance and acceptance criteria from Section 3.3, “Water Damage,” of NUREG-1537, Part 2. Consistent with the review procedures of NUREG-1537, Part 2, Section 3.3, the staff considered the site description and facility designs to ensure that all safety related SSCs with the potential for water damage, including damage due to external and internal flood hazards, are considered in this PSAR section. For any such safety related SSC, the staff reviewed the design bases to verify consequences are addressed and described in detail in appropriate chapters of the PSAR.

3.3.3.1 Internal Flooding

In Section 3.3.1, “Internal Flooding,” of the PSAR, Kairos noted that internal flooding events consider the flow rates and quantities of water from inside the safety related portion of the reactor building and pointed to PSAR Section 3.5.3.2 for additional information on design features that prevent damage from internal flooding. Section 3.5.3.2 notes that safety related SSCs that are vulnerable to water damage will be elevated above the floor and any water will be directed away from the SSCs via sloped floors and curbs. The PSAR further notes that internal flooding has three potential sources: water systems in the safety related portion of the building, water systems outside the safety related portion, and fire protection water. For the systems located in the safety related portion of the reactor building, the amount of water will be limited by design. For external sources, such as fire water, details about the automatic or manual termination of flow will be provided in the OL. Fire protection will be implemented in accordance with National Fire Protection Association (NFPA) 801, “Standard for Fire Protection for Facilities Handling Radioactive Materials,” and the water collection system in the safety related portion of the reactor building will be sized to accommodate the total fire water volume.

The staff reviewed the information provided in Section 3.5.3.2 and finds that the level of detail provided on internal flooding is adequate for the preliminary design. Kairos has noted that water sources in the safety related portion of the reactor building will be limited, and the water collection system will be adequately sized to accommodate postulated leaks. In addition, floor drains, slopes, and curbs will be used to ensure safety related SSCs are protected from possible internal flooding. The staff will defer its review of detailed descriptions of specific SSC layouts, water volumes, details about termination of flow, floor drains and slopes, and curb designs until the OL application as Kairos noted in PSAR Section 3.5.3.2.1.

3.3.3.2 External Flooding

In Section 3.3.2 of the PSAR, as updated by letter dated August 19, 2022, Kairos stated that there is no above grade safety related portion of the reactor building affected by the design basis flood since the flood elevation is below the grade. However, Kairos identified that the design basis flood impacts a portion of the safety related structure in the basement of the building. Further in the same section, Kairos indicated that the hydrologic loads of the design basis flood were evaluated in Sections 3.5.3.2 and 3.5.3.2.1 for the safety related SSCs below grade. Section 3.5.3.2 indicated that potential water damage will not preclude safety related SSCs from performing their functions and Section 3.5.3.2.1 indicated that the SSCs are designed based on PDC 2 for the design basis flood.

In Section 3.5.3.2.1, Kairos indicated that the specific site grading and drainage features will be described in the OL application. The staff included this item to Appendix A, “Staff Needs for an Operating Licensing Application,” of this SE; therefore, this issue will be reviewed in Kairos’s OL application.

As indicated in Section 3.5.2, “Design Basis” of the PSAR, Kairos designed the safety related portion of the reactor building consistent with PDC 2 to protect the safety related SSCs housed within the building.

The staff reviewed the information provided by Kairos and finds that the design basis flood presents no potential water damage to the site since the design basis flood elevation is approximately 5 feet below the grade elevation. In addition, the staff finds in SE Section 2.4.3 that extreme flood events causing inundation of the site are unlikely during the planned 4-year Hermes operational lifetime. However, the staff did not evaluate the impact of the water damage on the safety related structure due to a probable maximum flood (PMF) event, since Kairos stated, in Section 2.4.3, “Credible Hydrological Events and Design Basis,” of the PSAR, that the PMF is not used in the design basis of SSCs and the PMF analysis will be discussed with the application of an OL. The staff included this item to Appendix A of this SE, and therefore, it will be reviewed in Kairos’s OL application.

The staff will defer its review of the descriptions of specific grading and drainage features until the OL application , because the preliminary information is sufficient for issuance of a CP and the specific grading and drainage features may reasonably be left for later consideration .

3.3.4 Conclusion

Based on its review, the staff has determined that the level of detail provided on potential water damage is adequate for the preliminary design and supports the applicable acceptance criteria of NUREG-1537, Part 2, Section 3.3. The staff also finds that Kairos has adequately demonstrated that the safety related SSCs are designed to withstand external flooding are designed consistent with PDC 2 related to floods. The staff concludes that the preliminary information on the Hermes design provides reasonable assurance that SSCs will continue to perform required safety functions, including the ability to safely shutdown the reactor, and not cause or allow uncontrolled release of radioactive materials, because the design of the facility for the protection against water damage is based on applicable local building codes such as ACI 349 and the AISC N690. Therefore, the staff finds that the facility design features for coping with water damage meet the applicable guidance and regulatory requirements identified in this section for issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Further technical or design information required to complete the safety analysis may reasonably be left for later consideration. The staff will confirm that the final design conforms to this design basis during the evaluation of the Hermes FSAR.

3.4 Seismic Damage

3.4.1 Introduction

PSAR Chapter 3.4, “Seismic Damage,” discusses the design of SSCs that are required to remain functional in the event of an earthquake. The PSAR notes that Kairos followed the graded approach of ASCE 43-19, “Seismic Design Criteria for Structures, Systems and Components in Nuclear Facilities,” for the seismic design of Hermes. The safety related SSCs were identified by Kairos as Seismic Design Category (SDC) 3, consistent with ASCE 43-19, and the design response spectra were developed based on this category. Section 3.4 also discusses how the structure was modeled and how the response analysis was performed.

3.4.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of the Hermes SSCs for seismic damage are as follows:

- 10 CFR 50.34, "Contents of applications; technical information," paragraph (a), "Preliminary safety analysis report."
  - 10 CFR 50.34(a)(3)(iii), which requires that each application for a CP include in the PSAR information relative to materials of construction, general arrangement, and approximate dimensions, sufficient to provide reasonable assurance that the final design will conform to the design bases with adequate margin for safety.
  - 10 CFR 50.34(a)(4), which requires that each applicant for a CP include "[a] preliminary analysis and evaluation of the design and performance of [SSCs] of the facility with the objective of assessing the risk to public health and safety resulting from operation of the facility and including determination of the margins of safety during normal operations and transient conditions anticipated during the life of the facility, and the adequacy of [SSCs], provided for the prevention of accidents and the mitigation of the consequences of accidents…"
- 10 CFR 50.35, "Issuance of construction permits."
- 10 CFR 50.40, "Common standards."

For its evaluation of the Hermes seismic damage the staff used the following applicable guidance:

- NUREG-1537, Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors, Parts 1 and 2, Section 3.4, "Seismic Damage."

3.4.3 Technical Evaluation

The staff evaluated the sufficiency of the facility design features to cope with seismic damage, as described in PSAR Sections 3.4 and 3.5.3.3, as amended by letter dated June 27, 2022, using the guidance and acceptance criteria from Section 3.4, "Seismic Damage," of NUREG-1537, Part 2. Consistent with the review procedures of NUREG-1537, Part 2, Section 3.4, the staff considered the site description and facility design to ensure that the seismic inputs and design are adequately considered in this PSAR section. For any such safety related SSC, the staff reviewed the design bases to verify consequences are addressed and described in detail in appropriate chapters of the PSAR.

3.4.3.1 Seismic Design Criteria and Design Response Spectra

PSAR Section 3.4 notes that the graded approach of American Society of Civil Engineers (ASCE) 43-19 was followed for the seismic design. The safety related SSCs were identified as SDC-3, consistent with ASCE 43-19, because they are required to maintain their safety function in the event of a design basis earthquake. The PSAR further notes that SDC-3 structures are designed to ensure the integrity of the reactor vessel to support the functional containment, the capability to shut down the reactor and maintain it in safe shutdown, and the capability to prevent or mitigate the consequences of postulated events to potential offsite exposures. The non-safety related structures are designed to the local building code (2012 International Building Code), per the guidance in NUREG-1537.

PSAR Section 3.4.1.1, "Seismic Design Criteria," notes that safety related structures are designed based on the SDC-3 design response spectra (DRS), which were determined in accordance with Section 2 of ASCE 43-19. Design provisions in ASCE 43-19 achieve two goals: (1) less than 1 percent probability of unacceptable performance for design basis ground motion, and (2) less than 10 percent probability of unacceptable performance for 150 percent of design basis ground motion. Section 3.4.1.2, "Design Response Motion," notes that the DRS were developed based on the site hazard analysis detailed in PSAR Section 2.5, "Geology, Seismology, and Geotechnical Engineering," and PSAR Figure 3.4-1, "Horizontal and Vertical Design Response Spectra," which shows the 5 percent damped vertical and horizontal DRS. The PSAR notes that SSCs designed to this DRS achieve the target seismic performance goals summarized in Section 3.4.1.1.

The staff reviewed the information provided in the PSAR and finds the approach acceptable because the development of the DRS follows the guidance of ASCE 43-19 and the PSAR states that the SSCs will be designed in accordance with SDC 3 of ASCE 43-19. In addition, the site seismic hazard characterization is used to develop the DRS. Following this approach aligns with the applicable guidance and acceptance criteria in NUREG-1537, Part 1 and 2, Section 3.4, and provides reasonable assurance that the reactor can be shut down and maintained in a safe condition following a seismic event.

3.4.3.2 Seismic Response – Structural Model and Response Analysis

PSAR Section 3.4.1.5, "Structural Model," notes that the safety related portion of the reactor building was represented by a three-dimensional finite element model developed in accordance with Chapter 3 of ASCE 4-16, "Seismic Analysis of Safety related Nuclear Structures." The model will capture the primary elements of the lateral load resisting system as well as secondary elements that could impact the seismic response. Structural mass is assigned to the model to capture self-weight, the weight of permanently attached heavy equipment, and certain design loads (e.g., live loads). The PSAR notes that additional details of structural mass assignments and the finite element model, along with detailed results of the analysis, will be provided in the OL application.

PSAR Section 3.4.1.6, "Response Analysis," notes that the structural models are subjected to three-component seismic input to develop the structural forces and in-structure response spectra (ISRS). The seismic response analysis will be performed using linear analysis and follows the guidance in Chapter 4 of ASCE 4-16. Soil-structure interaction (SSI) effects are considered based on the guidance in Chapter 5 of ASCE 4-16. For SDC-3 structures, the analysis will be performed at seismic levels necessary to demonstrate the SSCs achieve their target performance goal. No additional details are provided on the SSI and seismic response analyses; however, the PSAR notes that additional details will be provided in the OL application, including information on SSI analysis results, modeling assumptions and methods, and details on structural forces and ISRS.

The staff reviewed the information provided in the PSAR and finds that it provides an adequate level of detail on the preliminary seismic design for the issuance of a CP. Although details of the seismic design have not been specified, the design approach aligns with a consensus design code (i.e., ASCE 4-16). The other structures will, at a minimum, meet the local building codes. Additionally, Kairos has clearly identified information that needs to be provided in the OL application. Further technical or design information required to complete the safety analysis may reasonably be left for later consideration.

3.4.3.3 Seismic Design of Non-Safety SSCs

PSAR Section 3.4.2, “Non-Safety Related SSCs and Seismic Design,” notes that non-safety SSCs are designed in accordance with the local building code, which is the 2012 International Building Code (IBC). The IBC refers to ASCE/SEI 7-10 for the seismic input, analysis, and design. The staff reviewed the information provided in PSAR Section 3.4.2 and finds that the level of detail provided for the seismic design of the non-safety SSCs is adequate for the preliminary design because the non-safety SSCs are designed in accordance with the local building codes. This provides a basis to conclude that significant damage to the non-safety SSCs due to seismic events is unlikely; and is, therefore, consistent with the applicable guidance and acceptance criteria in NUREG 1537, Part 1 and 2, Section 3.4.

3.4.3.4 Seismic Instrumentation

Section 3.4.3, “Seismic Instrumentation,” of the PSAR provides information about the location and operability of seismic instrumentation. Kairos states that two seismic sensors will be installed, one in the free-field outside of the facility and another in the safety related portion of the reactor building. Seismic instrumentation will be designed such that it will operate in the event of a loss of offsite power and during all modes of operation and will be accessible for maintenance. The instrumentation will record sufficient data in the event of an earthquake to provide operators with the ability to determine if the recorded ground motion exceeds the design basis of the facility. The staff reviewed the information provided by Kairos in Section 3.4.3 of the PSAR and determined that sufficient seismic instrumentation will be installed to determine if an exceedance of the DRS occurs in the event of an earthquake. The staff finds that the description of seismic instrumentation found in Section 3.4.3 of the PSAR meets the guidance and acceptance criteria of NUREG-1537, Part 1 and 2, Section 3.4.

3.4.4 Conclusion

Based on its review, the staff has determined that the level of detail provided on seismic damage and design methodology is adequate for the preliminary design and supports the applicable acceptance criteria of NUREG-1537, Part 2, Section 3.4. Therefore, the staff finds that the facility seismic design meets the applicable guidance and regulatory requirements identified in this section for issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Several areas have been identified where additional design information or details may be required for the staff to make a final safety finding. The staff has determined it is reasonable to leave this information for later consideration during the OL application review. The staff will confirm that the final design conforms to this design basis during the evaluation of the Hermes OL application.

3.5 Plant Structures

3.5.1 Introduction

PSAR Chapter 3.5, “Plant Structures,” describes the principal structural elements and general design of the reactor building. The PSAR notes that the reactor building is the only structure on the site that serves a safety function and that the structure is separated into safety related and non-safety related portions, which are separated by a seismic “moat.” The safety related portion of the reactor building is supported by a seismic base isolation system. This portion of the PSAR also lists the safety functions of the reactor building and the applicable PDC, which are 1, 2, 3, 75, and 76. The PSAR summarizes how the design is consistent with these criteria and provides additional detail on how the reactor building meets PDC 2. Much of this information supports or repeats information contained in earlier PSAR sections, specifically Sections 3.2, 3.3, and 3.4.

3.5.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of the Hermes SSCs for seismic damage are as follows:

- 10 CFR 50.34, “Contents of applications; technical information,” paragraph (a), “Preliminary safety analysis report.”
    - 10 CFR 50.34(a)(3)(ii), which requires that each application for a CP include the design bases and the relation of the design bases to the principal design criteria.
    - 10 CFR 50.34(a)(3)(iii), which requires that each application for a CP include in the PSAR information relative to materials of construction, general arrangement, and approximate dimensions, sufficient to provide reasonable assurance that the final design will conform to the design bases with adequate margin for safety.
    - 10 CFR 50.34(a)(4), which requires that each applicant for a CP include “[a] preliminary analysis and evaluation of the design and performance of [SSCs] of the facility with the objective of assessing the risk to public health and safety resulting from operation of the facility and including determination of the margins of safety during normal operations and transient conditions anticipated during the life of the facility, and the adequacy of [SSCs], provided for the prevention of accidents and the mitigation of the consequences of accidents…”
- 10 CFR 50.35, “Issuance of construction permits.”
- 10 CFR 50.40, “Common standards.”

For its evaluation of the Hermes plant structure the staff used the following applicable guidance:

- NUREG-1537, Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors, Parts 1 and 2, Section 3.2, “Meteorological Damage,” Section 3.3, “Water Damage,” and Section 3.4, “Seismic Damage.”

3.5.3 Technical Evaluation

3.5.3.1 Compliance with Identified PDCs (1, 2, 3, 75, 76)

The staff reviewed the information provided in PSAR Section 3.5 to ensure adequate information was provided to demonstrate that the preliminary design of the reactor building is consistent with the relevant PDC. PSAR Section 3.5.3, “System Evaluation,” discusses how the reactor building will meet the relevant PDC. The staff’s evaluation of each identified PDC is provided below.

PDC 1

PDC 1 states that SSCs which are safety related shall be designed, fabricated, erected, and tested to quality standards commensurate with the safety significance of the function(s) performed by the SSCs. PSAR Section 3.5.3, “System Evaluation,” notes that the safety related portions of the reactor building are designed in accordance with the local building code and augmented with design codes such as ACI 349, “Code Requirements for Nuclear Safety related Concrete Structures and American Institute of Steel Construction (AISC) N690, “Specification for Safety related Steel Structures for Nuclear Facilities." The requirements of the Kairos quality assurance program apply to the safety related portions of the reactor building.

The staff reviewed the information provided in the PSAR and notes that Kairos will design the structures in accordance with the local building code, as recommended by NUREG-1537, and will design safety related portions of the reactor building in accordance with the more stringent nuclear design codes ACI 349 and AISC N690. The staff has reviewed and approved these codes for use for commercial nuclear power plants, which require more robust structures than a non-power test reactor. Using ACI 349 and AISC N690 is a conservative approach, and the codes are more conservative than the design codes recommended by NUREG-1537. Based on its review, the staff finds the preliminary design of Hermes is consistent with PDC 1 for structures because the structures will be designed and fabricated in accordance with commensurate quality standards and the quality assurance program requirements will be applied to the safety related structures; this is reviewed in Chapter 12 of this SE.

PDC 2

PDC 2 states that safety related SSCs shall be designed to withstand natural phenomena such as earthquakes, tornadoes, or floods. PSAR Section 3.5.3, "System Evaluation," notes that the non-safety related portions of the reactor building are not credited to provide physical protection for safety related SSCs from natural phenomena, such as high winds, earthquakes, or flooding. The non-safety portion of the reactor building surrounds the safety related portion of the building; however, the safety related portion is designed to perform its safety functions, including protecting SSCs from natural phenomena, even if the non-safety portion of the building is damaged. PSAR Section 3.5.3.1 notes that the safety related portion of the reactor building is designed in accordance with industry codes and standards, including ACI 349 and AISC N690.

The staff finds the preliminary design of Hermes is consistent with PDC 2 for structures because designing the safety related portions of the reactor building to ACI 349 and AISC N690 ensures the safety related SSCs will withstand natural phenomena. Additional discussion on how structures meet PDC 2 can be found in SE Sections 3.2, 3.3, and 3.4.

PDC 3

PDC 3 states that safety related SSCs shall be designed and located to minimize the probability and effect of fires and explosions. PSAR Section 3.5.3, "System Evaluation," notes that the safety related portion of the reactor building is designed to perform its safety function in the event of a fire hazard. The design uses low combustible materials and physically separates SSCs to minimize the effects of fires in the reactor building. In addition, a fire protection program is used, which is discussed in PSAR Section 9.4, "Fire Protection Systems and Programs," to ensure appropriate fire protection is provided.

The staff finds the preliminary design of Hermes is consistent with PDC 3 for structures because the design uses low combustible materials and will physically separate SSCs to minimize the impacts of possible fires. In addition, Kairos will use a fire protection program to minimize the effects of fires. Additional information about the staff's review and acceptability of the fire protection program can be found in SE Section 9.4.

PDC 75

PDC 75 states that the reactor building shall be designed to protect the DHRS from the effects of natural phenomena. PSAR Section 3.5.3, “System Evaluation,” notes that the DHRS includes safety related SSCs, which are in the safety related portion of the reactor building and protected from design basis natural phenomena by the design of the reactor building.

The staff finds the preliminary design of Hermes is consistent with PDC 75 because the DHRS has been identified as safety related and placed inside the safety related portion of the reactor building, which ensures that the DHRS will be protected from the effects of natural phenomena.

PDC 76

PDC 76 states that the reactor building shall be designed to permit periodic inspection. PSAR Section 3.5.3, “System Evaluation,” notes that the reactor building, including the seismic base isolation system, is designed to permit periodic inspection, consistent with PDC 76.

The staff finds the preliminary design of Hermes is consistent with PDC 76 for the reactor building because the reactor building will be designed to allow inspection and surveillance in accordance with the PDC requirements. The staff will verify the inspectability of the final reactor building design during the OL application review.

3.5.3.2 Seismic Isolation System

PSAR Section 3.5.3.3.2, “Seismic Isolation System,” and 3.5.4, “Testing and Inspections,” discuss the seismic isolation system which will be used to limit seismic demands on the safety related portion of the reactor building. Minimal information is provided on how the system was designed and how it was accounted for in the seismic analysis of the structure. However, the PSAR notes that the design will implement Chapter 9, “Seismically Isolated Structures,” of ASCE 43-19 and that additional details of the base isolation system design, along with the associated structural analysis, will be provided in the OL application.

Based on its review of the PSAR, the staff finds that Kairos has provided an adequate level of detail on the seismic isolation system for the preliminary design and for issuance of a CP because, although details of the isolation system have not been specified, the design methodology aligns with a consensus code (ASCE 43-19) and Kairos has clearly identified information that will be provided in the OL application. Additional detailed design information can reasonably be left for later consideration and the staff will confirm that the final design conforms to this design basis during the evaluation of the Hermes OL application.

3.5.3.3 Aircraft Impact

PSAR Section 3.5.3.4, “Conformance with PDC 2 for Other Hazards,” discusses how the reactor building preliminary design addresses other hazards, including aircraft impact. The PSAR notes that the design of the reactor building was evaluated for global and local effects of accidental aircraft impact (AAI) from light general aviation aircraft. The global and local impact responses were analyzed using the energy balance method consistent with Department of Energy (DOE) Standard DOE-STD-3014-2006, “Accident Analysis for Aircraft Crash into Hazardous Facilities.” The analysis was used to calculate wall and ceiling requirements for the safety related portions of the structure. The staff reviewed the information provided by Kairos in Section 3.5.3.4 of the PSAR and finds that the level of detail provided on AAI is adequate for the preliminary design, because Kairos will prepare the final design of plant structures in accordance with appropriate standards to address the effects of AAI.

3.5.4 Conclusion

Based on its review, the staff has determined that the level of detail provided on the general design of the reactor building is adequate for the preliminary design and the information provided adequately demonstrates that the structural design of the reactor building is consistent with PDCs 1, 2, 3, 75, and 76. The staff finds that the general reactor building design meets the applicable guidance and regulatory requirements identified in this section for issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Further technical or design details required to complete the safety analysis may reasonably be left for later consideration and the staff will confirm that the final design conforms to this design basis during the evaluation of the Hermes FSAR.

3.6 Systems and Components

3.6.1 Introduction

PSAR Section 3.6, "Systems and Components," describes the design bases for the systems and components required to function for safe reactor operation and shutdown. Section 3.6.1 "General Design Basis Information," describes the safety functions performed by safety related SSCs and Section 3.6.2 "Classification of Structures, Systems, and Components," describes how SSCs are classified.

PSAR Section 3.6.1 identifies three fundamental safety functions provided by Hermes SSCs: (1) prevent uncontrolled releases of radionuclides, (2) remove decay heat in a postulated event and (3) control reactivity in the reactor core. The primary SSCs to prevent an uncontrolled radionuclide release are the reactor fuel (SE Section 4.2.1), reactor vessel (SE Section 4.3), reactor coolant (SE Section 5.1), and reactor protection system (SE Section 7.3). The SSCs used to ensure decay heat removal are the decay heat removal system (SE Section 6.3) with support from the reactor vessel (SE Section 4.3), the reactor vessel support system (SE Section 4.7), and the reactor protection system (SE Section 7.3). The primary means of reactivity control is provided by the reactivity control and shutdown system (SE Section 4.2.2) and the reactor protection system (SE Section 7.3) with support from reactor vessel (SE Section 4.3) and nuclear design (SE Section 4.5). The staff notes that the reactor building is designed to provide the necessary protection from external events for all of these SSCs. The staff evaluation of the reactor building is in SE Section 3.5.

3.6.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of the Hermes SSC design criteria are as follows:

- 10 CFR 50.34, "Contents of applications; technical information," paragraph (a), "Preliminary safety analysis report."
    - 10 CFR 50.34(a)(3)(ii), which requires that each application for a CP provide the design bases and the relation of the design bases to the PDCs.
    - 10 CFR 50.34(a)(3)(iii), which requires that each application for a CP provide information relative to materials of construction, general arrangement, and

approximate dimensions, sufficient to provide reasonable assurance that the final design will conform to the design bases with adequate margin for safety.

  - 10 CFR 50.34(a)(4), which requires that each applicant for a CP include "[a] preliminary analysis and evaluation of the design and performance of [SSCs] of the facility with the objective of assessing the risk to public health and safety resulting from operation of the facility and including determination of the margins of safety during normal operations and transient conditions anticipated during the life of the facility, and the adequacy of [SSCs], provided for the prevention of accidents and the mitigation of the consequences of accidents…"
- 10 CFR 50.35, "Issuance of construction permits."
- 10 CFR 50.40, "Common standards."

For its evaluation of the Hermes facility systems and components the staff used the following applicable guidance:

- NUREG-1537, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors," Parts 1 and 2, Section 3.5, "Systems and Components"
- RG 1.29, "Seismic Design Classification for Nuclear Power Plants," Revision 6
- RG 1.143, "Design Guidance for Radioactive Waste Management Systems, Structures, and Components Installed in Light-Water-Cooled Nuclear Power Plants," Revision 2
- RG 1.87, "Acceptability of ASME Section III, Division 5, High Temperature Reactors," Revision 2

3.6.3 Technical Evaluation

3.6.3.1 General Design Basis Information

The staff evaluated the sufficiency of the Hermes preliminary design features for systems and components, as described in Hermes PSAR Section 3.6, for the issuance of a CP using the guidance and acceptance criteria from Section 3.5, "Systems and Components," of NUREG-1537, Part 2.

Consistent with the review criteria of NUREG-1537, Part 2, Section 3.5, the staff verified that the design bases for the SSCs that are required to ensure safe operation of Hermes are described in the Hermes PSAR Section 3.6 or other PSAR sections in sufficient detail. The PDC are discussed in PSAR Section 3.1 and are based on the PDC TR as detailed in Section 3.1 of this SE. The staff reviewed the design and construction codes and standards for fluid systems that are identified in PSAR Section 3.6, Table 3.6-2, "Design and Construction Codes and Standards for Fluid Systems," and finds they are consistent with RG 1.143 and RG 1.87, Revision 2, Appendix A, and are, therefore, acceptable. Accordingly, the staff finds that the PSAR's preliminary information regarding the use of the design and construction codes and standards provides adequate design basis for a preliminary design.

3.6.3.1.1 Prevention of Uncontrolled Release of Radionuclides

PSAR Section 3.6.1 identifies the reactor fuel, reactor vessel, reactor coolant, and reactor protection system as important SSCs to prevent uncontrolled releases of radionuclides. In particular, TRISO fuel pebbles and the Flibe coolant contained in the reactor vessel are credited to contain fission products. PSAR Table 3.6-1, "Structures, Systems, and Components," classifies the fuel pebbles, reactor vessel, reactor coolant, and reactor protection system and as safety related. PSAR Table 3.6-1 further identifies the reactor vessel and reactor protection system as SDC-3 in accordance with ASCE 43-19.

The staff reviewed the information provided in the PSAR and finds that the safety and seismic classification of these SSCs is acceptable and conforms with the guidance in RG 1.29 because safety related SSCs needed for prevention of uncontrolled release of radionuclides are assigned correctly to the seismic classification, SDC-3 in accordance with ASCE 43-19. Therefore, the staff finds that the PSAR's preliminary information regarding the design basis of SSCs for the prevention of uncontrolled release of radionuclides is adequate for a preliminary design.

3.6.3.1.2 Removal of Decay Heat During a Postulated Event

PSAR Section 3.6.1 identifies the decay heat removal system (DHRS) with support from the reactor vessel, the reactor vessel support system, and the reactor protection system as important SSCs to ensure decay heat removal during a postulated event. As stated above, the DHRS removes energy from the core following a postulated event where normal cooling systems are unavailable. PSAR Section 4.3 explains that the reactor vessel contains the inventory of reactor coolant such that the reactor core is covered by the coolant during normal operation and postulated events. PSAR Section 4.3 further discusses a fluidic diode device inside the reactor vessel, which is needed to provide a flow path for natural circulation to transfer heat from the reactor core during and following postulated events. PSAR Section 1.3.9, "Research and Development," identifies the development of the fluidic diode device as one of the research and development activities required by 10 CFR 50.34(a)(8). SSCs in the DHRS, the reactor vessel, the reactor vessel support system, and the reactor protection system are identified in PSAR Table 3.6-1 as safety related and are identified to be SDC-3 in accordance with ASCE 43-19.

The staff reviewed the information provided in the PSAR and finds that the safety and seismic classification of these SSCs conforms with the guidance in RG 1.29, because safety related SSCs needed for decay heat removal are assigned correctly to the seismic classification, SDC-3 in accordance with ASCE 43-19. Therefore, the staff finds that the PSAR's preliminary information regarding the design basis for SSCs necessary for the removal of decay heat during a postulated event is adequate for a preliminary design.

3.6.3.1.3 Control of Reactivity in the Core

PSAR Section 3.6.1 identifies the reactivity control and shutdown system (RCSS) and the reactor protection system with support from reactor vessel and nuclear design as important SSCs to control reactivity in the core. The RCSS ensures that control and shutdown elements can be inserted into the reactor to control reactivity in response to postulated events. The RCSS only depends on the reactor protection system when normal power is available. When normal power is not available, the RCSS automatically inserts the control and shutdown elements to shutdown the reactor. The reactor vessel supports this safety function by ensuring the core geometry supports control and shutdown element insertion, while the nuclear design with negative reactivity coefficients supports reactivity control in normal operation and postulated events. SSCs in the RCSS (shutdown elements only), the reactor vessel, and the reactor protection system are identified in PSAR Table 3.6-1 as safety related and are identified to be SDC-3 in accordance with ASCE 43-19.

The staff reviewed the information provided in the PSAR and finds that the safety and seismic classification of these SSCs conforms with the guidance in RG 1.29, because safety related

SSCs needed to control reactivity in the core are assigned correctly to the seismic classification, SDC-3 in accordance with ASCE 43-19. Therefore, the staff finds that the PSAR's preliminary information regarding the design basis for SSCs necessary for the control of reactivity in the core is adequate for a preliminary design. Additional safety evaluations on SSC safety classifications that support the control of reactivity in the core are discussed below in the "Safety Classification" section.

3.6.3.2 Classification of Structures, Systems, and Components

3.6.3.2.1 Safety Classification

The Hermes reactor uses the definition of 10 CFR 50.2 for "safety related" SSCs to establish those SSCs that are classified as safety related, with the exception of "integrity of the reactor coolant pressure boundary" which has been modified to "integrity of the portions of the reactor coolant boundary relied upon to maintain coolant level above the active core." This modification was made because the Hermes reactor does not rely on the functional capability of the primary heat transport system (PHTS) to remove decay heat from the reactor core. PSAR Table 3.6-1 identifies the safety related classification of SSC in accordance with the 10 CFR 50.2 definition with the modification. The staff finds that the modification of "integrity of the portions of the reactor coolant boundary relied upon to maintain coolant level above the active core," is acceptable based on NRC's staff approval of KP-TR-004-NP-A "Regulatory Analysis for the Kairos Power Fluoride Salt-Cooled High Temperature Reactor." The staff-approved KP-TR-004-NP-A states that "safety-significant portions of the reactor coolant boundary" are safety related, unlike in LWRs where the entire reactor coolant pressure boundary is safety related. Therefore, the staff finds that the Kairos's definition of "safety related" SSCs for classification of Hermes SSCs is appropriate.

3.6.3.2.2 Seismic Classification

RG 1.29 describes a method that the staff considers acceptable for use in identifying and classifying those features of LWR nuclear power plants that must be designed to withstand the effects of the design basis earthquake. While the RG is applicable to LWRs, it provides guidance related to the SSCs that should be designed in accordance with seismic design criteria that can also be useful for non-LWRs like Hermes. RG 1.29 states that the important features are the reactor coolant boundary; the reactor core and reactor vessel internals; systems or portions of systems for emergency core cooling, post-accident heat removal, or post-accident containment atmosphere cleanup; and systems or portions thereof that are needed to shut down the reactor and maintain it shutdown, remove residual heat, control the release of radioactive material, and mitigate the consequences of an accident.

PSAR Table 3.6-1 identifies the SSCs that are safety related and non-safety related, indicates if the SSCs are quality-related, and their seismic classification. The table indicates that the SSCs that are relied upon to ensure the safety of the public are safety related, designed to SDC-3 of ASCE 43-19, and have a quality assurance program applicable to their design, fabrication, and testing. The table identifies the fuel pebbles, reactor vessel system (which includes the reactor internals) and the reactor vessel support system, biological shield, DHRS, the full core offload and spent fuel storage racks, reactor coolant, reactor protection system, and portions of the reactor building as safety related.

The staff reviewed the information provided in the PSAR and finds that all SSCs necessary for performing fundamental safety functions have been adequately designated as safety related and correspondingly will be classified as SDC-3 in accordance with ASCE 43-19. The staff finds that SSCs have been assigned with an appropriate seismic design classification and corresponding design criteria based on this safety classification. The staff finds that the safety and seismic classification of these components conforms with the guidance in RG 1.29, because safety related SSCs are assigned correctly to the seismic classification, SDC-3, in accordance with ASCE 43-19. Therefore, the staff finds that the PSAR's preliminary information regarding the seismic classifications of the Hermes SSCs is adequate for a preliminary design and is consistent with the applicable acceptance criteria from NUREG-1537, which states that the design bases of the SSCs should function as designed to ensure safe operation and safe shutdown of the reactor.

Seismic Qualification by Analysis

PSAR Section 3.6.2.2.1 "Seismic Qualification by Analysis" states that the seismic qualification by analysis will be performed in accordance with Section 8.2 of ASCE 43-19. Per ASCE 43-19, there are limitations to qualification by analysis:

- Qualification of active electrical equipment by analysis is not performed.
- Qualification of active mechanical equipment by analysis may be permitted if the component is such that the functionality during an earthquake can be established and a margin of loss of functionality during an earthquake can be quantified.
- Qualification of active mechanical components by analysis shall be justified.

The staff reviewed the information provided in the PSAR and finds the use of seismic qualification by analysis acceptable because it will be performed in accordance with ASCE 43-19. Accordingly, the staff finds that the PSAR's preliminary information regarding the seismic qualification by analysis is adequate for a preliminary design.

Seismic Qualification by Testing

PSAR Section 3.6.2.2.2 "Seismic Qualification by Testing" states that the seismic qualification by testing will be performed in accordance with Section 8.3 of ASCE 43-19. Hermes seismic qualification by testing is typically used for SSCs for which qualification by analysis is not permitted and for SSCs where dynamic behaviors are not sufficiently supported by seismic qualification by analysis. In accordance with the ASCE 43-19 code requirements, the seismic qualification is performed via testing to seismically qualify the safety related components.

The staff reviewed the information provided in the PSAR and finds that seismic qualification by testing in lieu of seismic qualification by analysis acceptable because it will be performed in accordance with ASCE 43-19. Accordingly, the staff finds that the PSAR's preliminary information regarding the seismic qualification by testing is adequate for a preliminary design.

3.6.3.2.3 Quality Classification

PSAR Section 3.6.2.2.3 "Qualification Classification" states that the quality classification for SSCs conforms with the requirements of Kairos Power's Quality Assurance Program for Hermes, which is described in PSAR Section 12.9, "Quality Assurance." Safety related SSCs are classified as Quality-Related, while non-safety related SSCs are classified as Not Quality-Related, as shown in PSAR Table 3.6-1.

The staff reviewed the information provided in the PSAR and noted that all safety -related SSCs in Table 3.6-1 are assigned to a quality-related classification. The staff finds that the quality-related classifications assigned for safety related SSCs in Table 3.6-1 are acceptable since the quality-related classifications of the safety -related SSCs conform to RG 1.29 guidance. Therefore, the staff finds that the quality classification approach of all SSCs in PSAR Table 3.6-1 conforms to RG 1.29 guidance because the safety related components are correctly assigned to quality-related classification. Accordingly, the staff finds that the PSAR's preliminary information regarding the qualification classification is adequate for a preliminary design and is consistent with the applicable acceptance criteria from NUREG-1537, which states that the design bases of the SSCs should function as designed to ensure safe operation and safe shutdown of the reactor.

PSAR Table 3.6-2 lists the design and construction codes and standards for fluid systems. The table includes information regarding pressure vessels, piping, valves, pumps, storage tanks, and core support structures. The safety related mechanical components will be designed and fabricated using the requirements in ASME Code, Section III, Division 5, with the exception that the Hermes will implement ANSI/ANS 15.8-1995 (R2005) Quality Assurance Program, as described in Section 12.9, "Quality Assurance," of the PSAR rather than the NQA-1 standard specified in the ASME Code. Therefore, the components will not meet ASME Code, Section III, Division 5, requirements that are dependent on or tied specifically to an NQA-1-compliant program. The staff notes that the use of ANSI/ANS 15.8-1995 (R2005) Quality Assurance Program is endorsed by RG 2.5, "Quality Assurance Program Requirements for Research and Test Reactors" Revision 1. The staff finds that the use of the ANSI/ANS 15.8-1995 (R2005) Quality Assurance Program is an appropriate deviation from ASME Code, Section III, Division 5, for Hermes components because this meets the intent of the code requirements and ensures adequate component performance. Therefore, the staff finds that Kairos's use of ASME Code Section III, Division 5, with the exception of the quality assurance program, is acceptable for the design and fabrication of Hermes SSCs. Accordingly, the staff finds that the PSAR's preliminary information regarding the design bases of fluid systems and components ensures that the facility systems and components will function as designed to ensure safe operation and safe shutdown of the reactor and is consistent with the applicable NUREG-1537 acceptance criteria.

3.6.4 Conclusion

Based on its review, the staff has determined that the level of detail provided on design bases for the systems and components that are required to function at the Hermes facility is adequate for the preliminary design and supports the applicable acceptance criteria of NUREG-1537, Part 2, Section 3.5. The staff concludes that the design bases of the systems and components give reasonable assurance that the facility systems and components will function as designed to ensure safe operation and safe shutdown of the reactor. Therefore, the staff finds that the facility systems and components meet the applicable guidance and regulatory requirements identified in this section for issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Further technical or design information required to complete the safety analysis may reasonably be left for later consideration. The staff will confirm that the final design conforms to this design basis during the review of the Hermes OL application.

3.7 Summary and Conclusions on Design of Structures, Systems, and Components

The staff evaluated the information in PSAR Chapter 3 regarding the design of SSCs for Hermes and finds that the preliminary information on, and design criteria of, the SSCs, including the PDC, design bases, and information relating to materials of construction, general arrangement, and approximate dimensions: (1) provide reasonable assurance that the final design will conform to the design bases, (2) meet all applicable regulatory requirements, and (3) meet the applicable acceptance criteria in NUREG-1537, Part 2. Based on these findings, the staff makes the following conclusions regarding issuance of a CP in accordance with 10 CFR 50.35 and 10 CFR 50.40:

- Kairos has described the proposed design of the SSCs, including, but not limited to, the principal architectural and engineering criteria for the design, and has identified the major features or components incorporated therein for the protection of the health and safety of the public.
- Such further technical or design information required to complete the safety analysis of the Hermes SSCs, and which can reasonably be left for later consideration, will be provided in the FSAR.
- There is reasonable assurance: (i) that the construction of the facility will not endanger the health and safety of the public, and (ii) that construction activities can be conducted in compliance with the Commission's regulations.
- The issuance of a permit for the construction of the facility would not be inimical to the common defense and security or to the health and safety of the public.

3.8 References

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-----. Regulatory Guide 1.221, “Design-Basis Hurricane and Hurricane Missiles for Nuclear Power Plants,” October 2011, ML110940300.

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-----. Safety Evaluation for Kairos Power LLC Topical Report “Regulatory Analysis for the Kairos Power Salt-Cooled, High Temperature Reactor,” Revision 3, May, 2022, ML22136A089

-----. Regulatory Guide 1.29, “Seismic Design Classification for Nuclear Power Plants,” Revision 6, July 2022, ML21155A003

-----. Regulatory Guide 1.87, “Acceptability of ASME Code, Section III, Division 5, High Temperature Reactors,” Revision 2, January 2023, ML22101A263

4 REACTOR DESCRIPTION

The reactor description addresses the principal features, operating characteristics, and parameters of the Hermes non-power test reactor. The reactor core of Hermes generates heat by controlled fission of the tristructural isotropic (TRISO) fuel in a molten fluoride salt (Flibe) coolant that provides heat removal.

This chapter of the Kairos Power LLC (Kairos) Hermes test reactor construction permit (CP) safety evaluation (SE) describes the U.S. Nuclear Regulatory Commission (NRC) staff's (the staff's) technical review and evaluation of the preliminary information regarding the Hermes reactor. This information is presented in Chapter 4, "Reactor Description," of the Hermes preliminary safety analysis report (PSAR), Revision 3, as supplemented. The staff reviewed PSAR Chapter 4, as supplemented, against applicable regulatory requirements using regulatory guidance and standards to assess the sufficiency of the preliminary information Kairos provided regarding the Hermes reactor for the issuance of a CP in accordance with Title 10, *Code of Federal Regulations* (10 CFR) Part 50. As part of this review, the staff evaluated information regarding the Hermes reactor, with special attention given to design and operating characteristics, unusual or novel design features, and principal safety considerations. The staff evaluated the preliminary design of the Hermes reactor to ensure the design criteria, design bases, and information relative to construction are sufficient to provide reasonable assurance that the final design will conform to the design basis. In addition, the staff reviewed Kairos's identification and justification for the selection of those variables, conditions, or other items which are determined to be probable subjects of technical specifications (TSs) for the facility, with special attention given to those items which may significantly influence the final design.

In its review of areas relevant to PSAR Chapter 4, the staff considered the information in Revision 1, dated September 29, 2022, of the technical report KP-TR-017, "KP-FHR Core Design and Analysis Methodology," and Revision 2, dated February 24, 2023, of the technical report KP-TR-018, "Postulated Event Analysis Methodology," which are part of the Hermes CP application, as supplemented, and which are referenced in the PSAR, Revision 3.

The staff's reviews and evaluations for areas relevant to PSAR Chapter 4, including regulations and guidance used, summaries of the application information reviewed, and evaluation findings and conclusions, are discussed in the SE sections below for each specific area of review. A summary and overall conclusion on the staff's technical evaluation of the Hermes reactor design is provided in SE Section 4.8, "Summary and Conclusions on the Reactor Description."

4.1 <u>Summary Description</u>

PSAR Section 4.1, "Summary Description," provides a high level overview of the reactor design. The Hermes reactor is a fluoride molten-salt cooled pebble bed reactor that can achieve a thermal power of up to 35 megawatts (MW). The reactor design employs a high-temperature graphite matrix coated TRISO particle fuel and a chemically stable, low pressure molten fluoride salt coolant (Flibe). The TRISO fuel and Flibe coolant constitute the functional containment. PSAR Section 4.1 provides an overview of the key design parameters, such as reactor power, inlet and outlet temperature, operating pressure, and fuel materials and enrichment levels. PSAR Chapter 4 describes various key aspects of the reactor design, including the reactor core (fuel, control and shutdown system, neutron startup source), reactor vessel and internals, biological shield, nuclear design, thermal-hydraulic design, and reactor vessel support system.

NUREG-1537, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors,” Part 1, “Format and Content,” and Part 2, “Standard Review Plan and Acceptance Criteria,” Section 4.1, “Summary Description,” do not stipulate any specific review findings for the summary description of the reactor design; therefore, the staff did not make any findings relative to PSAR Section 4.1. PSAR Sections 4.2 through 4.7 provide detailed descriptions of key aspects of the reactor design. The corresponding sections of this SE document the staff’s review findings on these aspects of the reactor design.

4.1.1 Common Regulatory Evaluation for Reactor Systems

Common regulatory requirements for reactor systems evaluated in Chapter 4 are identified below. Any additional requirements or guidance specific to a system are identified in the subsection for that system. The common applicable regulatory requirements for the evaluation of the Hermes reactor systems are:

- 10 CFR 50.34, “Contents of applications; technical information,” paragraph (a), “Preliminary safety analysis report.”
  - 10 CFR 50.34(a)(4) which requires “A preliminary analysis and evaluation of the design and performance of structures, systems, and components [SSCs] of the facility…”
- 10 CFR 50.35, “Issuance of construction permits.”
- 10 CFR 50.40, “Common standards.”

4.2 Reactor Core

The subsections within PSAR Section 4.2 provide a description of the reactor core, including the reactor fuel, reactivity control and shutdown and neutron sources.

4.2.1 Reactor Fuel

4.2.1.1 Introduction

PSAR Section 4.2.1.1 states that the Hermes reactor will use TRISO fuel particles embedded in a carbon matrix pebble. The TRISO fuel particle is composed of a uranium oxycarbide (UCO) fuel kernel encased in coating layers to limit fission product releases. PSAR Section 4.2.1.1 states that the TRISO fuel particle is credited with limiting radionuclide releases to the environment as part of Hermes functional containment design. PSAR Section 4.2.1.1 further explains that the TRISO particle specification is based on the Department of Energy Advanced Gas Reactor (AGR) program and the AGR experimental results form the basis for the TRISO particle qualification. The TRISO particles are arranged in a fuel annulus near the outer diameter of the pebble. There is a protective carbon matrix overcoat (fuel-free) outside of the fuel region which protects the TRISO particles during pebble handling, pebble-to-pebble interactions, and potential chemical interactions with the Flibe coolant. The pebble has a lower density inner core which maintains positive pebble buoyancy during normal operational and transient conditions.

PSAR Section 4.2.1.1 states that, in addition to the fuel pebbles, the reactor also contains moderator pebbles. The moderator pebbles have the same diameter as the fuel pebbles but contain no uranium and are made of graphite material. The graphite pebbles are non-safety related and serve to provide sufficient moderation for the thermal spectrum Hermes reactor.

Similar to the fuel pebbles, the moderator pebbles are designed to maintain positive buoyancy under normal operation and postulated events.

4.2.1.2 Regulatory Evaluation

The requirements in the common regulatory evaluation for reactor systems apply to the reactor fuel. Additional regulatory requirements for the reactor fuel are as follows:

- 10 CFR 50.34, "Contents of applications; technical information," paragraph (a), "Preliminary safety analysis report."
  - 10 CFR 50.34(a)(3)(ii) requires "The design bases and the relation of the design bases to the principal design criteria."
  - 10 CFR 50.34(a)(3)(iii) requires "Information relative to materials of construction, general arrangement, and approximate dimensions, sufficient to provide reasonable assurance that the final design will conform to the design bases with adequate margin for safety."

The applicable guidance for evaluating the Hermes reactor fuel is as follows:

- NUREG-1537, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors," Part 1, "Format and Content," and Part 2, "Standard Review Plan and Acceptance Criteria," Section 4.2.1, "Reactor Fuel."

4.2.1.3 Technical Evaluation

PSAR Section 3.1.1, "Design Criteria," describes the principal design criteria (PDC) that are applicable to the Hermes reactor. These PDC were reviewed and approved by the staff in KP-TR-003-NP-A, Revision 1, "Principal Design Criteria for the Kairos Power Fluoride Salt-Cooled, High Temperature Reactor." PSAR Section 4.2.1.4, "Fuel Design Bases," identified the design bases for the fuel. The PSAR states that the following PDCs are applicable to the fuel:

- PDC 10, "Reactor Design," which requires that the reactor core be designed to ensure specified acceptable system radionuclide release design limits (SARRDLs) are not exceeded.
- PDC 16, "Containment Design," which requires a functional containment to control the release of radioactivity to the environment.

In addition to PDCs 10 and 16, the staff evaluation found that the following PDCs are also applicable to the fuel:

- PDC 34, "Residual heat removal," which requires a system to remove residual heat at a rate such that SARRDLs and the design conditions of safety related elements of the reactor coolant boundary are not exceeded.
- PDC 35, "Passive residual heat removal," which requires a system to assure sufficient core cooling during postulated events and to remove residual heat following postulated events.

PSAR Section 4.2.1.1 states that the primary fission product barriers of the TRISO particle are the UCO fuel kernel, the inner pyrolytic carbon (IPyC) layer, the silicon carbide (SiC) layer, and the outer pyrolytic carbon layer. These are four of the five credited fission product barriers which make up the functional containment, where the fifth barrier is the Flibe coolant, as noted above. In addition to the coating layers, a porous carbon buffer layer exists between the fuel kernel and IPyC with the primary design function of providing a void volume for fission product gases. PSAR Section 4.2 describes how the TRISO particle is used to meet PDC 16 where the remainder of the fuel element (inner low density core and carbon matrix overcoating) protect particle integrity from external conditions.

4.2.1.3.1 TRISO Particle Properties and Proposed Operating Conditions

The proposed TRISO particle properties given in PSAR Table 4.2-1, “Fuel Particle Properties,” are based on the AGR particle nominal, mean specification values. While consistent with the AGR program specification values, the staff’s SE for EPRI–AR-1(NP)-A “Uranium Oxycarbide (UCO) Tristructural (TRISO)-Coated Particle Fuel Performance,” noted the AGR-1 and 2 radionuclide retention characteristics are based on the measured UCO coated fuel particles given in Table 5-5 of EPRI–AR-1(NP)-A, “Coating layer property ranges for irradiated AGR-1 and AGR-2 UCO particles” which are more restrictive than the AGR program specification ranges. In KP-TR-011-NP-A, “Fuel Qualification Methodology for the Kairos Power Fluoride Salt-Cooled High Temperature Reactor (KP-FHR),” Revision 2, Section 3.4.1, “TRISO Fuel Particle Specification,” Kairos states, “Manufacturing the KP-FHR fuel to this fuel specification along with implementation of a quality control program will produce fuel that is equivalent to the fuel used in the AGR irradiation tests.” Therefore, the staff notes that the manufactured fuel will be equal to or within the values given by EPRI–AR-1(NP)-A, Table 5-5. For parameter values which fall outside those in Table 5-5, EPRI–AR-1(NP)-A directs that additional justification must be provided to demonstrate acceptable fuel radionuclide retention to ensure resulting dose predictions remain within the acceptance criteria.

Expected fuel radionuclide releases are also a function of the proposed operating conditions. PSAR Section 4.2.1.2 states that the Hermes test reactor is expected to operate within the limits of the AGR-2 operating envelope. Detailed comparisons of the expected Hermes operating envelope and that of the AGR-2 program can be found in PSAR Table 4.2-5, “Fuel Qualification Envelope” and KP-TR-011-NP-A, Revision 2, Table 3-17, “TRISO Performance Parameters in the KP-FHR Core and AGR Irradiation Tests.” The staff notes that all values for the Hermes operating conditions are equal to or below those of the AGR-2 test program. The staff notes the normal operation, peak SiC temperature of less than 830 °C given in PSAR Table 4.2-6, “Fuel Performance Results for Normal Operation,” which includes the predicted peaking factors, has substantial margin to the AGR-2 time-averaged SiC value given in PSAR Table 4.2-5. Example transient kernel temperatures for reactivity insertion and loss of forced circulation events are given in KP-TR-018-NP, “Postulated Event Analysis Methodology,” Figures A1-2 and A4, respectively. The maximum kernel temperatures include the effects of the hot channel model described in KP-TR-018-NP, Section 4.1.3, “Plant KP-SAM Model.” The maximum kernel temperature is less than 1100 °C, which is well below the approximately 1600 °C SiC coating failure temperature as estimated from EPRI–AR-1(NP)-A, Figure 7-15, “SiC layer and full TRISO failure fractions (upper limit at 95% confidence) for combined AGR-1 and AGR-2 UCO results during irradiation and safety tests.” Therefore, the staff finds that the proposed TRISO particle operating regime is within the bounds of EPRI–AR-1(NP)-A and the preliminary information is consistent with the relevant criteria from NUREG-1537, which states that the chemical, physical, and metallurgical characteristics of the fuel constituents should be compatible with each other and the expected environment. The staff also finds that this preliminary information is consistent with PDC 16 because the TRISO particle operating conditions will not approach conditions that would cause TRISO failures or significant radionuclide releases.

4.2.1.3.2 Overpower Transients

In the SE for KP-TR-011-NP-A, Revision 2, the staff imposed a limitation that future license applications for non-power KP-FHRs will include justification of the applicability of this methodology during rapid reactor transient events. The purpose of this limitation was to evaluate failure mechanisms beyond just the maximum event temperature but also address the rate of temperature change during a postulated event. The AGR program safety cases heated compacts slowly (ranging from approximately 36 °C per hour to 360 °C per hour) until a target temperature was reached (e.g., 1600 °C) and then held the target temperature constant for a period of time, typically 300 hours. The AGR safety case heat-up rates are slower than the heat-up rate caused by a bounding, design basis overpower transient for Hermes. The most rapid transient with significant energy deposition is expected to be a control element withdrawal at maximum withdrawal rate, as rod ejection is precluded by the operating conditions, specifically low operating pressure.

Kairos presented a reactivity insertion analysis in a technical report attached to the PSAR, KP-TR-018-NP, Appendix A, for a full control element withdrawal at the maximum speed until reaching the high-power trip. The transient heat-up phase lasts approximately 10 seconds with a time-averaged heat-up rate of approximately 18,000 °C per hour (or about 50 °C over 10 seconds). This higher heat-up rate could potentially create particle failures caused by kernel melt and rapid non-melt kernel thermal expansion, which are discussed here. For potential kernel melt, the maximum overpower kernel temperature, based on KP-TR-018-NP, Figure A1-2, is significantly below the carbide phase (UC and UCx) melting temperature range precluding a significant kernel volumetric expansion due to a phase change. The estimated energy deposited due to the increase in reactivity is also relatively low and significantly below the 1,400 J/g established in Umeda, et al. (2010) for melt-induced failures of unirradiated UO_2 kernels. While this reference did not investigate UCO fuel, the estimated energy should still be applicable and relevant to UCO fuel. Accounting for the lower melting temperature of various UC phases, based on the similar phenomena and margin to the melting temperatures, the staff finds the low predicted energy deposition of the withdrawal event is not expected to cause UCO melt and incremental coating failures.

Likewise, a non-melt kernel thermal expansion leading to stress-induced coating failure is not expected based on the temperature difference between the kernel and coatings. For event durations significantly longer than the fuel thermal time constant (approximately 30 to 300 milliseconds), such as a control element withdrawal, the temperature difference across the particle kernel is near zero based on a 2011 Request for Additional Information (RAI) response on TRISO fuel performance for the Next Generation Nuclear Project (CNN 224915, “Contract No. DE-AC07-05ID14517 – Next Generation Nuclear Project Submittal – Response to Nuclear Regulatory Commission Request for Additional Information Letter No. 002 Regarding Next Generation Nuclear Plant Project Qualification and Mechanistic Source Terms – NRC Project #0748”). This near zero temperature difference is largely insensitive to the amount of energy deposited for transient durations on the order of 10 seconds or longer. Therefore, transient non-melt thermal expansion is expected to cause negligible failures during the course of similar transients, especially with thermal gradients consistent with the maximum AGR-2 particle power. For other fluoride high temperature reactor designs using higher steady-state particle powers beyond that established by the AGR program and/or higher event heat-up rates beyond

Hermes, additional justification would be necessary to demonstrate that non-melt thermal expansion does not cause significant incremental failures.

The staff's assessment of negligible incremental failures is consistent with the KP-BISON fuel performance code calculations in KP-TR-018-NP, Table A1-2, "95% Confidence Level Upper Limit on In-service Failure Fractions for Normal Operation and Reactivity Insertion Postulated Event," which reported zero incremental transient failures using the event-specific core power and coolant temperature increases. Furthermore, the staff notes that a safety related positive flux rate trip exists in the Hermes design, which would likely terminate the reactivity insertion event before achieving the reported maximum kernel temperature and maximum temperature rate of change. PSAR Chapter 14 includes an upper bound limit for the high-power flux trip function as a proposed Limiting Safety Systems Setting. The effect of the flux rate trip on the control element reactivity insertion event progression will be evaluated during the operating license (OL) review. Based on the margin to melt and the differential temperature across the TRISO particle, the staff finds that incremental failures due to kernel melt and rapid thermal expansion are not expected for the bounding Hermes reactivity insertion (overpower transient) event. Therefore, the preliminary information satisfies the applicable acceptance criteria from NUREG-1537, which states that the fuel design should take into account characteristics that could limit fuel integrity, such as heat capacity, conductivity, and melting temperature and propose TSs to ensure that the fuel meets the safety related design requirements. Accordingly, the staff also finds that this preliminary information is consistent with PDC 10 and 16.

4.2.1.3.3 Fuel Performance Testing and Analysis

Section 4.2 of KP-TR-018-NP, "Fuel Performance," describes how the methodology in KP-TR-010-NP-A, "KP-FHR Fuel Performance Methodology," Revision 3, is used to determine the pre-transient and postulated event incremental fuel failure fractions, which are calculated using event-specific powers and temperatures. The event-specific failure fractions and the associated releases are compared with the fuel releases assumed in the Maximum Hypothetical Accident (MHA) to ensure the MHA analysis remains bounding. Table A4-4 of KP-TR-018-NP provides example fuel failure fractions used to compare to those in the MHA. In KP-TR-018-NP, the KP-BISON code is also used to analyze the radionuclide release from the manufacturing defect fraction and, when combined with the assumed amount of dispersed uranium, yields the total event specific radionuclide release. The manufactured defect population and amount of dispersed uranium are set by a manufacturing specification.

The staff notes that while the fuel pebble matrix is not credited to retain fission products, the pebbles serve to protect the integrity of the fuel containing TRISO particles. The design functions of the pebbles include: (1) protecting TRISO particles from mechanical forces such as pebble-to-pebble interactions, Pebble Handling and Storage System (PHSS) operations and shipping, (2) maintaining a net positive buoyance during normal and postulated events and (3) protecting against adverse chemical interactions with the Flibe coolant, cover gas and an air environment. The mechanical, tribology, buoyancy and material testing program is described in KP-TR-011-NP-A, Revision 2, which applies to both the Hermes non-power reactor and a commercial KP-FHR. The mechanical tests address static and dynamic pebble impact forces with the highest pebble impact force anticipated to be shutdown element insertion. The preliminary analysis by Kairos demonstrates about a 50 percent margin between the impact force and pebble crush limit.

Tribology tests are used to confirm an adequate pebble matrix outer fuel-free zone thickness and the amount of dust generation from pebble-to-pebble contact, pebble-to-reflector contact, and pebble handling by the PHSS. The dust generation rates from the tribology test program will be either used in or determined to be less conservative than those already used in the PSAR Chapter 13 postulated events where dust release is a dose contributor. The pebble buoyancy tests will demonstrate that a net positive buoyancy will be maintained during all operating conditions, including the effects of salt ingress. The test program includes testing both the pebble attributes which affect density, as well as the changes in Flibe salt density as a function of temperature and pressure.

Finally, the material compatibility testing program examines the carbon matrix material interaction with Flibe and air. The Flibe tests will determine if the pebble outer matrix material degrades with exposure as a function of Flibe chemistry and temperature. The pebble material tests will also examine the oxidation of the pebble outer matrix surface at intermediate temperatures expected during air ingress events such as a break in the PHSS handling line. The oxidation tests will be used to validate existing correlations or develop new correlations for use in the air ingress events. The staff's safety evaluation of KP-TR-011-NP-A, Revision 2 found the Kairos testing methodology acceptable to qualify fuel for the Hermes. The staff finds that the preliminary information is consistent with PDC 10, 16, 34 and 35 because the fuel testing methodology is acceptable and the resulting data will be evaluated and included, if necessary, in the OL application. The staff also finds this preliminary information is consistent with the relevant criteria from NUREG-1537, which states that the chemical, physical and metallurgical characteristics of the fuel constituents should be compatible with each other and the expected environment.

The core also includes moderator pebbles, which contain neither fuel nor the lower density inner pebble core but are made of the same material as the fuel element matrix. Unexpected failure of the moderator pebbles could cause unexpected amounts of graphite debris and/or unanalyzed power shapes. Large amounts of unexpected debris could challenge the natural circulation flow path depending on the final flow path diameter, fluidic diode design, and the ability to monitor potential flow degradation. To preclude unexpected moderator pebble degradation, PSAR Section 4.2.1.1 states the moderator pebbles will be tested using the same methodology described in the KP-TR-011-NP-A, Revision 2 for buoyancy, wear, strength, and salt ingress. Like the fuel elements, the moderator pebbles will be inspected by the PHSS for physical damage. The staff identified no new failure mechanisms which would require testing beyond that established for the fuel pebbles. The staff finds that the preliminary design is consistent with PDC 34 and 35 because the moderator pebble testing methodology is acceptable and the resulting data will be evaluated and included, if necessary, in the OL application.

4.2.1.3.4 Fuel Performance Monitoring

To ensure the TRISO particles and fuel pebbles are performing their intended design functions, Hermes will have two non-destructive means of monitoring fuel performance. The first is to monitor the cover gas and Flibe coolant for unexpected increases in circulating activity. As described in PSAR Section 9.1, "Reactor Coolant Auxiliary Systems," the Flibe circulating activity limits are monitored and compared to a TS limit. Likewise, PSAR Section 9.1.2.1, "Inert Gas," describes that radiation monitoring of the argon cover gas will be performed and the activity limited by establishment of a TS Limiting Condition for Operation which would need to be met under specific modes of operation. The second non-destructive means to monitor fuel performance is inspection of pebbles by the PHSS as they are removed from the core. The pebbles are inspected for wear, cracking, and missing surface area. The criteria used to determine if a pebble is removed from service due to wear, cracking and/or missing surface area are further discussed in Section 3.9.2, "Fuel Pebble Non-destructive Examination," of

KP-TR-011-NP-A, Revision 2. The PHSS also measures burnup to determine if the pebble can be reinserted into the core without exceeding the burnup limit given in PSAR Table 4.2-5.

In addition to the non-destructive monitoring, Kairos has indicated in KP-TR-011-NP-A, Revision 2, Section 3.9.3, “Fuel Destructive Examinations” that it will perform destructive testing. The destructive testing will determine the TRISO failed fuel fractions, pebble wear, and possible Flibe salt ingress in the pebble overcoat. Likewise, the destructive testing and out-of-pile pebble testing would confirm the conservative results of the fuel performance modeling (e.g., failed fuel fractions) and pebble testing program and, if necessary, provide valuable information to update the fuel element Phenomena Identification and Ranking Table (PIRT) for future licensing actions. Consistent with the staff’s safety evaluation for KP-TR-011-NP-A, Revision 2, the staff finds the preliminary information on fuels performance monitoring is consistent with relevant criteria from NUREG-1537, which states Kairos should propose TSs to ensure that the fuel meets the safety related design requirements.

4.2.1.4 Conclusion

In PSAR Section 4.2.1, Kairos provided the relevant PDC, a design description of the TRISO particle and corresponding fuel and moderator elements (pebbles), and a preliminary analysis and evaluation of the fuel element demonstrating the margins of safety during normal operations and transient conditions anticipated during the life of the facility. Based on the preliminary information provided, including information regarding Kairos’s use of TRISO particles within the limits specified in EPRI–AR-1(NP)-A, the normal and transient operating temperature margins relative to the AGR-2 test program envelope and the results from the fuel qualification testing program outlined in KP-TR-011-NP-A, Revision 2, the staff finds that the preliminary information on the reactor fuel design is consistent with PDC 10, 16, 34 and 35. The staff also finds the preliminary information is consistent with the relevant acceptance criteria in NUREG-1537, Part 2, Section 4.2.1. Consistency with PDCs 10, 16, 34 and 35 helps to ensure the dose criteria of 10 CFR 100.11 will be met based on the importance of retaining the majority of the fission products within the TRISO particle.

Based on its findings above, the staff concludes the information in Hermes PSAR Section 4.2.1 is sufficient and meets the applicable guidance and regulatory requirements identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Further information as may be required to complete the review of Hermes reactor fuel can reasonably be left for later consideration at the OL stage since this information is not necessary for the review of a CP application.

4.2.2 Reactivity Control and Shutdown System

4.2.2.1 Introduction

PSAR Section 4.2.2, “Reactivity Control and Shutdown System,” discusses the Hermes reactivity control and shutdown system (RCSS). The RCSS inserts and withdraws control and shutdown elements to control reactivity in the reactor core during normal operation and in response to abnormal conditions or postulated events, to ensure safe shutdown. There are four control elements that insert into the graphite reflector and three shutdown elements that insert into the pebble bed. The control elements insert into guide structures in the upper and side reflector, near the periphery of the core. The shutdown elements insert into guide structures in the upper reflector, then directly into the pebble bed. Control elements can be positioned throughout their range of travel. The portion of the control elements that relates to their release and insertion on a reactor trip is non-safety related. Shutdown elements are safety related and have two positions: (1) fully withdrawn or (2) fully inserted. Both the control and shutdown elements are positioned via counter-weighted winch systems.

The control and shutdown elements have boron carbide (B_4C) absorber material contained in pellets which are stacked in cylindrical tubes that are made of high carbon Type 316 stainless steel (316H SS) (cladding) and pressurized with inert gas. The upper portions of the control and shutdown elements are exposed to reactor cover gas above the reactor coolant free surface. The control and shutdown drive mechanisms are made of stainless steel.

4.2.2.2 Regulatory Evaluation

The requirements in the common regulatory evaluation for reactor systems apply to the RCSS. Additional regulatory requirements for the RCSS are as follows:

- 10 CFR 50.34, "Contents of applications; technical information," paragraph (a), "Preliminary safety analysis report."
  - 10 CFR 50.34(a)(3)(ii) requires "The design bases and the relation of the design bases to the principal design criteria."
  - 10 CFR 50.34(a)(3)(iii) requires "Information relative to materials of construction, general arrangement, and approximate dimensions, sufficient to provide reasonable assurance that the final design will conform to the design bases with adequate margin for safety."

The applicable guidance for evaluating the Hermes control and shutdown elements are as follows:

- NUREG-1537, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors," Part 1, "Format and Content," and Part 2, "Standard Review Plan and Acceptance Criteria," Section 4.2.2, "Control Rods."

4.2.2.3 Technical Evaluation

PSAR Section 4.2.2.2, "Design Basis," identified the design bases for the RCSS. The PSAR states that the following PDCs are applicable to the RCSS:

- PDC 2, "Design bases for protection against natural phenomena," which requires safety related SSCs to withstand natural phenomena such as earthquakes, tornadoes, hurricanes, floods, tsunami, and seiches without loss of capability to perform their safety functions.
- PDC 4, "Environmental and dynamic effects design bases," which requires safety related SSCs to accommodate the effects of and to be compatible with the environmental conditions associated with normal operation, maintenance, testing, and postulated accidents and to be appropriately protected against dynamic effects, including the effects of missiles, pipe whipping, and discharge fluids that may result from equipment failures and from events and conditions outside the nuclear power unit.
- PDC 23, "Protection system failure modes," which requires the protection system to fail into a safe state or into some other defined basis.
- PDC 26, "Reactivity control systems," which requires a minimum of two reactivity control systems to provide key reactivity control functions.

- PDC 28, “Reactivity limits,” which requires the reactivity control systems to have appropriate limits on the potential amount and rate of reactivity increase.
- PDC 29, “Protection against anticipated operational occurrences,” which requires the protection and reactivity control systems to assure an extremely high probability of accomplishing their safety functions in the event of anticipated operational occurrences.

PSAR Section 4.2.2.3, “System Evaluation,” relates the design bases to the design criteria and identifies how the RCSS satisfies the PDC applicable to the design of the RCSS. In the following paragraphs, the staff addresses each PDC by summarizing the information presented in the PSAR and explaining the staff evaluation of the adequacy of the preliminary information in the Kairos PSAR relative to NUREG-1537 acceptance criteria.

4.2.2.3.1 PDC 2, Design bases for protection against natural phenomena:

PSAR Section 4.2.2.3 states that the design basis earthquake is described in PSAR Section 3.4. The design basis earthquake is used to determine the maximum deflection of the RCSS shutdown element insertion path. PSAR Section 4.2.2.3 states that shutdown element insertion capability will be assessed through a one-time, out-of-pile, at scale test prior to operation that deflects the shutdown element guide structures consistent with the maximum misalignment caused by the design basis earthquake and accounts for expected changes in pebble bed packing fraction and concurrent insertion of all three shutdown elements into the pebble bed. This testing will confirm that the element insertion time is bounded by the insertion time assumed in the postulated event analysis in PSAR Chapter 13 and that the shutdown elements fully insert to the depth assumed in the shutdown margin calculations presented in PSAR Table 4.5-5. In addition, PSAR Section 4.3 describes the reflector blocks that maintain the element insertion pathway.

Since the RCSS shutdown elements will be subject to a test at the maximum misalignment due to a design basis earthquake with the insertion time confirmed to be bounded by the relevant Chapter 13 analyses, the staff finds that the preliminary information for RCSS design and pre-operational testing is consistent with PDC 2. The staff also finds that the preliminary information is consistent with the relevant acceptance criteria in NUREG-1537.

4.2.2.3.2 PDC 4, Environmental and dynamic effects design bases:

PSAR Section 4.2.2.3 states that the RCSS shutdown elements are made with stainless steel cladding and the neutron absorbing material is enclosed in two stainless steel barriers. PSAR Section 4.2.2.3 also states that the shutdown elements are not adversely affected by neutron and gamma heating and that the design will account for the effects of irradiation on 316H SS. Materials are chosen to ensure reactor coolant-induced diffusion bonding does not occur at interfaces where movement or separation is necessary. PSAR Section 4.2.2.3 further states that the shutdown elements will be tested prior to operation ensure that wear during shutdown element movement is acceptable.

PSAR Section 4.2.2.3 states that an analysis will be performed on the shutdown elements to determine internal gas release and swelling of the B_4C during normal operation over their design lifetime. The resulting increase in gas pressure will be analyzed to ensure that stresses on the shutdown element tubes are within allowable stress limits for 316H SS. A finite element model will be developed to calculate the forces on the shutdown elements during normal operation and postulated events. This analysis will include thermal stresses from internal heat generation, will be performed under maximum heat generation conditions, and will be used to demonstrate that control and shutdown element cladding stresses are within limits and are not subject to bowing or binding due to differential thermal expansion. PSAR Section 4.2.2.3 also states that control and shutdown elements and drive mechanisms will be analyzed to meet the requirements of American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (BPVC) 2017 edition Section III, Division 5, due to loads from operational stepping, reactor trip, stuck element, fatigue, and shipping and handling.

The staff notes that the PSAR describes the RCSS design and materials of construction, as well as testing and analyses that will be performed to ensure the RCSS can perform its intended functions and compatible with the Hermes operating environment. This includes consideration of irradiation effects, wear, reactor coolant-induced diffusion bonding, internal gas release, B_4C swelling, and thermal stresses from internal heat generation. In addition, the PSAR also indicates that these components will be analyzed to meet the requirements of ASME BPVC Section III, Division 5. Based on the planned testing and analysis for these components, the staff finds that the preliminary information for RCSS design is consistent with PDC 4. The staff also finds that the preliminary information is consistent with the relevant acceptance criteria in NUREG-1537, Part 2, which states that the RCSS should be designed to withstand all anticipated stresses and the chemical and radiation environment. The staff will review the final design and analyses during the OL application review.

4.2.2.3.3 PDC 23, Protection system failure modes:

PSAR Section 4.2.2.3 states that the safety related reactor trip function of the RCSS is initiated through the reactor trip system (RTS). The shutdown elements accomplish a safe shutdown (reactor trip) via gravity insertion on a reactor trip signal or on a loss of normal electrical power after a short time delay to mitigate spurious trips. When the RTS actuates, the energy holding the normally open relays closed is removed and this loss of supply power initiates a reactor trip. Shutdown elements fall into the core by gravity when power is removed from the electromagnetic clutch in the RCSS.

Since the RCSS shutdown elements are designed to fail into a safe state due to a gravity insertion design that initiates with the removal or loss of power causing the relays to open, the staff finds that that the preliminary information on RCSS design is consistent with PDC 23. The staff also finds the preliminary information is consistent with the acceptance criteria in NUREG-1537, which identifies the need for a rapid, fail-safe shutdown of the reactor from any operating condition, including due to loss of normal electrical power.

4.2.2.3.4 PDC 26, Reactivity control systems:

PSAR Section 4.2.2.3 states that conformance with PDC 26 is discussed in PSAR Section 4.5. Therefore, the staff evaluation of PDC 26 is similarly contained in SE Section 4.5.

4.2.2.3.5 PDC 28, Reactivity limits:

PSAR Section 4.2.2.1 states that the maximum withdrawal and insertion time for the control and shutdown elements is 100 seconds over the full range of motion for motor-driven operation and that the control and shutdown elements reach full insertion by gravity in no more than 10 seconds. PSAR Section 4.2.2.3 states that the maximum design speed is analyzed in PSAR Chapter 13 to ensure that the rate of reactivity addition does not impact the safety related portions of the reactor coolant boundary and also does not disturb the core and internals and impair cooling of the core. PSAR Section 13.1.10.7 states that the Hermes design precludes the possibility of shutdown element ejection due to its low operating pressure.

The staff performed scoping calculations based on the preliminary information available at this stage of the design that determined the TRISO fuel maintains integrity during a postulated insertion of excess reactivity event. These scoping calculations are discussed in SE Chapter 13. The scoping calculations showed reasonable agreement with Kairos's preliminary transient analyses for the same event that is discussed in PSAR Chapter 13.

The staff finds that the preliminary information on the Hermes RCSS design is consistent with PDC 28 because (1) the reactor operates at low pressure, (2) staff scoping calculations had reasonable agreement with Kairos's preliminary transient analyses for the insertion of excess reactivity postulated event, and (3) the MHA remains bounding for the insertion of excess reactivity postulated event. In addition, the staff finds that the preliminary information on the Hermes RCSS design is consistent with the relevant acceptance criteria from NUREG-1537, which states that a credible insertion of excess reactivity should not lead to fuel or reactor damage.

4.2.2.3.6 PDC 29, Protection against anticipated operational occurrences:

PSAR Section 4.2.2.3 states that the RCSS has a high probability of accomplishing its design function, because the trip function is safety related and allows the elements to be inserted passively via gravity. In addition, the RCSS has two separate means of inserting negative reactivity: (1) using the motor to lower the element and (2) allowing the element to drop into the core by gravity upon a reactor trip. PSAR Section 4.2.2.3 also notes that the two separate means of shutdown allow for the highest worth reactivity element to fail to insert and the safe shutdown is still accomplished. PSAR Section 4.2.2.4 states that periodic inspection of the shutdown elements and coolant will be performed to look for evidence of shutdown element damage or failure.

Based on the design features and the planned testing of the shutdown elements, including the shutdown element deflection and insertion testing discussed with respect to PDC 2, the staff finds that the preliminary information on the RCSS design is consistent with PDC 29. The staff also finds the preliminary information is consistent with the relevant acceptance criteria from NUREG-1537, which states that the reactor should be able to shut down with minimum shutdown margin with the highest worth shutdown element stuck out of the core.

4.2.2.3.7 Testing and Inspection

PSAR Section 4.2.2.3 states that the control and shutdown elements can be removed for inspection or replaced if necessary. PSAR Section 4.2.2.4 states that shutdown elements will be periodically inspected for wear or other damage to the cladding that encapsulates the B_4C absorber material. Reactor coolant will also be periodically examined for an increase in boron from the B_4C absorber material, which provides an indication of element cladding failure.

Based on the design for replaceability and inspectability, the staff finds that the preliminary information on RCSS design is consistent with NUREG-1537, which identifies that the control elements should allow for replacement and inspection. The final design and inspection and surveillance requirements will be addressed during the OL review.

4.2.2.3.8 Other NUREG-1537 Criteria

PSAR Section 4.2.2.1 states that element positions are monitored using both an absolute encoder and a high-density reed switch array. The encoder determines the angle that the sheave has swept from a known reference point, which directly correlates to the element position. The reed switch array measures the position of the counterweight over its full range of motion. The encoder provides a digital signal, and the switch array provides an analog signal. Both signals provide the ability to determine element position.

Based on the multiple independent means of determining element position, the staff finds that the preliminary information on the RCSS design is consistent with relevant acceptance criteria in NUREG-1537, which identifies the need for control element positioning to be reproducible and available for all reactor operating conditions.

4.2.2.4 Conclusion

Based on the information provided by Kairos and the staff evaluation documented above, the staff finds that Kairos provided sufficient preliminary information in accordance with 10 CFR 50.34(a) to develop an RCSS design that the staff has reasonable assurance will perform its safety functions of reactivity control and shutdown. The staff finds that the preliminary information provided for the RCSS is adequate at this stage of the design and is consistent with PDCs 2, 4, 23, 28, and 29. The staff also finds the preliminary information is consistent with the relevant acceptance criteria of NUREG-1537, Part 2, Section 4.2.2, “Control Rods.”

Based on its findings above, the staff concludes the information in Hermes PSAR Section 4.2.2 is sufficient and meets the applicable guidance and regulatory requirements identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Further information as may be required to complete the review of Hermes RCSS can reasonably be left for later consideration at the OL stage since this information is not necessary for the review of a CP application.

4.2.3 Neutron Startup Source

4.2.3.1 Introduction

PSAR Section 4.2.3, “Neutron Startup Source,” discusses the Hermes neutron startup source, which provides a neutron flux to the source range ex-core detectors for initial and subsequent startups.

4.2.3.2 Regulatory Evaluation

The requirements in the common regulatory evaluation for reactor systems apply to the neutron startup source. There are no additional regulatory requirements for the neutron startup source. The applicable guidance for evaluating the Hermes neutron startup source are as follows:

- NUREG-1537, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors,” Part 1, “Format and Content,” and Part 2, “Standard Review Plan and Acceptance Criteria,” Section 4.2.4, “Neutron Startup Source.”

4.2.3.3 Technical Evaluation

PSAR Section 4.2.3 states that a neutron startup source is used to provide a neutron flux to the source range ex-core detectors for initial and subsequent startups. The startup neutron source will have sufficient strength to provide a detectable count rate and allows monitoring the change in neutron multiplication during the addition of fuel and during the approach to criticality. The neutron source(s) will be encased in a metal sheath and placed in the reflector region of the core near an excore source range detector for best detectability of criticality. The PSAR states that the neutron startup source can be removed and replaced during the life of the plant and does not perform any safety related functions.

The staff evaluated the sufficiency of the preliminary information for the neutron startup source, as discussed in PSAR Section 4.2.3, using the guidance and acceptance criteria from Section 4.2.4, "Neutron Startup Source," in NUREG-1537, Parts 1 and 2. The staff notes that the neutron startup source will be placed in a metal sheath and be compatible with the expected environmental conditions. The source is also designed to be able to be removed and replaced. Based on its review, the staff finds that the preliminary information on the Hermes neutron startup source is consistent with the applicable acceptance criteria of NUREG-1537, Part 2 because the PSAR provides information to support NUREG-1537 criteria that the neutron startup source should be capable of performing in the environment and be able to be removed and replaced. The staff notes that the PSAR does not specify the source type and decay rate, but specific details of the neutron startup source can reasonably be left for further consideration at the OL stage.

4.2.3.4 Conclusion

Based on the findings above, the staff concludes that the information in Hermes PSAR Section 4.2.3 is sufficient and meets the applicable guidance and regulatory requirements identified in this SE section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Further information as may be required to complete the review of Hermes reactor neutron startup source can reasonably be left for later consideration at the OL stage since this information is not necessary for the approval of a CP application.

4.3 Reactor Vessel System

4.3.1 Introduction

PSAR Section 4.3.1 states that the reactor vessel system contains the reactor core and provides for circulation of reactor coolant and pebbles as well as insertion of the RCSS elements in the reactor core. The reactor vessel consists of a shell, a flat top head, and a flat bottom head, and contains the reactor internals. The reactor internals include the graphite reflector blocks, fluidic diodes, the core barrel, and reflector support structure. The reactor vessel system is secured to the reactor vessel support system (RVSS), which is evaluated in SE Section 4.7. The top head of the reactor vessel system contains penetrations and is described in PSAR Section 4.3.1, "Reactor Vessel System." PSAR Section 1.3.3.2 states that the planned operational lifetime of the reactor at 35 MW thermal power is 4 years.

4.3.2 Regulatory Evaluation

The requirements in the common regulatory evaluation for reactor systems apply to the reactor vessel system. Additional regulatory requirements for the reactor vessel system are as follows:

- 10 CFR 50.34, “Contents of applications; technical information,” paragraph (a), “Preliminary safety analysis report.”
    - 10 CFR 50.34(a)(3)(ii) requires “The design bases and the relation of the design bases to the principal design criteria.”
    - 10 CFR 50.34(a)(3)(iii) requires “Information relative to materials of construction, general arrangement, and approximate dimensions, sufficient to provide reasonable assurance that the final design will conform to the design bases with adequate margin for safety.”
    - 10 CFR 50.34(a)(5) requires “…identification and justification for the selection of those variables, conditions, or other items which are determined as a result of preliminary safety analysis and evaluation to be probable subjects of technical specifications for the facility…”
    - 10 CFR 50.34(a)(8) requires “… identification of those structures, systems, and components of the facility, if any, which require research and development to confirm the adequacy of their design; and identification and description of the research and development program which will be conducted to resolve any safety questions…; and a schedule of the research and development program…”.

The applicable guidance for evaluating the Hermes reactor vessel system are as follows:

- NUREG-1537, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors,” Part 1, “Format and Content,” and Part 2, “Standard Review Plan and Acceptance Criteria,” Parts 1 and 2, Section 4.3, “Reactor Tank or Pool.”

4.3.3 Technical Evaluation

4.3.3.1 PSAR System Description

PSAR Section 4.3.1 states that the reactor vessel system includes the reactor vessel and vessel internals. Major functions of the system are to direct the coolant flow through the reactor core to the primary heat transfer system (PHTS), provide a flow path for fuel pebble insertion and extraction, provide support for the reactor internals, and maintain geometry for the reactor control and shutdown elements. PSAR Sections 4.3.1 and 4.3.1.2.1 state that the reflector blocks and the reactor vessel system are designed to ensure system integrity and geometry are maintained during and after postulated events to permit insertion of the shutdown elements into the core to shut down the reactor.

PSAR Section 4.3.1.1 states that the reactor vessel will be designed and constructed in accordance with ASME BPVC Section III, Division 5, and will consist of 316H SS welded with ER16-8-2 weld metal. The staff notes that 316H SS is an allowable material for use in high temperature applications in accordance with ASME BPVC Section III, Division 5. In RG 1.87, “Acceptability of ASME BPVC Section III, Division 5, ‘High Temperature Reactors’,” Revision 2, the staff endorses the 2017 edition of ASME BPVC Section III, Division 5, with exceptions and limitations, as a method acceptable for the materials, mechanical/structural design, construction, testing, and quality assurance of mechanical systems and components and their supports of high-temperature reactors.

PSAR Section 4.3.1.1 states that the reactor vessel is designed so that all penetrations are above the normal coolant operating level. Most of the vessel penetrations are in the top head. PSAR Section 4.3.1 and Figure 4.3-1 show that there are two penetrations near the top of the vessel shell for coolant inlet. PSAR Section 4.3.1.1.1 states that a hold down structure sub-assembly is welded underneath the top head to provide structural support against upward loads during normal operation and most postulated events. PSAR Section 4.3.1.1.1 also indicates there is a secondary hold down structure installed through the upper graphite layers into submerged graphite layers to transfer upward loads from the submerged graphite to the top head during postulated air ingress events. PSAR Section 4.3.1.1.3 states that the bottom head is designed to support the reactor internals, maintain the coolant boundary, and transfer loads from the vessel and internals to the RVSS. PSAR Sections 4.3.1.1 and 4.3.2 state that the reactor vessel is designed to be inspected, monitored, and/or functionally tested to assess that the structural integrity and leak tightness is maintained.

PSAR Section 4.3.1.2 states that the reactor vessel internals will consist of the reflector blocks, fluidic diodes, core barrel, and reflector support structure. PSAR Section 4.3.1.2.1 indicates that the reflector blocks will be constructed from ET-10 graphite, provide a heat sink for the core, and form coolant flow channels, the pebble defueling chute, and channels for insertion and withdrawal of reactivity control and shutdown elements. According to PSAR Section 4.3.1.2.1, the reflector is also designed to reflect neutrons back into the core, which will increase fuel utilization and protect the reactor vessel from the effects of neutron fluence. PSAR Section 4.3.1.2.1 states that the reflector blocks will also form a hot well and pathways to each of the fluidic diodes, which allow for natural cooling through each of the four fluidic diodes from the core to the downcomer region when the PHTS is not available. The response to RAI Package 339, Question 399, provides additional details on the natural circulation flow path and the preliminary design of the fluidic diodes. During natural circulation, the flow passes in the low-resistance direction of the diode from the hot well through the diodes to the top of the downcomer via a penetration in the core barrel. PSAR Section 4.3.1.2.2 states that the core barrel creates an annular space between itself and the reactor vessel, which defines the downcomer coolant flow path, and includes cutout features to limit the siphoning of coolant in the event of a cold leg break. Finally, PSAR Section 4.3.1.2.3 describes how the reflector support structure supports and controls the positions of the reflector blocks as well as defines the flow path from the downcomer into the core.

4.3.3.2 Staff Evaluation of Design Basis and System Design

PSAR Section 4.3.2, “Design Basis,” identified the design bases for the Hermes reactor vessel system. The PSAR states that the following PDCs are applicable to the reactor vessel system design:

- PDC 1, “Quality standards and records,” which requires SSCs that are safety related be designed, fabricated, erected, and tested to appropriate quality standards, and to identify generally recognized codes and standards that are used.
- PDC 2, “Design bases for protection against natural phenomena.”
- PDC 4, “Environmental and dynamic effects design bases.”
- PDC 10, “Reactor design.”
- PDC 14, “Reactor coolant boundary,” which requires safety related elements of the reactor coolant boundary to have an extremely low probability of abnormal leakage, rapidly propagating failure, and gross rupture.

- PDC 30, “Quality of reactor coolant boundary,” which requires that components that are part of the reactor coolant boundary to be designed, fabricated, erected, and tested to quality standards and that means will be provided for detecting leakage from safety related elements of the reactor coolant boundary.
- PDC 31, “Fracture prevention of reactor coolant boundary,” which requires the safety related elements of the reactor coolant boundary to have sufficient margin to ensure it does not fail under conditions including postulated accidents.
- PDC 32, “Inspection of reactor coolant boundary,” which requires safety related portions of the reactor coolant boundary be designed to permit periodic inspection, monitoring, or functional testing and include an appropriate material surveillance program for the vessel.
- PDC 33, Reactor coolant inventory maintenance,” which requires a system to maintain reactor coolant inventory to protect against small breaks in order to ensure SARRDLs are not exceeded.
- PDC 34, “Residual Heat Removal.”
- PDC 35, “Passive residual heat removal.”
- PDC 36, “Inspection of the passive residual heat removal system,” which requires the system to permit appropriate periodic inspection of important components.
- PDC 37, “Testing of the passive residual heat removal system,” which requires the system to permit appropriate periodic functional testing.
- PDC 74, “Reactor vessel and reactor system structural design basis,” which requires the design of the reactor vessel and reactor system to maintain integrity during postulated accidents to ensure geometry for passive heat removal and permit sufficient insertion of neutron absorbers.

PSAR Section 4.3.3, “System Evaluation,” relates the design bases to the design criteria and identifies how the reactor vessel system satisfies the PDC applicable to the design of the system. In the following subsections, the staff addresses each PDC by summarizing the information presented in the PSAR and explaining the staff evaluation of the adequacy of the preliminary information in the Kairos PSAR relative to NUREG-1537 acceptance criteria.

4.3.3.3 PDC 1, Quality standards and records:

PSAR Section 4.3 describes several components that comprise the reactor vessel system. These components will be made from 316H SS that meets the chemistry requirements of ASME BPVC Section III, Division 5, Article HGB-2000, and uses the associated weld metal ER16-8-2. PSAR Section 4.3.3 also states that the graphite reflector blocks will be subject to quality controls and the requirements of ASME BPVC Section III, Division 5, as applicable.

The staff notes that Kairos plans to fabricate the reactor vessel system components consistent with ASME BPVC Section III, Division 5, which the staff endorsed in RG 1.87, Revision 2. The staff evaluated the Kairos metallic materials qualification plan in KP-TR-013-NP-A, “Metallic Materials Qualification for the Kairos Power Fluoride Salt-Cooled High-Temperature Reactor,” Revision 4. The staff evaluated the Kairos graphite material qualification plan in KP-TR-014-NP-A, “Graphite Material Qualification for the Kairos Power Fluoride Salt-Cooled High-Temperature Reactor,” Revision 4, including quality assurance portions of ASME BPVC Section III Division 5.

The PSAR discusses quality standards and records that have been evaluated by the staff as part of other activities, specifically RG 1.87, Revision 2, KP-TR-013-NP-A, Revision 4, and KP-TR-014-NP-A, Revision 4. Based on the PSAR’s consistency with the staff’s previous evaluations and guidance, the staff finds that the preliminary information on the reactor vessel system design is consistent with PDC 1. The staff also finds the preliminary information is consistent with acceptance criteria from NUREG-1537, which states that the vessel fabrication methods should be discussed and the design features should offer reasonable assurance of its reliability and integrity. Further information as may be required to complete the review of Hermes reactor vessel system can reasonably be left for later consideration at the OL stage, including how applicable exceptions and limitations on the use of ASME BPVC Section III, Division 5, as stated in RG 1.87, Revision 2 are addressed. The broader staff evaluation of Hermes quality assurance requirements can be found in SE Chapter 12.

4.3.3.4 PDC 2, Design bases for protection against natural phenomena:

PSAR Section 4.3.3 states that the dynamic response (behaviors) of the reactor vessel and vessel internals during a design basis earthquake are accounted for in the design of the reactor and its internals to ensure their continued functionality during and after an earthquake. The PSAR further states that models are used to understand fluid migration tendencies within the reactor vessel and design the reactor to prevent damage to the vessel during an earthquake. Finally, the PSAR states that the reactor vessel, vessel internals, and vessel attachments are classified as Seismic Design Category (SDC)-3 per ASCE 43-19 “Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities” and are designed such that the safety related SSCs will be protected from the failure of nearby non-safety related SSCs during a design basis earthquake.

The staff notes that dynamic behaviors will be accounted for in the design of reactor vessel and vessel internals to ensure their continued functionality during and after an earthquake, and the reactor vessel and vessel internals are designed such that the safety related SSCs will be protected from the failure of nearby non-safety related SSCs during a design basis earthquake. Based on the design accounting for dynamic behaviors and protecting safety related SSCs, the staff finds that the preliminary information on the reactor vessel system is consistent with PDC 2.

4.3.3.5 PDC 4, Environmental and dynamic effects design bases:

PSAR Section 4.3.3 states that the reactor vessel is designed to account for internal and external static and dynamic loads, including static weight, seismic loads, and forces from the pebble bed, coolant, and core components. The vessel shell is designed to handle internal pressure loads and transfer static and dynamic loads between the top and bottom head to the RVSS. The PSAR states that the RVSS is designed to prevent damage to the decay heat removal system (DHRS) and ensure vessel integrity and position. PSAR Section 4.3.3 states that pipe whip hazards are not a concern because there are no pressurized piping systems near the reactor vessel. Additionally, PSAR Section 4.3.1.1 states that the reactor vessel will be designed and fabricated in accordance with ASME BPVC Section III Division 5. Finally, PSAR Table 4.3-2 provides the methods used to combine the internal and external static and dynamic loads. Thermal expansion considerations are detailed in PSAR Section 4.7 and evaluated by the staff in SE Section 4.7.

The staff reviewed PSAR Table 4.3-2 and finds the load combination methodology conforms to Table 3, “Design Load Combinations,” of RG 1.143, “Design Guidance for Radioactive Waste Management Systems, and Components Installed in Light-Water-Cooled Nuclear Power Plants.” Based on this conformance, the staff considers the methodology acceptable. The staff notes that because the reactor vessel will be designed and fabricated to ASME BPVC Section

III, Division 5, the stresses due to the internal and external static and dynamic loads on the reactor vessel system will be evaluated to meet the ASME BPVC Section III Division 5 requirements. Finally, the staff notes that the absence of pressurized piping in the design precludes the possibility of pipe whip hazards. Based on the load combination methodology, use of ASME BPVC Section III, Division 5, and design features, the staff finds that the preliminary information on the reactor vessel system is consistent with PDC 4.

4.3.3.6 PDC 10, Reactor design:

PSAR Section 4.3.3 states that the vessel and vessel internals define the coolant flow path in order to ensure sufficient core cooling. The PSAR indicates that the vessel needs to resist corrosion of the stainless steel and the graphite reflector blocks need to maintain their spacing to support coolant flow and maintain a coolable core geometry. Additionally, the PSAR states that the reactor vessel system, including the vessel, its supports, and internals, has been analyzed and designed to ensure that vessel integrity and core geometry will be maintained during a design basis earthquake to ensure sufficient passive heat removal.

The PSAR describes the removal of residual moisture from the system prior to coolant fill to limit the corrosion of 316H SS components from the initial fill of Flibe. In addition to removing residual moisture, the PSAR states that coolant purity limits will be set in the OL application and qualification testing to quantify degradation rates that consider impurities in the salt will be provided as described in KP-TR-013-NP-A, Revision 4, approved by the staff. The staff finds that the preliminary information on the reactor vessel system is consistent with PDC 10, in terms of corrosion prevention for SS components, because the coolant purity limits and the removal of residual moisture will help to ensure the integrity of the vessel by limiting corrosion.

The staff notes that the design of the graphite reflectors should consider spacing to mitigate stresses, thermal expansion, and hydraulic forces to ensure gaps between the blocks support coolant flow sufficient to maintain a coolable core geometry. This is important because properties of the graphite and the dimensions of graphite components will change as a function of dose and temperature. The staff finds that the preliminary information on the reactor vessel system is consistent with PDC 10, in terms of graphite reflector spacing and integrity, because consideration of stresses and coolant flow through the graphite reflector will help to ensure there is a coolable core geometry and adequate coolant flow to maintain vessel wall temperature below its design limits. The staff finds the design can achieve this because the graphite properties needed for design (e.g., change in dimensions as a function of dose) will be gathered according to KP-TR-014-NP-A, Revision 4, approved by the staff. Additionally, the staff finds that the preliminary information on the reactor vessel system is consistent with the NUREG-1537 guidance that graphite components should allow for dimensional changes resulting from radiation exposure and thermal expansion to avoid malfunctions of the reflector.

As described in KP-TR-014-NP-A, oxidation testing will be performed to determine the effect of graphite oxidation on the structural integrity of the graphite reflector. The staff finds that this preliminary information regarding graphite oxidation testing is consistent with PDC 10, in terms of graphite reflector structural integrity, because consideration of reduction in strength due to oxidation will allow the reflector to be designed to maintain its shape and structural integrity under air ingress conditions. The staff also finds that this is consistent with NUREG-1537 guidance that graphite components should be compatible with their environment. As noted in Appendix A to the SE, Kairos stated that the OL application will address how the graphite reflector design meets ASME BPVC Section III Division 5 requirements, including departures, if needed, from the ASME BPVC. Kairos also stated the OL application will provide final Flibe purity limits and results of material compatibility testing from KP-TR-013-NP-A, Revision 4, for metallic materials.

PSAR Section 4.3.3 states that the reactor vessel, vessel internals, and vessel attachments are classified as SDC-3 per ASCE 43-19 to account for dynamic behaviors to ensure continued functionality during and after a design basis earthquake event and that the reactor vessel system is protected from the failure of nearby non-safety related SSCs impacting safety related SSCs. Based on the design accounting for dynamic behaviors and the impact of non-safety related SSC failures, the staff finds that the preliminary information on the reactor vessel system is consistent with PDC 10 for dynamic loading analyses. The staff will review the dynamic loading analyses for the final design at the OL stage. Based on the staff evaluation, the staff finds that the preliminary information on the reactor vessel system is consistent with PDC 10.

4.3.3.7 PDC 14, Reactor Coolant Boundary:

PSAR Section 4.3.3 states that the reactor vessel material and weld metal will have an extremely low probability of leakage, rapidly propagating failure, and gross rupture. These materials will be qualified consistent with ASME BPVC Section III, Division 5, and KP-TR-013-NP-A. The vessel will be designed to accommodate operational and transient stresses and monitoring for changes (due to irradiation, thermal effects, corrosion, creep, etc.) to the vessel via inservice inspection and testing to support a 4-year operating life, according to the PSAR. As noted in Appendix A to the SE, Kairos stated that the OL application will provide details on inspection, monitoring, and testing programs for the reactor vessel and internals.

PSAR Table 4.3-2, “Load Combinations for the Reactor Vessel System,” provides the load combination methodology for as-designed operational loads. The load combination methodology will be used to demonstrate that the final design will meet the allowable stress limits per ASME BPVC Section III, Division 5 requirements. The staff evaluation of the load combination methodology is located in the discussion regarding PDC 4, above.

The staff notes that KP-TR-013-NP-A, Revision 4, contains qualification testing to quantify degradation mechanisms applicable to the reactor vessel and was evaluated by the staff for how this qualification testing is consistent with PDC 14. Additionally, the PSAR states that the reactor vessel, welds, attachments, and penetrations are designed to be monitored via inservice inspections as well as catch basins to detect leakage using the plant control system. The staff notes this will provide confirmation of degradation rates and allow for corrective actions, if necessary, to ensure the reactor coolant boundary is maintained. Details of the inspection and monitoring programs, including how the vessel is designed to allow for these programs, will be provided with the OL application and the staff will review them at that time. Based on the qualification testing described in KP-TR-013-NP-A, Revision 4, and the ability of the vessel to be monitored via inservice inspection and leak detection, the staff finds that the preliminary information on the reactor vessel system is consistent with PDC 14. In addition, the staff finds the preliminary information on the reactor vessel system is consistent with the guidance in NUREG-1537 as it will quantify chemical interactions between the coolant and vessel.

4.3.3.8 PDCs 30 and 31, Quality of Reactor Coolant Boundary and Fracture Prevention of the Boundary:

PSAR Section 4.3.3 states that the reactor vessel will be fabricated, erected, and tested in accordance with ASME BPVC Section III, Division 5, as a Class A metallic pressure boundary component to account for stresses up to 750 ^{o}C and that the vessel resists creep, fatigue, thermal, mechanical, and hydraulic stresses. PSAR Chapter 14 contains a proposed safety limit that states reactor vessel surface temperatures will not exceed an upper bound temperature. PSAR Section 4.3.3 also states that catch basins will detect leaks via the plant control system. The PSAR references ASME BPVC Section III, Division 5, which contains stress rupture factors for the 316H SS base metal and ER16-8-2 weld metal, considers creep effects, and provides for reductions in tensile and yield strength as a function of temperature. PSAR Section 4.3.3 indicates that additional testing will be performed as described in KP-TR-013-NP-A, Revision 4, to assess factors such as service degradation of material properties, chemical attack, environmental creep and fatigue, helium (He) embrittlement, and other degradation mechanisms.

The staff notes that the reactor vessel will be designed by analysis using high temperature design methods per ASME BPVC Section III, Division 5, which also accounts for creep and creep-fatigue behaviors. The staff endorsement and evaluation of ASME BPVC Section III, Division 5 are provided in RG 1.87, Revision 2, and its technical basis document, NUREG-2245. In addition, the staff notes that the data contained in ASME BPVC Section III, Division 5, and the planned testing in KP-TR-013-NP-A, Revision 4 will extend the stress rupture values of ER16-8-2 weld metal to match the ASME BPVC Section III, Division 5, values for 316H SS and these values will encompass reactor conditions up to and including postulated accident conditions for the Hermes reactor.

The staff finds that the preliminary information on the reactor vessel system is consistent with PDC 30 because these components will be designed, fabricated, erected, and tested to applicable staff-endorsed ASME Code standards and allow for leakage detection through catch basins tied to the plant control system. The safety related components will conform to the staff-endorsed requirements in ASME BPVC Section III, Division 5, and the remainder of the PHTS will conform to ASME B31.3 Code, “Process Piping,” which is evaluated in SE Chapter 5.

PSAR Section 4.3.3 states that the design of the vessel head will minimize air ingress into the cover gas space, which will minimize corrosion of vessel internals, and that coolant purity limits will be established with consideration to chemical attack and fouling of the vessel. The staff notes that in addition to the KP-TR-013-NP-A, Revision 4, qualification testing, it is appropriate to minimize air ingress into the cover gas in order to mitigate corrosion and set purity limits to reduce chemical attack and fouling.

As noted in Appendix A to this SE, Kairos stated that the OL application will contain analysis to demonstrate how the design of the reactor vessel system considers materials aging and performance consistent with ASME BPVC Section III, Division 5, requirements and the results of the proposed qualification testing in KP-TR-013-NP-A, Revision 4.

The staff notes that RG 1.87, Revision 2, limits the use of stress rupture values for 316H SS at certain temperatures and durations. However, as discussed in KP-TR-013-NP-A, Revision 4, the time the vessel will experience an elevated temperature during a postulated event is consistent with the staff endorsement of ASME BPVC Section III, Division 5, in RG 1.87, Revision 2. The staff finds these temperature limits will be met, and reactor vessel integrity maintained, because PSAR Chapter 14 contains a proposed safety limit to ensure the reactor vessel surface temperature does not exceed a maximum value under any condition of operation. SE Section 4.5 evaluates reactor vessel fluence calculations, which are generally consistent with values found in KP-TR-013-NP-A, Revision 4. Based on the evaluation above regarding conformance to ASME Code, additional qualification testing, air ingress minimization, temperature limits, and fluence calculations, the staff finds that the preliminary information on the reactor vessel system is consistent with PDC 31. The staff also finds that the preliminary information is consistent with NUREG-1537 criteria associated with assessing irradiation and chemical damage, minimizing corrosion, ensuring chemical compatibility between the components in the primary coolant system and the coolant, and mechanical and hydraulic stresses during operation.

4.3.3.9 PDC 32, Inspection of Reactor Coolant Boundary:

PSAR Section 4.3.3 describes how coupons and component monitoring will examine irradiation-assisted corrosion. In addition, it states that the vessel and weld material will be inspected for structural integrity and leak tightness. The PSAR also states that fracture toughness for 316H SS is sufficiently high, as discussed in ASME BPVC Section III, Division 5, that additional surveillance or testing for fracture toughness is not needed.

The staff notes that coupons and component monitoring are reliable and appropriate methods to identify irradiation-assisted corrosion. Additionally, the PSAR states that vessel and weld material will be designed to allow for online monitoring, inservice inspection, and maintenance. The fracture toughness properties of the vessel material are evaluated in NUREG-2245 for ASME BPVC Section III, Division 5, allowable stresses, and KP-TR-013-NP-A, Revision 4, for additional tests to examine environmental effects on 316H SS failure modes. Based on the planned qualification testing and use of coupons and monitoring, the staff finds that the preliminary information on the reactor vessel is consistent with PDC 32, which requires periodic inspections, monitoring, or testing of important areas, and an appropriate material surveillance program for the vessel. The staff also finds that the preliminary information on the reactor vessel system is consistent with guidance in NUREG-1537 to have a plan to assess irradiation of vessel materials. At the OL stage, the staff will evaluate the final design of the reactor vessel to confirm whether the fracture toughness is sufficiently high under operating conditions to not need a material surveillance program as well as to evaluate how vessel integrity will be assured through monitoring and inspection programs and confirm the vessel is designed to allow for those programs.

4.3.3.10 PDC 33, Reactor Coolant Inventory Maintenance:

PSAR Section 4.3.3 states that there are anti-siphon features to limit loss of reactor coolant in the event of breaks in the PHTS cold leg. The staff evaluation of PDC 33 and the relevant NUREG-1537 guidance is provided in SE Chapter 5.

4.3.3.11 PDC 34, Residual Heat Removal:

PSAR Section 4.3.3 describes how the reactor vessel internals design supports decay heat removal during normal operations (forced flow) and postulated events (natural circulation) by ensuring an appropriate coolant flow path in either situation. Since the design maintains a pathway for the coolant both in conjunction with the PHTS for forced flow in normal operation and via the fluidic diodes to maintain natural circulation in postulated events, the staff finds that the preliminary information on the reactor vessel internals is consistent with PDC 34.

SE Section 4.6 provides the staff evaluation of the thermal-hydraulic aspects of PDC 34. The broader evaluation of the functionality of the DHRS is provided in SE Section 6.3 and SE Chapter 13. Additionally, the staff evaluation of the anti-siphon device to ensure the loss of reactor coolant is limited during a postulated PHTS breach is provided in SE Chapter 5.

4.3.3.12 PDCs 35, 36, and 37, Passive Residual Heat Removal, Inspection and Testing of Passive Residual Heat Removal:

PSAR Section 4.3.3 describes how the fluidic diodes establish a flow path for natural circulation of the coolant during postulated events. The PSAR states that this prevents damage to vessel internals from overheating and ensures coolable geometry of the core. The PSAR states that the fluidic diode will be constructed of stainless steel and the design temperature and fluence should be bound by the qualification testing in KP-TR-013-NP-A, Revision 4.

PSAR Section 4.3.3 further describes the inspection and monitoring capabilities of the components needed to ensure passive residual heat removal. Temperature monitoring at the exit of the reactor vessel will be used to confirm functional capability of the normal flow path. The PSAR states that the fluidic diode and diode pathway will be subject to temperature monitoring during normal operation to provide assurance the natural circulation flow path is available when needed. In addition, there will be inspection ports that allow visual inspection of the fluidic diodes to ensure that the natural circulation flow path is maintained.

The staff finds that the preliminary information on the reactor vessel system is consistent with PDC 35 because the fluidic diode and reactor design allow for a passive natural circulation flow path that can be monitored and fluidic diode integrity will be ensured by planned qualification testing as well as the ability to inspect the fluidic diode. The staff finds that the preliminary information on the reactor vessel system is consistent with PDCs 36 and 37 because it allows for the inspection of the fluidic diodes, monitoring of the fluidic diode pathway, and monitoring of the normal flow path to ensure the design function of passive residual heat removal is maintained. SE Section 4.6 provides the staff evaluation of the thermal-hydraulic aspects of PDC 35.

4.3.3.13 PDC 74, Reactor Vessel and Reactor System Structural Design Basis:

PSAR Section 4.3.3 describes how the graphite reflector allows for insertion of reactivity control and shutdown elements and also provides a coolant flow path. The PSAR also states that the graphite reflector will be qualified as described in KP-TR-014-NP-A, Revision 4. The reflector will be designed to meet ASME BPVC Section III, Division 5, rules related to graphite components, consistent with the staff's endorsement found in RG 1.87, Revision 2.

The staff's evaluation of neutronic characteristics of the reflector is contained in SE Section 4.5.

KP-TR-014-NP-A, Revision 4 includes qualification testing to gather the data necessary to design the reflector, including chemical, mechanical, irradiation and thermal effects. The staff notes that this data will allow the reflector to be designed so that operating conditions and environmental effects on the integrity of the reflector can be appropriately assessed and accounted for at the OL stage. The staff finds that this preliminary information on the reactor vessel system is consistent with guidance in NUREG-1537 that states the reflector should be compatible with its chemical, mechanical, irradiation, and thermal environments, and that the reflector should be compatible with the reactor coolant so that it will not affect safe operation, shutdown, or cause an uncontrolled release of radioactivity. Because the graphite reflector components will be designed based on properties developed through qualification testing, the staff also finds that the preliminary information on the graphite component design is consistent with PDC 74, in terms of maintaining a physical geometry for the reactor core to support core cooling and heat removal and providing a pathway for reactivity element insertion.

The staff also evaluated the information provided for the design of the graphite reflector. Based on its evaluation, the staff finds that the reflector will be designed to perform its safety functions because the reflector will be designed to meet ASME BPVC Section III, Division 5, requirements related to graphite components, which requires a graphite component be designed to meet reliability targets based on stress limits. It also requires that the design account for the full range of operating conditions (i.e., temperature and fluence) as well as environmental effects (i.e., coolant, oxidation, abrasion, erosion) to which the graphite will be exposed. ASME BPVC Section III, Division 5 also requires an analysis of stresses that will be imparted on the graphite and calculation of a probability of failure for graphite components. Criteria to develop loadings for graphite components based on several factors, including thermal stresses and irradiation-induced stresses, are specified by ASME BPVC Section III, Division 5. The staff finds the preliminary information on the graphite component design is consistent with PDC 74 because it will be designed consistent with the staff-endorsed requirements of ASME BPVC Section III, Division 5.

The staff evaluated the proposed thermal mapping of the graphite reflector that will be performed using thermocouples. The staff notes this information will allow for operational verification that the qualification envelope (i.e., temperature-fluence combinations) is not exceeded during operations. Based on its review, the staff finds that this preliminary information is consistent with the guidance in NUREG-1537 to include appropriate design limits and surveillance requirements for the reflector. The staff will review final design limits, limiting conditions for operation, and surveillance requirements in the OL application.

PSAR Section 4.3.3 states that the reactor vessel, vessel internals, and RCSS are classified as SDC 3 under ASCE 43-19 for the seismic design and will maintain geometry to ensure RCSS elements can be inserted during earthquakes and other postulated events. PSAR Table 4.3-2, "Load Combinations for the Reactor Vessel System," provides the load combinations for the reactor vessel system, including seismic loads. The staff notes that the stresses due to the applicable loads on the reactor vessel system will be evaluated to meet the ASME BPVC Section III, Division 5 requirements. Based on the load combination methodology and use of staff-endorsed requirements from ASME BPVC Section III, Division 5, the staff finds that the preliminary information on the design of the reactor vessel system is consistent with PDC 74 in terms of reactor vessel and internals structural design.

4.3.3.14 Testing and Inspection

PSAR Section 4.3.4 states that any tests and inspections of the reactor vessel and internals will be included with the submission of the OL application. However, the staff notes that the PSAR states that the design of the reactor vessel and vessel internals allows for access for monitoring, inspection, and maintenance, which is important for demonstrating consistency with PDC 32, 35, 36, and 37, as noted in those PDCs above.

The testing and surveillance program will be submitted as part of the OL application and evaluated at the OL stage. These programs will be tracked in Appendix A of this SE and evaluated during the OL application review.

4.3.4 Conclusion

Based on the information provided by Kairos and the staff evaluation documented above, the staff finds that Kairos provided sufficient preliminary information in accordance with 10 CFR 50.34(a) to develop a reactor vessel system design. Therefore, the staff has reasonable assurance that the reactor vessel system will perform its safety functions of maintaining structural integrity, geometry, and coolant inventory to ensure sufficient heat removal and control element insertion for reactor shutdown. The staff concludes that the preliminary information provided for the reactor vessel system is adequate at this stage of the design and is consistent with PDCs 1, 2, 4, 10, 14, 30, 31, 32, 33, 34, 35, 36, 37, and 74 and with the acceptance criteria of NUREG-1537, Part 2, Section 4.3, "Reactor Tank or Pool."

Based on its findings above, the staff concludes the information in Hermes PSAR Section 4.3, as supplemented by the response to RAI 339, is sufficient and meets the applicable guidance and regulatory requirements identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Further information as may be required to complete the review of Hermes reactor vessel system can reasonably be left for later consideration at the OL stage since this information is not necessary for the review of a CP application.

4.4 Biological Shield

4.4.1 Introduction

PSAR Section 4.4 provides preliminary design information on the biological shield, including its design bases. The biological shield functions to protect plant workers and the public from radiological exposure as well as to reduce radiation damage to plant equipment. The biological shield also reduces the potential exposure of plant workers to beryllium, should there be a coolant leak. The biological shield is made up of a primary biological shield, which surrounds the reactor vessel, and a secondary biological shield which encloses the primary heat exchanger and the inventory management system. The primary and secondary biological shields are composed of reinforced concrete.

4.4.2 Regulatory Evaluation

The requirements in the common regulatory evaluation for reactor systems apply to the biological shield design.

As described in SE Section 1.1.2, the staff did not evaluate whether requirements in 10 CFR Part 20 would be met for the construction of the Hermes reactor. Instead, the staff assessed whether Kairos identified the relevant requirements for an operating facility and provided descriptions of the preliminary facility design. The staff assessed this to determine whether the PSAR provides an acceptable basis for the development of systems and whether there is reasonable assurance that Kairos will comply with the regulations in 10 CFR Part 20 during Hermes facility operation.

The applicable guidance for evaluating the Hermes biological shield design are as follows:

- NUREG-1537, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors," Part 1, "Format and Content," and Part 2, "Standard Review Plan and Acceptance Criteria," Section 4.4, "Biological Shield."

4.4.3 Technical Evaluation

The staff evaluated the Hermes biological shield as described in the PSAR to determine whether the objectives of the shield design basis are sufficient to protect the health and safety of the public and facility staff, and whether it is reasonable to conclude that the final design will achieve the design bases.

PSAR Section 4.4 describes the biological shield design and design basis at a high level and states that the biological shield is provided for worker protection to meet 10 CFR Part 20 requirements. PSAR Figure 4.4-1, “Primary and Secondary Biological Shield,” provides a drawing of the location of the biological shield and the SSCs that are contained within the shield. PSAR Section 4.4.3 states that an evaluation of the biological shield’s performance to meet the requirements of 10 CFR Part 20 will be provided with the OL application.

The biological shield is classified as a safety related component as indicated in PSAR Chapter 3, Table 3.6-1, “Structures, Systems, and Components.” Note 2 of this table indicates that the function of the biological shield is not safety related. However, the physical structure of the biological shield is a safety related element for reactor building structural support and external event protection reasons. The biological shield is classified as SDC 3 in accordance with ASCE 43-19 for the seismic design, which means the structure is designed with the intent to ensure that the reactor can be shut down and maintained in a safe condition and maintain its safety function in the event of a design basis earthquake. The staff’s evaluation of the design bases for safety related systems and components, including the biological shield structure, is discussed in SE Section 3.6.

The staff evaluated the sufficiency of the preliminary information on the Hermes biological shield using the guidance and acceptance criteria from Section 4.4 of NUREG-1537, Part 2, with respect to the radiation shielding design, specifically the principal objective to ensure that the projected radiation dose rates and accumulated doses in occupied areas do not exceed the limits of 10 CFR Part 20 and the guidelines of the facility as low as is reasonably achievable (ALARA) program. During the general audit (ML23160A287), Kairos confirmed to the staff that they had developed preliminary shielding design analyses, including consideration of radiation sources, types of shielding materials, and shielding dimensions to support the information in the PSAR on the biological shield and associated design bases. The staff’s overall review of the acceptability of the Hermes preliminary design with respect to radiation protection and ALARA, including radiation sources, is discussed in SE Section 11.1. The staff will confirm that the final design conforms to the design basis during the evaluation of the Hermes OL application. Therefore, the staff finds that Kairos’s descriptions of the biological shield preliminary design and design bases is consistent with the applicable acceptance criteria from NUREG-1537.

4.4.4 Conclusion

Based on its review discussed above, the staff concludes the information in Hermes PSAR Section 4.4 is sufficient and meets the applicable guidance and regulatory requirements identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Further information, as may be required to complete the review of Hermes biological shield, can reasonably be left for later consideration at the OL stage since this information is not necessary for the review of a CP application.

4.5 Nuclear Design

4.5.1 Introduction

PSAR Section 4.5, “Nuclear Design,” describes the Hermes nuclear design, including core design, fuel and moderator pebbles, reactor coolant, and graphite reflectors for neutron moderation and shielding. PSAR Section 4.2.1 states that the reactor core is comprised of a packed bed of spherical fuel pebbles and spherical moderator pebbles. PSAR Section 4.5.1.1 states that each fuel pebble contains approximately 6 grams of uranium, and the moderator pebbles are made entirely of graphite matrix material. The reactor core contains approximately 36,000 pebbles (fueled and moderator). The core is roughly 60 percent pebbles and 40 percent reactor coolant by volume. Neutron moderation is provided by a graphite reflector, which also increases neutron economy and shields the reactor structures from fast neutrons, moderator pebbles, graphite in the fueled pebbles, and the reactor coolant, Flibe. The core is slightly under-moderated during all operating conditions.

PSAR Section 4.5.1.1 states that the reactor is continuously refueled with fresh pebbles and with recirculated pebbles that have not yet reached their design burnup. Pebbles are introduced at the bottom of the core and transit slowly to the top of the core in approximately 30 to 50 days where they exit to the PHSS. The pebbles make multiple passes through the core during their lifetime before reaching the design burnup. The total residence time of a fuel pebble in the core at equilibrium is approximately 316 days. As pebbles exit the core, they are examined for burnup and potential physical damage.

PSAR Section 4.5.1.1 states that there are four main periods of core operation: startup, power ascension, transition to equilibrium, and equilibrium operation. Startup is defined as the approach to criticality. The reactor may initially be started up with a mixture of fuel pebbles with natural uranium, fuel pebbles with enrichments ranging from 10 to 15 wt% U-235, and moderator pebbles. PSAR Section 4.5.1.1 states that the initial startup and power ascension will be discussed in the OL application. Power ascension is the process of increasing to full power and can be characterized in two phases: Low Power (0-10 percent of full power) and Ascension to Full Power (10-100 percent of full power). During the transition to equilibrium, the natural uranium pebbles will be gradually replaced by fresh pebbles until all fuel pebbles contain particles of just under 20 wt% U-235. The PSAR states that equilibrium operation is achieved when the radionuclide inventory in the core is no longer changing, the ratio of insertion of fuel and moderator pebbles is stable, the enrichment of the fresh pebbles being inserted into the core is not changing, and control elements are not repositioning (or are very minimally engaged).

4.5.2 Regulatory Evaluation

The requirements in the common regulatory evaluation for reactor systems apply to the nuclear design. Additional regulatory requirements for the nuclear design are as follows:

- 10 CFR 50.34, "Contents of applications; technical information," paragraph (a), "Preliminary safety analysis report."
  - 10 CFR 50.34(a)(3)(ii) requires "The design bases and the relation of the design bases to the principal design criteria."
  - 10 CFR 50.34(a)(3)(iii) requires "Information relative to materials of construction, general arrangement, and approximate dimensions, sufficient to provide reasonable assurance that the final design will conform to the design bases with adequate margin for safety."

The applicable guidance for the evaluation of Hermes nuclear design is as follows:

- NUREG-1537, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors,” Part 1, “Format and Content,” and Part 2, “Standard Review Plan and Acceptance Criteria,”, Section 4.5, “Nuclear Design”

4.5.3 Technical Evaluation

PSAR Section 4.5.2, “Design Basis,” identified the design bases for the Hermes nuclear design. The PSAR states that the following PDCs are applicable to the nuclear design:

- PDC 10, “Reactor design.”
- PDC 11, “Reactor inherent protection,” which requires the core to be designed with prompt inherent nuclear feedback characteristics to compensate for a rapid increase in reactivity.
- PDC 12, “Suppression of reactor power oscillations,” which requires the reactor core be designed to ensure power oscillations that can result in conditions that exceed SARRDLs are not possible or can be reliably and readily detected and suppressed.
- PDC 26, “Reactivity control systems.”

4.5.3.1 Analytical Methods

PSAR Section 4.5.1.6 states that the core design methods include the Serpent 2, STAR–CCM+, KPACS, and KPATH computer codes. The staff reviewed the core design methodology in KP-TR-017-NP, “KP-FHR Core Design and Analysis Methodology.” Kairos uses a core design code package that includes Serpent 2 and STAR–CCM+. Serpent 2 is a three-dimensional continuous-energy Monte Carlo particle (neutrons and gammas) transport code, and STAR–CCM+ is a computational fluid dynamics code. Serpent 2 is used to calculate power distribution, reactivity coefficients, element worth, shutdown margin, kinetic parameters, depletion, and vessel fluence. STAR–CCM+ is used to calculate material temperature distributions. STAR–CCM+ also has a Discrete Element Method (DEM) methodology used to calculate pebble distribution, the pebble flow profile, and the residence time in the core. Serpent 2 and STAR–CCM+ are coupled together to output power distributions and material temperature distributions.

The staff finds that the use of STAR–CCM+ associated with the Hermes core design methodology is appropriate for this preliminary design stage because:

1. STAR–CCM+ is capable of calculating material temperature distributions and steady-state heat transfer and fluid flow in a 3D porous media model for a pebble bed fluoride salt cooled high temperature reactor, as shown by Hu, et al. (2020), which showed reasonable agreement between STAR–CCM+ and SAM,
2. DEM methodologies have been used for porous media models by Hu, et al. (2020) and shown to provide reasonable predictions,
3. STAR–CCM+’s DEM is capable of calculating pebble distribution, the pebble flow profile, and the residence time in the core, for a pebble bed fluoride salt cooled high temperature reactor, as shown by Hu, et al. (2020), which showed reasonable agreement between STAR–CCM+ and SAM,
4. STAR–CCM+ is not directly being used to calculate figures of merit, only used to calculate intermediate temperature values to pass to the code used via coupling, and
5. NRC scoping calculations (discussed in SE Chapter 13) showed reasonable agreement with Kairos’s preliminary transient analyses provided in the PSAR.

As part of the OL application, the staff will perform a review of STAR–CCM+ code and its capability and applicability to the Hermes design.

The staff finds that the use of Serpent 2 associated with the Hermes core design methodology is appropriate for this preliminary design stage because:

1. Serpent 2 is capable of calculating power distribution, reactivity coefficients, element worth, shutdown margin, kinetic parameters, depletion, vessel fluence, neutron and gamma transport in a 3D geometry, and is capable of accounting for the double-heterogeneity of TRISO particles and pebbles.
2. Serpent has been used to model a pebble bed fluoride salt cooled high temperature reactor in Maul, et al. (2016), which showed reasonable agreement between Serpent 2 and other neutronics codes, MCNP and SCALE.
3. NRC scoping calculations (discussed in SE Chapter 13) showed reasonable agreement with Kairos's preliminary transient analyses provided in the PSAR.

As part of the OL application, the staff will perform a review of Serpent 2 code and its capability and applicability to the Hermes design.

While the staff reviewed uncertainties in models, the staff did not make any findings on Kairos's validation and verification plan of codes or derivations of uncertainties because it is not required or necessary for the issuance of a CP. Kairos's validation and verification of codes and derivations of uncertainties will be reviewed during the OL application.

While the staff reviewed Kairos's PIRT given in KP-TR-017-NP, Section 2.5, "Phenomena identification and ranking table," the staff did not make any findings on Kairos's PIRT because it is not required or necessary for the issuance of a CP. Kairos's PIRT will be reviewed during the OL application.

Based on the technical discussion above, the staff finds that the preliminary information for the analytical methods for nuclear design is consistent with the guidance in NUREG-1537 for this preliminary design stage. The staff notes that it will review specific details of Kairos's validation and verification plan of codes and derivations of uncertainties as part of its review of Kairos's OL application.

Analytical methods with respect to the transient analyses are discussed in SE Section 13.1.2, "Insertion of Excess Reactivity." Further discussion on thermal-hydraulic methodology is in SE Section 4.6, "Thermal-Hydraulic Design."

4.5.3.2 Power Distribution

Kairos states in KP-TR-017-NP Section 1.2.2, "Principal Design Criteria," that core power distributions are an input to Kairos's fuel performance calculations for demonstrating that SARRDLs will satisfy PDC 10, which provides that the reactor core be designed to ensure SARRDLs are not exceeded. Kairos states in KP-TR-017-NP Section 3.2, "Modeling Paradigm," that their explicit neutronic model of the core is used to inform their thermal-hydraulic modeling power distribution used to provide materials' temperatures feedback for reactivity calculations and power distributions. KP-TR-017-P Figure 3-1 shows that Serpent 2 is used to calculate the power distribution in the core and that STAR–CCM+ is used to calculate material temperature distributions. KP-TR-017-P Section 4.2.3, “KPATH,” states that Serpent 2 and STAR–CCM+ exchange these distributions until convergence criteria are met.

In KP-TR-017-NP, Kairos states that axial peaking factor, radial peaking factor, and total peaking factor are used to characterize the core power distribution. Pebble-by-pebble peaking factors are calculated by tallying fission power from Serpent 2 in each pebble and dividing by the average power per pebble in the core. Also, in KP-TR-017-NP Section 2.4, “Operational regimes,” Kairos states that neutron flux distributions will be verified during startup using ex-core detectors.

The staff also performed scoping calculations for transient analyses, which included calculating power distributions, axial peaking factors, radial peaking factors, and total pebble peaking factors. The scoping calculations showed reasonable agreement with Kairos’s preliminary calculations of power distribution and total pebble peaking factors. The staff will review and verify the acceptability of the final design at the OL stage. While this is not needed to directly support the staff finding for PDC 10, the staff also notes that Kairos will perform neutron flux distribution verification tests during startup and that Kairos has a means to monitor power, as discussed below in “Monitoring” of SE Section 4.5, which will allow Kairos to infer that the power distribution remains within limits.

Based on the acceptable core design methodology, as discussed above in SE Section 4.5 “Analytical Methods,” and the transient analysis methodology, as discussed in SE Chapter 13, and the reasonable agreement between Kairos’s calculations and staff scoping calculations, the staff finds the preliminary information on the Hermes nuclear design is consistent with PDC 10. The staff will review the core design methodology, including details of core boundaries and Flibe composition, as part of its review of Kairos’ OL application to verify the acceptability of the final design.

4.5.3.3 Shutdown Margin

PDC 26 states that a minimum of two reactivity control systems must provide:

1. A means of inserting negative reactivity to ensure SARRDLs are not exceeded and safe shutdown is achieved and maintained.
2. A means which is independent and diverse from the other(s), capable of controlling the rate of reactivity changes resulting from planned, normal power changes to assure that the SARRDLs are not exceeded.
3. A means of inserting negative reactivity to assure that the capability to cool the core is maintained and a safe shutdown condition is maintained following a postulated event.
4. A means for holding the reactor shutdown under conditions which allow for interventions such as fuel loading, inspection and repair.

PSAR Section 4.5.1.4 states that shutdown margin is defined for the most limiting core at the reactor coolant freezing temperature. The shutdown margin design criterion is that k-effective must be less than 0.99. KP-TR-017-NP states that shutdown margin is maintained at all core states. PSAR Section 4.5.1.4 states that shutdown margin calculations assume the single most reactive shutdown element to be fully withdrawn from the core and accounts for power defect, xenon decay, operating excess reactivity, and margin for uncertainties. Control element worth is calculated from changes in neutron multiplication factor of the core resulting from perturbing the elements' axial positions in Serpent 2. As discussed in KP-TR-017-NP Section 2.4 Kairos will perform source range control element worth testing.

In the following three paragraphs, the staff describes the various aspects of PDC 26 and how they apply to the Hermes design.

In the Hermes design, PDC 26 Conditions 1 and 3 address the safety related function of negative reactivity insertion used to evaluate the Chapter 13 postulated events (i.e., the SCRAM curve). In the Hermes design this safety related function is met by the insertion of the shutdown elements into the pebble bed reactor core. Condition 1 addresses the insertion of sufficient negative reactivity so the SARRDLs are not violated, and safe shutdown is achieved and maintained. Condition 3 is similar, but the SARRDL criterion is replaced with the capability to cool the core, which is less restrictive, followed by a safe shutdown after the postulated event (i.e., shutdown in long-term). For a power reactor application, Condition 3 was created to apply a less restrictive criterion to a less frequent event (i.e., accidents). For non-power reactors, the event frequency is not considered, and only postulated events are evaluated; hence, satisfying Condition 1 satisfies Condition 3. Kairos states in PSAR Section 4.5.3.1 that Condition 1 is met and hence so is Condition 3.

The staff notes that PDC 26 Condition 2 states there should be a means, which is independent and diverse from others, capable of controlling the rate of reactivity changes from planned, normal power changes to assure the SARRDLs are not exceeded. Condition 2 refers to normal plant power changes using a method or system of reactivity control which differs from that used to satisfy Conditions 1 and 3. The staff notes that, in the Hermes design, the normal operation reactivity control function is satisfied by the control elements which are independent and diverse from the shutdown elements. The staff also notes that the control and shutdown elements are independent and diverse based on differences in (1) input signals (though both receive a trip signal from the RPS, which is conservative because control elements provide additional negative reactivity upon a trip), (2) the control mechanisms (motor-driven vs gravity), and (3) insertion geometries (reflector vs pebble bed).

PDC 26 Condition 4 refers to keeping the reactor shutdown, typically at a lower temperature, such that plant maintenance, inspections, and refueling activities can occur. The inserted negative reactivity should be sufficient to prevent a return to power at the conditions which correspond to these activities. In the Hermes design this is achieved by the safety related shutdown elements. To address PDC 26 Condition 4, PSAR Section 4.5.3.1 states that shutdown elements provide a means for maintaining the reactor shutdown to allow for interventions such as fuel loading, inspection, and repair.

Based on its review, the staff finds that the preliminary level of detail provided on Hermes shutdown margin is adequate at this stage of the design and is consistent with PDC 26 because (1) the shutdown margin is sufficiently high, (2) the shutdown margin calculation methodology assumes the single most reactive control or shutdown element to be fully withdrawn from the core, which is conservative, (3) the element worth calculation methodology is sufficient, and (4) Kairos will perform source range control element worth testing. The staff also finds that the preliminary information is consistent with the relevant acceptance criteria from NUREG-1537, which states that the design should analyze and justify a minimum negative reactivity to ensure safe reactor shutdown. The staff notes that, while specific details of shutdown margin are not needed to issue a CP, the staff will review specific details of the shutdown margin in an OL application, so that the staff can review and verify the acceptability of the final design.

4.5.3.4 *Reactivity Coefficients*

PDC 11 requires that the reactor core and associated systems be designed such that the net effect of the prompt inherent nuclear feedback characteristics tends to compensate for a rapid increase in reactivity in the power operating range.

PSAR Section 4.5.1.2 states that important reactivity coefficients include fuel temperature, moderator temperature, coolant temperature, coolant void, and reflector temperature. The fuel and reflector temperature reactivity coefficients, respectively, are the change in reactivity due to a fuel or reflector temperature change. The moderator temperature reactivity coefficient is the change in reactivity due to the change in temperature in fuel pebble graphite and graphite pebbles. The coolant temperature reactivity coefficient is the change in reactivity due to a change in reactor coolant temperature (accounting for density changes, as well). Finally, the coolant void reactivity coefficient is the change in reactivity due to a change in coolant void fraction. KP-TR-017-NP Section 5.2.3 states that reactivity coefficients are calculated from changes in neutron multiplication factor of the core resulting from changing temperatures in Serpent 2.

PSAR Section 4.5.3.1, “Evaluation of Design Bases,” states the following relative to the reflector reactivity coefficient:

> The reflector reactivity coefficient is the result of spectrum hardening at the periphery of the core due to increased reflector temperature. This change in spectrum reduces the fission rate next to the reflector and shifts flux more towards the inner part of the core, effectively reducing leakage. This effect combined with local over-moderated conditions ultimately leads to a positive feedback coefficient.

The PSAR further states that the reflector reactivity coefficient is conservatively calculated because thermal expansion of the reflector is not assumed, which would provide negative reactivity feedback.

The staff notes that all reactivity coefficients are negative during startup and equilibrium except the reflector coefficient, which is slightly positive during both startup and equilibrium. The reflector coefficient’s positivity is due to local spectral hardening with increasing temperature, which decreases the fission rate in fuel adjacent to the reflector and pushes flux to the interior of the core. This effect reduces neutron leakage and, combined with locally over-moderated conditions contributes to a slightly positive reactivity effect. The staff further notes that this calculation conservatively does not account for thermal expansion of the reflector due to temperature increase, which would increase leakage and contribute a negative reactivity effect. Most importantly, the staff notes that the *overall* reactivity coefficient is substantially negative, which is consistent with PDC 11. In KP-TR-017-NP Section 2.4, Kairos states that once criticality is achieved and at zero power, isothermal reactivity coefficient testing will be performed. The staff notes that this will allow for confirmation of the expected overall negative reactivity feedback behavior.

As part of scoping calculations performed by the staff to assist in review of the transient analyses, the SCALE/KENO code was used to evaluate reactivity coefficients. These calculations showed general agreement with Hermes reactivity coefficients and provide an additional degree of assurance that the underlying physics are modeled correctly by Kairos. Based on the overall negative reactivity coefficient, the planned isothermal reactivity coefficient testing, and the scoping calculations, the staff finds that the preliminary information on the

Hermes nuclear design is consistent with PDC 11. The staff also finds that the preliminary information is consistent with the applicable acceptance criteria of NUREG-1537, Part 2, Section 4.5, "Nuclear Design" because the overall reactivity feedback is negative, Kairos's calculation methodology is adequate, Kairos will perform reactivity coefficient testing, and staff scoping calculations showed reasonable agreement. The staff will review details of the graphite density of the core structure and reflector and the Flibe composition in an OL application, so that the staff can review and verify the acceptability of the final design. This may include conducting additional scoping calculations with increased model similarity to allow the staff to calculate more accurate reactivity coefficients.

4.5.3.5 Nuclear Stability

PDC 12 requires that the reactor core, associated structures, and associated coolant, control, and protection systems be designed to ensure that power oscillations that can result in conditions exceeding SARRDLs are not possible or can be reliably and readily detected and suppressed. PSAR Section 4.5.3.1 states that the nuclear characteristics of the reactor, including its small size and long diffusion length of neutron in the core, make it inherently stable with regard to both axial and radial power oscillations.

Based on the inherent nuclear characteristics of the Hermes reactor, the staff finds that the preliminary information on the Hermes nuclear design is consistent with PDC 12. The staff notes that it will review specific details of Hermes's nuclear stability with an OL application to demonstrate compliance with PDC 12.

4.5.3.6 Vessel Irradiation

SE Section 4.3 provided the staff's evaluation of reactor vessel integrity. Part of the reactor vessel integrity evaluation in SE Section 4.3 covers the effects of neutron irradiation on reactor vessel integrity and includes a reference to this evaluation of estimated neutron fluence on the reactor vessel.

PSAR Section 4.5.3.2 states that the fast neutron fluence on the reactor vessel is attenuated by the core barrel, reflector, and the reactor coolant. The methodology for calculating best estimate vessel fluence includes the use of conservative uncertainties. PSAR Section 4.5.3.2 states that the preliminary calculations of best estimate of displacements per atom in the reactor vessel, including uncertainty, is within 30 percent of the low-level irradiation value discussed in KP-TR-013-NP-A, Revision 4. KP-TR-017-P Section 5.2.8 states that Serpent 2 is used to calculate the fast neutron fluence and the alpha generation (for He embrittlement) on the reactor vessel received from the reactor core and pebble insertion and extraction lines.

Based on the staff's review of Serpent 2 discussed above and Serpent 2's ability to calculate vessel fluence, the staff finds that the information provided on Hermes vessel fluence calculations is appropriate for the preliminary design stage associated with a CP in support of the broader staff evaluation of the effects of neutron irradiation on reactor vessel integrity in SE Section 4.3. The staff notes that while specific details of the vessel fluence calculations are not needed to issue a CP, the staff will review specific details of the vessel irradiation calculations provided in an OL application.

4.5.3.7 *Nuclear Transient Parameters/Nuclear Transient Analysis*

The staff's evaluations of transient analyses are described in SE Chapter 13, including transients involving inadvertent movement and flooding, which are both discussed in SE Section 13.1.9. PSAR Section 4.5.3.2 describes the nuclear transient analysis approach in support of the Chapter 13 transient analyses. PSAR Table 4.5-7 provides values for neutron generation time and delayed neutron from during startup and equilibrium. KP-TR-017-NP Sections 4.1.2 and 5.2.5 state that Hermes's delayed neutron fraction and prompt neutron lifetime are calculated using Serpent 2 and are used as inputs to the Hermes point kinetics model for transient analysis.

The staff notes that Kairos indicates plans to perform uncertainty analyses for nuclear transient parameters as described in KP-TR-017-NP Section 6, "Uncertainty analysis and nuclear reliability factors."

Based on its review and Kairos's plans for further uncertainty analyses in support of the final design, the staff finds that the preliminary information provided for nuclear transient analysis, including the neutron mean lifetime, neutron mean generation time, and delayed neutron fraction groups and their decay constants during startup and equilibrium operation, are consistent with the applicable acceptance criteria from NUREG-1537, which states that analyses should show that control system with prevent loss of fuel integrity or uncontrolled reactivity addition. The staff notes that while specific details of the nuclear transient parameters are not needed to issue a CP, the staff will review specific details of the nuclear transient parameters in an OL application.

4.5.3.8 *Nuclear Core Design Limits*

The staff's evaluation of the nuclear core design limits, which include burnup, peak fuel temperature, peak particle power, and peak fluence, is discussed in SE Section 4.2.1.

4.5.3.9 *Monitoring*

PSAR Section 4.5.4.2 states that neutron flux and burnup will be monitored during normal operation and startup to ensure that the core is performing within the design limits. PSAR Section 7.3.1 states that neutron flux will be monitored using four power range ex-core detectors located in azimuthally symmetric locations outside the reactor vessel at mid-core elevation and four source range ex-core detectors located in relation to the startup source for best detectability of criticality. PSAR Section 7.3.1 further states that during normal operation, the power range and source range ex-core detectors will be used to monitor core power and will be used as input for the flux rate trip signal. The source range ex-core detectors will also be used during reactor startup. PSAR Section 9.3.1.5 states that a gamma spectrometer will be used to evaluate fuel pebble burnup relative to a maximum burnup limit. The PSAR states that the final design for the neutron flux and burnup monitoring will be provided with the OL application.

Since Kairos will perform neutron flux distribution verification tests during startup and Kairos has a means to monitor power, which will allow Kairos to infer that the power distribution remains within limits, the staff finds that the preliminary information on Hermes monitoring for neutron flux is consistent with PDC 10. While the staff is aware Kairos plans to include burnup monitoring in the final design and mentions it in the PSAR, the staff did not make any findings on Kairos's burnup monitoring plan because it is not required or necessary for the issuance of a CP. Further staff evaluation of Hermes monitoring for neutron flux and burnup is provided in SE

Chapter 7. The staff notes that while specific details of the monitoring for neutron flux and burnup are not needed to issue a CP, the staff will review specific details of the monitoring for neutron flux and burnup provided in an OL application.

4.5.4 Conclusion

Based on the information provided by Kairos and the staff evaluation documented above, the staff finds that Kairos provided sufficient preliminary information in accordance with 10 CFR 50.34(a) to develop a nuclear design that the staff has reasonable assurance will perform its safety functions of controlling reactivity, ensuring shutdown margin, preventing power oscillations, and ensuring SARRDLs are not exceeded in any postulated events or normal operation. The staff concludes that the preliminary information provided for the nuclear design is adequate at this stage of the design and is consistent with PDCs 10, 11, 12, and 26 and with the acceptance criteria of NUREG-1537, Part 2, Section 4.5, “Nuclear Design.”

Based on its findings above, the staff concludes the information in Hermes PSAR Section 4.5 is sufficient and meets the applicable guidance and regulatory requirements identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Further information as may be required to complete the review of Hermes nuclear design can reasonably be left for later consideration at the OL stage since this information is not necessary for the review of a CP application.

4.6 Thermal-Hydraulic Design

4.6.1 Introduction

PSAR Section 4.6, “Thermal-Hydraulic Design,” discusses the Hermes thermal-hydraulic design. Hermes includes a number of design features that ensure effective heat transport from the fuel pebble to the reactor coolant and ultimately to the heat rejection system.

PSAR Sections 4.6.1.1 and 4.6.1.2 state that the core geometry is maintained in part by graphite reflector blocks that keep the pebbles, which are buoyant in the coolant, in a generally cylindrical core shape. During normal operation, reactor coolant enters the reactor vessel from two PHTS cold leg nozzles at a temperature of approximately 550 °C and flows through a downcomer that is formed between the metallic core barrel and the reactor vessel shell. The coolant is then distributed along the vessel bottom head through the reflector support structure and travels up through coolant inlet channels in the graphite reflector blocks and up through the fueling chute into the core. Some coolant travels up through gaps between the reflector blocks via bypass flow, avoiding the core but providing cooling to the reflector block. Coolant travels out of the active core through the upper plenum via the coolant outlet channels and exits the reactor vessel via the PHTS outlet.

Four fluidic diodes in the upper plenum provide alternate flow paths during postulated events where the normal heat removal path through the PHTS is unavailable. During normal operation, the fluidic diode minimizes reverse flow, and, when forced flow is lost, the fluidic diode directs flow from the hot well to the downcomer via natural circulation. The nominal core outlet temperature is dependent on the amount of corresponding bypass flow through the reflector blocks. The maximum core outlet temperature is 650 °C assuming no bypass flow.

4.6.2 Regulatory Evaluation

The requirements in the common regulatory evaluation for reactor systems apply to the thermal-hydraulic design. Additional regulatory requirements for the thermal-hydraulic design are as follows:

- 10 CFR 50.34, "Contents of applications; technical information," paragraph (a), "Preliminary safety analysis report."
    - 10 CFR 50.34(a)(3)(ii) requires "The design bases and the relation of the design bases to the principal design criteria."
    - 10 CFR 50.34(a)(3)(iii) requires "Information relative to materials of construction, general arrangement, and approximate dimensions, sufficient to provide reasonable assurance that the final design will conform to the design bases with adequate margin for safety."
    - 10 CFR 50.34(a)(8) requires "identification of those structures, systems, and components of the facility, if any, which require research and development to confirm the adequacy of their design; and identification and description of the research and development program which will be conducted to resolve any safety questions…; and a schedule of the research and development program…".

The applicable guidance for evaluating the Hermes thermal-hydraulic design are as follows:

- NUREG-1537, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors," Part 1, "Format and Content," and Part 2, "Standard Review Plan and Acceptance Criteria," Section 4.6, "Thermal-Hydraulic Design."

4.6.3 Technical Evaluation

PSAR Section 4.6.2, "Design Basis," identified the design bases for the Hermes thermal-hydraulic design. The PSAR states that the following PDCs are applicable to the thermal-hydraulic design:

- PDC 10, "Reactor design."
- PDC 12, "Suppression of reactor power oscillations."
- PDC 34, "Residual heat removal."
- PDC 35, "Passive residual heat removal."

4.6.3.1 Thermal-hydraulic codes and correlations:

The following staff evaluation of the thermal-hydraulic codes and correlations is related to the findings for PDC 10, 34, and 35.

The staff's evaluation of analyses for preventing fuel overheating and loss of fuel integrity are in SE Section 4.2.1 and SE Chapter 13. Transient analyses are evaluated in SE Chapter 13, which is consistent with the format of NUREG-1537 and the PSAR.

The staff's evaluation of Limiting Safety System Settings is in SE Chapter 14, which is consistent with the format of NUREG-1537 and the PSAR.

The Hermes core design methodology, which includes Serpent 2, STAR–CCM+, and DEM, is evaluated in SE Section 4.5, and the transient analysis methodology, which includes KP-SAM and KP-BISON, is evaluated in SE Chapter 13.

Kairos states in KP-TR-018-P Section 4.1.3, “Plant KP-SAM Model,” that KP-SAM models a 2D Hermes geometry and uses a point kinetics model and a decay heat model. Kairos states that temperature profiles within pebbles are modeled with a 1D conduction model.

Kairos states in KP-TR-017-P Section 4.1.1, “STAR-CCM+,” that bypass flow in the core design methodology is not explicitly modeled but a bypass flow fraction is used as an input parameter. Kairos states in KP-TR-018-P Section 4.1.3, “Plant KP-SAM Model,” that a bypass flow channel and a bypass flow path containing a fluidic diode are modeled in KP-SAM for transient analyses.

PSAR Section 4.6.1.1 states that the Hermes models use the following heat transfer modes:

- Pebble-to-pebble convective heat transfer
- Pebble radiative heat transfer
- Pebble-to-pebble heat transfer via pebble contact conduction
- Pebble-to-pebble heat transfer via conduction through the coolant
- Conductive, convective, and radiative heat transfer to the reflector

The staff reviewed the thermal conductivity equations describing pebble-to-pebble and pebble-to-coolant heat transfer in KP-TR-017-NP. The staff finds that the effective thermal conductivity equation 5-11 in KP-TR-017-NP is sufficient for this preliminary stage of the design because it has a form similar to the effective thermal conductivity equation found in Section 9.4.4 of ANL/NSE-17/4, Revision 1, “SAM Theory Manual,” (Hu, et al., 2021) for effective thermal conductivity in pebble bed reactors. The staff also finds that the thermal conductivity for the fluid phase equation 5-12 in KP-TR-017-NP is sufficient for this preliminary stage of the design because it has a form similar to the thermal conductivity for the fluid phase correlation found in “Heat Transfer in Pebble-Bed Nuclear Reactor Cores Cooled by Fluoride Salts” (Huddar, 2016) for thermal dispersion in pebble bed reactors.

Kairos states that the Kerntechnischer Ausschuss (KTA) correlation was used to account for pebble bed pressure drop in both the core design methodology and the preliminary transient analyses given in the PSAR. The staff finds that the KTA correlation is sufficient for this preliminary stage of the design because it can be found in Section 9.4.1 of ANL/NSE-17/4, Revision 1 (Hu, et al., 2021).

The staff is not approving the use of these codes or correlations beyond their support for the staff’s findings related to issuance of a CP. While the staff reviewed uncertainties in models, the staff did not make any findings on Kairos’s validation and verification plan of codes or derivations of uncertainties because it is not required or necessary for the issuance of a CP. Kairos’s validation and verification plan of codes and derivations of uncertainties will be reviewed at the OL stage.

4.6.3.2 PDC 10, Reactor design:

PSAR Section 4.6.3 states that the thermal-hydraulic design of the reactor core and heat removal systems provides appropriate margin to ensure SARRDLs are not exceeded in any plant condition. PSAR Section 4.6.3 further states that the mass flow rate and core temperature difference given in PSAR Table 4.6-1 are adequate to provide sufficient heat removal and that the primary pump will be designed to accommodate the maximum mass flow rate.

As discussed above, the staff finds that Kairos's selection of codes and correlations are appropriate for this stage of the design. The staff also performed scoping calculations, discussed in SE Chapter 13, which concluded that the TRISO fuel maintains integrity during postulated events, based on the preliminary information available at this stage of the design. These scoping calculations showed reasonable agreement with Kairos's preliminary transient analyses in PSAR Chapter 13. Based on the results of the scoping calculations, the staff finds that the preliminary information on the Hermes thermal-hydraulic design is consistent with PDC 10.

PSAR Section 4.6.3 also states that the height of the core and the axial decay heat profile provide sufficient driving force to enable natural circulation in the event of a loss of forced circulation. The staff finds this is consistent with the acceptance criteria in NUREG-1537, which states that a forced flow reactor should be capable of switching to natural circulation without damaging fuel and jeopardizing safe reactor shutdown.

4.6.3.3 PDC 12, Suppression of reactor power oscillations:

PSAR Section 4.6.3 states that the reactor is kept at atmospheric pressure and that the coolant in the core does not experience two-phase flow and has a high thermal inertia. PSAR Section 4.6.3 also states that the results of analyses supporting the inherent stability of the reactor will be provided with the OL application to demonstrate conformance to PDC 12.

Based on the design features of low pressure, no two-phase flow, and high coolant thermal inertia, the staff finds that the preliminary information on the thermal-hydraulics design is consistent with PDC 12. The staff also finds that the preliminary information is consistent with the acceptance criteria in NUREG-1537 on flow instability. Further staff evaluation of PDC 12 is provided in SE Section 4.5.

4.6.3.4 PDC 34, Residual heat removal:

PSAR Section 4.6 states that during normal operation, including startup and shutdown, forced flow in the PHTS removes residual heat. The primary system functions of the PHTS are non-safety related. When the PHTS is unavailable, residual heat is removed via natural circulation in an alternative flow path through the design of the reactor downcomer, reflector blocks, and fluidic diodes and removed via the DHRS. The fluidic diodes and DHRS both perform safety functions during postulated events. PSAR Section 4.6.3 further states that the mass flow rate and core temperature difference given in PSAR Table 4.6-1 are adequate to provide sufficient heat removal and that the primary pump will be designed to accommodate the maximum mass flow rate.

As discussed above, the staff finds that Kairos's selection of codes and correlations are appropriate for this stage of the design. The staff's scoping calculations, also discussed above and in SE Chapter 13, concluded that the TRISO fuel maintains integrity during postulated events. In addition, the staff notes that for all preliminary transient analyses the MHA remains bounding. The relationship between power and flow of the thermal-hydraulic system as well as the thermal inertia of the coolant ensures that heat transfer can be achieved at a rate that maintains the design conditions of the core. Based on the results of the staff's scoping calculations, the bounding MHA, and the thermal inertia of the coolant, the staff finds that the preliminary information on the Hermes thermal-hydraulic design is consistent with PDC 34. Further staff evaluation of residual heat removal with respect to PDC 34 is provided in SE Section 4.3, and further staff evaluation of the PHTS with respect to PDC 34 is provided in SE Section 6.3.

4.6.3.5 PDC 35, Passive residual heat removal:

PSAR Section 4.6 states that following postulated events, residual heat is removed via natural circulation in an alternative flow path through the design of the reactor downcomer, reflector blocks, and fluidic diodes and removed via the DHRS. The fluidic diodes and DHRS both perform safety functions during postulated events.

As discussed above, the staff finds that Kairos's selection of codes and correlations are appropriate for this stage of the design. The staff's scoping calculations, also discussed above and in SE Chapter 13, concluded that the TRISO fuel maintains integrity during postulated events. In addition, the staff notes that for all preliminary transient analyses the MHA remains bounding. Based on the results of the staff's scoping calculations and the bounding MHA, the staff finds that the preliminary information on the Hermes thermal-hydraulic design is consistent with PDC 35. Further staff evaluation of residual heat removal with respect to PDC 35 is provided in SE Section 4.3, and further staff evaluation of the PHTS with respect to PDC 35 is provided in SE Section 6.3.

4.6.4 Conclusion

Based on the information provided by Kairos and the staff evaluation documented above, the staff finds that Kairos provided sufficient preliminary information in accordance with 10 CFR 50.34(a) to develop a thermal-hydraulic design that the staff has reasonable assurance will perform its safety functions of providing sufficient heat removal and preventing power oscillations. The staff concludes that the preliminary information provided for the thermal-hydraulics is adequate at this stage of the design and is consistent with PDCs 10, 12, 34, and 35 and with the acceptance criteria of NUREG-1537, Part 2, Section 4.6, "Thermal-Hydraulic Design."

Based on its findings above, the staff concludes the information in Hermes PSAR Section 4.6 is sufficient and meets the applicable guidance and regulatory requirements identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Further information as may be required to complete the review of Hermes RCSS can reasonably be left for later consideration at the OL stage since this information is not necessary for the review of a CP application.

4.7 Reactor Vessel Support System

4.7.1 Introduction

PSAR Section 4.7, "Reactor Vessel Support System," discusses the Hermes reactor vessel support system (RVSS) design. PSAR Section 4.7.1 states that the RVSS provides structural support for the reactor vessel and the vessel internals. The RVSS supports the full weight of the vessel, fuel, coolant, vessel internals, and the head-mounted components. The RVSS is designed to transmit pressure, seismic, and thermal loads to the cavity structures and address thermal expansion during initial heat-up and postulated events.

4.7.2 Regulatory Evaluation

The requirements in the common regulatory evaluation for reactor systems apply to the RVSS. Additional regulatory requirements for the RVSS are as follows:

- 10 CFR 50.34, "Contents of applications; technical information," paragraph (a), "Preliminary safety analysis report."
    - 10 CFR 50.34(a)(3)(ii) requires "The design bases and the relation of the design bases to the principal design criteria."
    - 10 CFR 50.34(a)(3)(iii) requires "Information relative to materials of construction, general arrangement, and approximate dimensions, sufficient to provide reasonable assurance that the final design will conform to the design bases with adequate margin for safety."

The applicable guidance for the evaluation of the Hermes RVSS is as follows:

- NUREG-1537, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors," Part 1, "Format and Content," and Part 2, "Standard Review Plan and Acceptance Criteria," Parts 1 and 2, Section 4.2.5 "Core Support Structure" and Section 4.3, "Reactor Tank or Pool."

4.7.3 Technical Evaluation

PSAR Section 4.7.2, "Design Basis," identified the design bases for the Hermes RVSS. The PSAR states that the following PDCs are applicable to the RVSS:

- PDC 2, "Design bases for protection against natural phenomena."
- PDC 4, "Environmental and dynamic effects design bases."
- PDC 74, "Reactor vessel and reactor system structural design basis."

PSAR Section 4.7.3, "System Evaluation," relates the design bases to the design criteria and identifies how the RVSS satisfies the PDC applicable to the design of the RVSS. In the following paragraphs, the staff addresses each PDC by summarizing the information presented in the PSAR and explaining the staff evaluation of the adequacy of the preliminary information in the PSAR relative to the applicable NUREG-1537 acceptance criteria.

4.7.3.1 PDC 2, Design bases for protection against natural phenomena:

PSAR Section 4.7.1 states that the RVSS is designed to prevent reactor uplift and shear during seismic events and to transfer these loads to the reactor building. The seismic isolation system of the reactor building aids in reducing the seismic effects on the reactor vessel, the reactor vessel support structure, and the head-mounted components. PSAR Section 4.7.3 states that the RVSS bottom support meets the requirements of ASCE 43-19 and prevents linear buckling in the vessel support columns under static and design basis earthquake loads, including uplift due to vertical anchoring. PSAR Section 4.7.3 also states that the vessel connectors are designed to meet ASCE 43-19 and provide lateral and uplift support to the vessel and vessel top head components. Finally, the reactor cavity is seismically isolated and load combinations for the RVSS and safety related portions of the reactor building are provided in PSAR Table 4.7-1 and PSAR Table 3.5-1.

The staff notes that PSAR Table 4.7-1, "Load Combinations for the Reactor Vessel Support System," provides the load combinations for the RVSS, including seismic loads due to design basis earthquake events. The staff also notes that the load combination methodology will be used to demonstrate that the final design will meet the allowable stress limits specified in ASME BPVC Section III, Division 5. Based on the acceptable load combination methodology, the staff finds that the preliminary information on the RVSS design is consistent with PDC 2. Further information as may be required to complete the review of Hermes RVSS can reasonably be left for later consideration at the OL stage.

4.7.3.2 PDC 4, Environmental and dynamic effects design bases:

PSAR Section 4.7.3 states that the RVSS is protected from coolant spills by catch basins with sensors and probes to detect leaks and prevent RVSS damage. PSAR Section 4.7.3 states that pipe whip hazards are precluded by design due to a lack of pressurized piping systems in proximity to the RVSS. PSAR Section 4.7.3 states the RVSS accommodates the reactor vessel temperature loading cycles in combination with relevant mechanical loading cycles to ensure creep-fatigue damages are precluded. Finally, PSAR Section 4.7.3 states that the RVSS is designed to accommodate the growth of the reactor due to thermal expansion between startup and equilibrium conditions.

The staff notes that the Hermes reactor includes design features intended to address environmental and dynamic effects on the RVSS. Pipe whip hazards are precluded by design due to a lack of pressurized piping and discharging fluids are addressed by catch basins with a leak detection system. The RVSS is designed to address temperature and mechanical loading cycles in order to prevent damage from creep-fatigue and to allow for thermal expansion of the reactor during startup and operation. This preliminary information addresses all relevant aspects of PDC 4. Based on the design features to manage pipe whip hazards, discharging fluids, and loading cycles, the staff finds that the preliminary information on the RVSS is consistent with PDC 4. The staff also finds that the preliminary information is consistent with the relevant acceptance criteria in NUREG-1537, which state that the design should be able to withstand all stresses and forces that it may be subjected to and address local environmental effects. Further information as may be required to complete the review of Hermes RVSS can reasonably be left for later consideration at the OL stage.

4.7.3.3 PDC 74, Reactor vessel and reactor system structural design basis:

PSAR Section 4.7.1 states that the RVSS is designed to prevent the reactor vessel from uplift and shear during seismic events with the design leveraging the seismic isolation of the Reactor Building to reduce seismic effects on the reactor vessel, RVSS, and the head-mounted components. PSAR Section 4.7.3 also states that the reactor thermal management system (RTMS) is designed to remove heat actively during normal operation and passively during postulated events to maintain the integrity of the reactor vessel. Heat from the reactor core is transferred via the vessel wall to the RVSS. The RVSS support columns are sized and spaced to maximize heat transfer between the bottom support and the environment. PSAR Section 4.7.3 further describes how the bottom support insulation provides a thermal break between the RVSS and the reactor building to ensure concrete integrity meets the requirements of ACI 349-13, "Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary," and conditions in the surrounding cavity do not exceed maximum allowable parameters.

The staff notes that the RVSS design helps ensure sufficient heat removal from the reactor vessel, while also providing structural support for the reactor vessel under static and dynamic loadings (e.g., seismic). The heat is removed via the RTMS, actively during normal operation and passively during postulated events. Based on the design for sufficient heat removal and structural support, the staff finds that the preliminary information on the RVSS design is consistent with PDC 74. Further information as may be required to complete the review of Hermes RVSS can reasonably be left for later consideration at the OL stage.

4.7.4 Conclusion

Based on the information provided by Kairos and the staff evaluation documented above, the staff finds that Kairos provided sufficient preliminary information in accordance with 10 CFR 50.34(a) to develop an RVSS design that the staff has reasonable assurance will perform its safety functions of providing structural support to ensure vessel integrity. The staff concludes that the preliminary information provided for the RVSS is adequate at this stage of the design and is consistent with PDCs 2, 4, and 74 and with the acceptance criteria of NUREG-1537, Part 2, Section 4.2.5 “Core Support Structure,” and Section 4.3, “Reactor Tank or Pool.”

Based on its findings above, the staff concludes the information in Hermes PSAR Section 4.7 is sufficient and meets the applicable guidance and regulatory requirements identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Further information as may be required to complete the review of Hermes RVSS can reasonably be left for later consideration at the OL stage since this information is not necessary for the review of a CP application.

4.8 Summary and Conclusions on the Reactor Description

The staff evaluated the information regarding the Hermes reactor, as described in PSAR Chapter 4, as supplemented, and finds that the preliminary information on, and design criteria of, the reactor, including the PDC, design bases, and information relating to materials of construction, general arrangement, and approximate dimensions: (1) provide reasonable assurance that the final design will conform to the design bases, (2) meet all applicable regulatory requirements, and (3) meet the applicable acceptance criteria in NUREG-1537. Part 2. Based on these findings, the staff makes the following conclusions regarding issuance of a CP in accordance with 10 CFR 50.35 and 10 CFR 50.40:

- Kairos has described the proposed design of the reactor, including, but not limited to, the principal engineering criteria for the design, and has identified the major features or components incorporated therein for the protection of the health and safety of the public.

- Such further technical or design information as may be required to complete the safety analysis of the reactor, and which can reasonably be left for later consideration, will be provided in the FSAR.

- Safety features or components which require research and development have been described by Kairos and research and development program (see SE Section 1.1.5) will be conducted that is reasonably designed to resolve any safety questions associated with such features or components.

- There is reasonable assurance that safety questions will be satisfactorily resolved at or before the latest date stated in the application for completion of construction of the proposed facility.

- There is reasonable assurance: (i) that the construction of the Hermes facility will not endanger the health and safety of the public, and (ii) that construction activities can be conducted in compliance with the Commission's regulations.

- The issuance of a permit for the construction of the Hermes facility would not be inimical to the common defense and security or to the health and safety of the public.

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5 REACTOR COOLANT SYSTEM

For the Hermes non-power test reactor, the reactor coolant system consists of the primary heat transport system (PHTS) that circulates coolant through the reactor core to a radiator that rejects energy to the atmosphere.

This chapter of the Kairos Power LLC (Kairos) Hermes test reactor construction permit (CP) safety evaluation (SE) describes the U.S. Nuclear Regulatory Commission (NRC) staff's (the staff's) technical review and evaluation of the preliminary information regarding the Hermes PHTS. This information is presented in Chapter 5, "Heat Transport Systems," of the Hermes preliminary safety analysis report (PSAR), Revision 3, as supplemented. The staff reviewed PSAR Chapter 5, as supplemented, against applicable regulatory requirements using regulatory guidance and standards to assess the sufficiency of the preliminary information Kairos provided regarding the Hermes facility PHTS for the issuance of a CP in accordance with Title 10, *Code of Federal Regulations* (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities." As part of this review, the staff evaluated information on the Hermes PHTS, with special attention to design and operating characteristics, unusual or novel design features, and principal safety considerations. The staff evaluated the preliminary design of the Hermes PHTS to ensure the design criteria, design bases, and information relative to construction is sufficient to provide reasonable assurance that the final design will conform to the design basis. In addition, the staff reviewed Kairos's identification and justification for the selection of those variables, conditions, or other items which are determined to be probable subjects of technical specifications (TS) for the facility, with special attention given to those items which may significantly influence the final design.

The staff's reviews and evaluations for areas relevant to PSAR Chapter 5, including regulations and guidance used, summaries of the application information reviewed, and evaluation findings and conclusions, are discussed in the SE section below for the major area of review (the reactor coolant system) covered in this SE chapter. A summary and overall conclusions on the staff's technical evaluation of Hermes PHTS are provided in SE Section 5.2, "Summary and Conclusions on Reactor Coolant System."

5.1 <u>Primary Heat Transport System</u>

5.1.1 Introduction

The PHTS transfers heat from the reactor core by circulating reactor coolant between the reactor core and the heat rejection radiator (HRR) subsystem during normal operations. The PHTS includes a primary salt pump, heat rejection system, and associated piping. The PHTS also includes thermal management features to maintain the reactor coolant in the liquid phase when the reactor core is not generating heat and the capability to drain external piping and the HRR to allow cooldown, inspection, and maintenance. The PHTS performs non-safety related functions as described in PSAR Section 5.1.1, "Description." The PHTS interfaces with various systems, including the reactor thermal management system, inert gas system, tritium management system, and inventory management system as described in PSAR Chapter 9.

5.1.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of the Hermes non-power test reactor PHTS design criteria are as follows:

- 10 CFR 50.34, “Contents of applications; technical information,” paragraph (a), “Preliminary safety analysis report.”
    - 10 CFR 50.34(a)(3)(ii) requires “The design bases and the relation of the design bases to the principal design criteria.”
    - 10 CFR 50.34(a)(3)(iii) requires “Information relative to materials of construction, general arrangement, and approximate dimensions, sufficient to provide reasonable assurance that the final design will conform to the design bases with adequate margin for safety.”
    - 10 CFR 50.34(a)(4) which requires “A preliminary analysis and evaluation of the design and performance of structures, systems, and components [SSCs] of the facility…”
- 10 CFR 50.35, “Issuance of construction permits.”
- 10 CFR 50.40, “Common standards.”

The applicable guidance for the evaluation of Hermes reactor coolant system is as follows:

- NUREG-1537, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors,” Part 1, “Format and Content,” and Part 2, “Standard Review Plan and Acceptance Criteria,” Chapter 5, “Reactor Coolant Systems.” Based on the role of the PHTS in the Hermes design, the staff evaluated the system using the applicable acceptance criteria in Section 5.2, “Primary Coolant System” for a non-light water reactor.

5.1.3 Technical Evaluation

5.1.3.1 PSAR System Description

PSAR Section 5.1.1 states that the PHTS is a non-safety related system which serves the function of the reactor coolant system. The PSAR states that the PHTS is used to remove heat from the reactor core and transfer the heat to the HRR subsystem, which functions as the ultimate heat sink. If the PHTS is not available to remove heat from the core, the decay heat removal system (DHRS) is the safety related system which will remove the heat to maintain the core within proper temperature limits. PSAR Section 5.1.3 states that the PHTS piping and supports are designed to American Society of Mechanical Engineers (ASME) B31.3 Code, “Process Piping,” and the HRR is designed to ASME Boiler and Pressure Vessel Code (BPVC) Section VIII standards. PSAR Section 5.1.1.4 states that the PHTS piping is made of austenitic stainless steel.

PSAR Section 5.1.1.1 states that the reactor coolant is a mixture of fluorine, lithium, and beryllium (i.e., Flibe) in a composition that is described in KP-TR-005-NP-A, Revision 1 “Reactor Coolant for the Kairos Power Fluoride Salt-Cooled High-Temperature Reactor.” PSAR Section 5.1.1.1 states that the safety functions of the coolant are to support reactivity control and to serve as a fission product barrier. PSAR Chapter 14 contains a proposed TS Limiting Condition for Operation (LCO) to maintain the reactor coolant composition within allowable limits to ensure that the thermophysical properties are maintained.

Unlike a light water reactor, the reactor coolant is credited for fission product retention in the Hermes design. Additionally, the staff notes that it is important for the Flibe coolant to maintain the expected thermophysical properties needed for natural circulation heat transfer. Flibe purity and its effect on corrosion is evaluated by the staff in SE Section 4.3.

5.1.3.2 Staff Evaluation of Design Basis and System Design

PSAR Section 3.1.1, "Design Criteria," describes the principal design criteria (PDC) that are applicable to the Hermes reactor. These PDC were reviewed and approved by the staff in KP-TR-003-NP-A, Revision 1, "Principal Design Criteria for the Kairos Power Fluoride Salt-Cooled, High Temperature Reactor." PSAR Section 5.1.2, "Design Basis," identified the design bases for the PHTS. The PSAR states that the following PDCs are applicable to the PHTS:

- PDC 2, "Design bases for protection against natural phenomena," which requires safety related SSCs be designed to withstand the effects of natural phenomena.
- PDC 10, "Reactor design," which requires the reactor core be designed to ensure specified acceptable system radionuclide release design limits (SARRDLs) are not exceeded.
- PDC 12, "Suppression of reactor power oscillations," which requires the reactor core be designed to ensure power oscillations that can result in conditions that exceed SARRDLs are not possible or can be reliably and readily detected and suppressed.
- PDC 16, "Containment design," which requires a functional containment to control the release of radioactivity to the environment.
- PDC 33, "Reactor coolant inventory maintenance," which requires a system to maintain coolant inventory to protect against small breaks in the safety related elements of the reactor coolant boundary.
- PDC 60, "Control of releases of radioactive materials to the environment," which requires the plant design to control the release of radioactive materials, including during postulated events.
- PDC 70, "Reactor coolant purity control," which requires systems to maintain reactor coolant purity considering chemical attack, fouling and plugging of passages, radionuclide concentrations, and air or moisture ingress.

PSAR Section 5.1.3, "System Evaluation," relates the design bases to the design criteria and identifies how the PHTS satisfies the PDC applicable to the design of the PHTS. In the following paragraphs, the staff addresses each PDC by summarizing the information presented in the PSAR and explaining the staff evaluation of the adequacy of the preliminary information in the Kairos PSAR relative to NUREG-1537 acceptance criteria.

5.1.3.2.1 PDC 2, Design bases for protection against natural phenomena:

PSAR Section 5.1.3 states that the design of the non-safety related PHTS SSCs is such that a failure of PHTS SSCs would not affect the performance of safety related SSCs due to a design basis earthquake. The non-safety related PHTS pipe connections to the reactor vessel nozzles have sufficiently small wall thickness such that, if loaded beyond elastic limits, an inelastic response would occur in the non-safety related PHTS piping prior to any impacts to the safety related SSCs, such as the reactor vessel or DHRS.

PSAR Section 6.3 states that a failure of the PHTS piping or HRR does not lead to inadequate heat removal because the safety related DHRS or parasitic heat loss removes the residual heat. PSAR Section 5.1 describes how adequate reactor coolant inventory is maintained following a failure in the PHTS by anti-siphon design features on the hot and cold legs. This aspect of the design is described and evaluated under PDC 33 below.

The staff notes that the ability of the Hermes design to remove residual heat following a failure in the PHTS is consistent with the guidance given in NUREG-1537, Part 2, Section 5.2, which states, the primary coolant system (of a forced-convection coolant flow) should be designed to convert in a passive or fail-safe method, to natural-convection flow sufficient to avoid loss of fuel integrity. Therefore, the staff finds that the anti-siphon features of the design will ensure sufficient heat removal and maintain reactor coolant inventory if a failure in the PHTS piping or HRR occurs due to a natural phenomenon.

Because failures in the PHTS would not affect the ability of safety related SSCs to perform their safety function, the staff finds that the preliminary design of the PHTS is consistent with PDC 2. Further, the preliminary design of the PHTS is consistent with the guidance provided in NUREG-1537, Part 2, Section 5.2, which states the primary coolant system should be designed to ensure sufficient heat removal to maintain fuel integrity and prevent uncontrolled leakage or discharge of contaminated coolant to the unrestricted environment.

5.1.3.2.2 PDC 10, Reactor design:

PSAR Section 5.1.3 states that thermal hydraulic analysis of the core ensures adequate coolant flow is maintained to ensure SARRDLs are not exceeded. PDC 10 has two components: (1) normal operation, which is evaluated by the staff in SE Sections 4.3 and 4.6, and (2) during postulated events, when the normal PHTS heat removal path is unavailable, which is evaluated by the staff in SE Section 6.3.

Relative to the PHTS design, the staff notes that it is important for the Flibe coolant to maintain the expected thermophysical properties needed for natural circulation heat transfer. In order for the reactor coolant to maintain the thermophysical properties specified in KP-TR-005-NP-A, Revision 1, the staff finds that the composition of the coolant needs to be controlled. The staff finds that the preliminary design will allow the composition of the coolant to be controlled because the chemistry control system (CCS) provides means for adjusting salt chemistry, as needed. Additionally, the proposed TS in PSAR Chapter 14 include a LCO to maintain the reactor coolant composition within allowable limits to ensure that the thermophysical properties are maintained. This will allow the coolant to maintain the thermophysical properties needed to achieve adequate heat removal.

Based on the conclusions documented in the preceding paragraphs and in SE Sections 4.3, 4.6 and 6.3, the staff finds that the preliminary design of the PHTS provides adequate heat removal during normal operation and postulated events and is consistent with PDC 10. This is also consistent with the guidance and associated acceptance criteria in NUREG-1537, Part 2, Section 5.2, which state that the system should be designed to remove sufficient heat from the fuel without exceeding SARRDLs.

5.1.3.2.3 PDC 12, Suppression of reactor power oscillations:

PSAR Section 5.1.3 states that the reactor coolant is designed, in part, to ensure power oscillations can't exceed SARRDLs consistent with PDC 12. The PHTS supports this design objective through its ability to detect and suppress, if needed, inlet temperature and mass flow rate oscillations, limiting entrained gas in the coolant (via a proposed TS LCO in PSAR Chapter 14), maintaining coolant specifications, and the resistance of the coolant to thermal-hydraulic instability events. PSAR Section 4.5 describes the inherent features of the nuclear design which tend to limit flow- and inlet temperature-induced power oscillations, including a small core height and diameter and a long neutron diffusion length. PSAR Chapter 7 further details the Hermes instrumentation and controls, including the reactor coolant auxiliary control system. SE Chapter 7 provides the staff evaluation of the Hermes instrumentation and controls, including the reactor coolant auxiliary control system.

SE Chapter 4 evaluates PSAR Section 4.5 and finds that the inherent features of the nuclear design, including a small core height and diameter and long neutron diffusion length, make uncontrolled power oscillations unlikely. The proposed TS LCO to limit air in the reactor coolant provides further assurance that voiding in the coolant will be limited such that power oscillations exceeding SARRDLs are not possibly or can be detected and suppressed. Based on these inherent features and the proposed TS LCO, the staff finds the staff finds that the preliminary design of the PHTS is consistent with PDC 12.

5.1.3.2.4 PDC 16, Containment design; and PDC 60, Control of releases of radioactive materials to the environment:

PSAR Section 5.1.3 states that the Flibe reactor coolant provides retention of fission products that may escape the fuel. These retention properties are credited in the safety analysis as a barrier to release of radionuclides accumulated in the coolant. PSAR Section 5.1.3 notes that the design aspects of the Flibe reactor coolant are discussed in KP-TR-005-NP-A, Revision 1. PSAR Chapter 14 states that a proposed TS LCO related to limiting circulating activity in the Flibe will be established.

The staff previously evaluated the ability of Flibe to serve as a fission product barrier in KP-TR-012-NP-A, Revision 3, "Mechanistic Source Term Methodology for the Kairos Power Fluoride Salt-Cooled High-Temperature Reactor." Based on the evaluation in KP-TR-012-NP-A, Revision 3, the staff finds the Flibe will perform consistent with PDCs 16 and 60 because the reactor coolant can retain certain radionuclides in a salt-soluble form, as described in KP-TR-012-NP-A, Revision 3. The staff finds that the preliminary design of the PHTS is consistent with PDCs 16 and 60 because the proposed TS LCO on circulating activity will provide assurance that key assumptions in the topical report (KP-TR-012-NP-A, Revision 3) are maintained (e.g., to limit positive deviations from ideal vapor pressures). As per Appendix A to this SE, the staff will review the thermodynamic data used to model radionuclide retention and release in Flibe during the operating license (OL) application review.

The full analysis of the functional containment is contained in SE Section 6.2 and tritium transport and processing are described in SE Section 9.1.3. In addition to the proposed TS LCO related to limiting circulating activity in the Flibe, additional proposed TS LCOs related to Flibe performance that support PDCs 16 and 60 include LCOs to maintain the Flibe coolant composition, limit the radionuclide inventory of the reactor coolant in steady state conditions within an upper bound limit, to maintain PHTS pressure and flow rate within an upper bound limit, and to maintain air in the reactor coolant within an acceptable limit based on considerations for voiding and corrosion.

5.1.3.2.5 PDC 33, Reactor coolant inventory maintenance:

PSAR Sections 4.3 and 5.1 state that there are anti-siphon features to limit loss of reactor coolant in the event of breaks in the PHTS cold leg. The hot leg anti-siphon design feature is formed by the elevation difference between the pump inlet and DHRS natural circulation flow path allowing air or cover gas to break the siphon. On the cold leg, a cutout in the core barrel allows air or cover gas to expand into the downcomer, breaking the siphon as the cold leg inventory drains down.

The staff notes that adequate reactor coolant inventory is maintained following a failure in the PHTS by anti-siphon design features on the hot and cold legs. The design's ability to remove residual heat following a failure in the PHTS is consistent with the guidance given in NUREG-1537 which states, the primary coolant system (of a forced-convection coolant flow) should be designed to prevent coolant loss and convert, in a passive or fail-safe method, to natural-convection flow sufficient to avoid loss of fuel integrity. Accordingly, the staff finds that the preliminary design of the PHTS is consistent with PDC 33. The staff also finds that this preliminary information for the PHTS design is consistent with the relevant guidance in NUREG-1537.

5.1.3.2.6 PDC 70, Reactor coolant purity control:

The staff evaluated the ability of the PHTS to maintain reactor coolant purity considering fouling and plugging of passages, radionuclide concentrations, chemical attack, and air or moisture ingress.

PSAR Section 5.1.3 states that fouling or plugging of the reactor coolant flow path is not expected as a result of a reduction in coolant purity, but the temperature of the reactor coolant in the downcomer and core can be monitored to determine if coolant purity affects heat removal capability as a result of fouling or plugging.

The staff finds that the information provided regarding temperature monitoring in the downcomer and core will allow Kairos to design the system to detect potential fouling or plugging, and, if detected, coolant purity can be restored by the CCS as described in PSAR Section 9.1.1 and SE Chapter 9. The staff finds that the preliminary information regarding monitoring and the CCS is consistent with the PDC 70 criteria to control coolant purity based on the potential for fouling or plugging.

The ability of the reactor coolant to retain radionuclides is discussed in KP-TR-012-NP-A, Revision 3 and PSAR Section 5.1.3. Based on the evaluation in KP-TR-012-NP-A, Revision 3, the staff finds that the preliminary information provided about Flibe as a reactor coolant is consistent with PDC 70 with respect to radionuclide retention, because, as described in the referenced topical report, the reactor coolant can retain certain radionuclides in a salt-soluble form. Further discussion of this topic can be found above under PDCs 16 and 60.

KP-TR-013-PNP, Revision 4, "Metallic Materials Qualification for the Kairos Power Fluoride Salt-Cooled High-Temperature Reactor," and KP-TR-014-NP, Revision 4, "Graphite Material Qualification for the Kairos Power Fluoride Salt-Cooled High-Temperature Reactor" both address the issue of chemical attack or corrosion of primary system components within the broader discussion of materials qualification. PSAR Section 9.1.1 describes the CCS and its ability to adjust Flibe purity.

The staff evaluated the impact of Flibe as a coolant on the corrosion of primary system components as described in PSAR Chapter 5, as well as KP-TR-013-NP, Revision 4 and KP-TR-014-NP, Revision 4. The staff finds that Flibe purity can be maintained in a manner that minimizes corrosion, consistent with NUREG-1537, Part 2, Section 5.2. This finding is based on the following: (1) Kairos will perform qualification testing that will quantify degradation rates of high carbon 316 austenitic stainless steel (316H SS) and graphite in contact with Flibe, and (2) the CCS, as described in PSAR Section 9.1.1 and evaluated in SE Chapter 9, will be able to adjust Flibe purity, if needed.

PSAR Section 5.1.3 states that air ingress could affect the purity and inventory of the reactor coolant in the vessel, but significant forced air ingress into the PHTS is excluded by the design basis due to design features of the HRR and reactor trip system. PSAR Chapters 4 and 13 discuss air entrapment events which are considered separate from forced air events. The response to Request for Additional Information (RAI) Package 350, Question 410 states that structural integrity of metallic and graphite components will remain within bounding conditions as per the KP material qualification programs described in KP-TR-013-PNP, Revision 4, and KP-TR-014-NP, Revision 4. Additionally, PSAR Chapter 14 contains a proposed TS LCO to limit the quantity of air in the reactor coolant during operations.

The staff notes that material qualification programs will provide data to analyze degradation of both metallic materials in the PHTS, as well as the graphite reflector, for postulated air ingress events. This data can be used to ensure these components can maintain their safety functions because it will allow for appropriate corrosion and oxidation allowances to be incorporated into the design. Additionally, the staff notes that the response to RAI Package 350, Question 410 describes design features to limit forced air ingress and the availability of compensatory measures after the anticipated seven day postulated accident time to ensure that the material qualification programs bound postulated air ingress scenarios. Therefore, the staff finds that the preliminary design of the PHTS is consistent with PDC 70 with respect to air ingress. The full staff assessment of the structural integrity of safety related components is documented in Chapter 4 of this SE.

Based on the preliminary information provided in PSAR Chapter 5 and the referenced topical report, the staff finds that the preliminary design is consistent with PDC 70 in accordance with 10 CFR 50.34(a)(3) and the guidance in NUREG-1537, Part 2, Section 5.2, such that the quality of the primary coolant will be maintained to limit corrosion of fuel components, control rod cladding, vessel material, and other essential components in the primary system.

5.1.3.2.7 10 CFR Part 20

PSAR Section 5.1.3 states that because the reactor coolant contains radiological contaminants, the system will be designed to minimize contamination and support eventual decommissioning as described in PSAR Chapter 11. PSAR Sections 4.4 and 11.1.5 further discuss radiation shielding considerations.

The broader staff evaluation of radiation protection and waste management, including radiation shielding, is provided in SE Chapter 11.

5.1.3.2.8 System Design and High Point Vents

The regulation in 10 CFR 50.34(a)(4) requires an analysis in accordance with 50.46 and 50.46a of emergency core cooling system performance and the need for high point vents following postulated loss-of-coolant accidents. However, the regulation in 50.46 is specifically for light water reactors, and thus is not applicable to the molten salt cooled Hermes reactor. Similarly, the regulation in 50.46a states that it is for power reactors, so this regulation also does not apply to the Hermes reactor. However, for assurance that there is no undue risk to the health and safety of the public as required by 10 CFR 50.35, the staff considers it appropriate to consider whether non-condensable gases could have safety implications in the Hermes design. The Hermes reactor system is designed to maintain a blanket of inert gas above the Flibe coolant. The inert gas is a non-condensable gas. The presence of the inert gas or the introduction of other non-condensable gases would not cause a loss of the cooling function during normal operation or postulated events. Thus, the staff finds that non-condensable gases in the reactor coolant system would not cause a loss of function and present no undue risk.

5.1.3.3 Testing and Inspection

PSAR Section 5.1.4 states that any tests and inspections of the PHTS will be included with the submission of the OL. The testing and surveillance program will be submitted as part of the Hermes OL application. These programs will be tracked in Appendix A of this SE and evaluated during the OL review.

5.1.3.4 Technical Evaluation Summary

The staff evaluated the sufficiency of the preliminary information on the design of the Hermes PHTS, as described in PSAR Chapter 5 and other relevant portions of the PSAR, using the guidance and acceptance criteria from Section 5.2 of NUREG-1537, Parts 1 and 2. As part of its review, the staff evaluated if PSAR Section 5.1 identifies the appropriate PDC and offers sufficient information and design description to provide reasonable assurance that the design bases will be met at the OL stage. That evaluation is described above in the “Design Basis and System Evaluation” section.

Based on the information provided by Kairos and the staff evaluation documented above, the staff finds that Kairos provided sufficient preliminary information in accordance with 10 CFR 50.34 to develop a primary coolant system design that staff has reasonable assurance will be able to accomplish the design functions of fuel integrity and sufficient heat removal, coolant loss prevention, conversion to passive natural-convection flow, limited corrosion of essential components, and sufficient radiation shielding for limiting personnel exposures. The staff finds that the preliminary information provided for the PHTS is adequate at this stage of the design and is consistent with PDCs 2, 10, 12, 16, 33, 60, and 70 and with the acceptance criteria of NUREG-1537, Part 2, Section 5.2, “Reactor Coolant System.”

5.1.4 Conclusion

Based on its findings above, the staff concludes the information in Hermes PSAR Chapter 5, as supplemented by the response to RAI 350, is sufficient and meets the applicable guidance and regulatory requirements identified in this chapter for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Further information as may be required to complete the review of Hermes reactor coolant system can reasonably be left for later consideration at the OL stage since this information is not necessary for the review of a CP application.

5.2 Summary and Conclusions on the Reactor Coolant System

The staff evaluated the information on the Hermes reactor coolant system as described in PSAR Chapter 5, as supplemented, and finds that the preliminary information on, and design criteria of, the reactor coolant system, including the PDC, design bases, and information relating to materials of construction, general arrangement, and approximate dimensions: (1) provide reasonable assurance that the final design will conform to the design bases, (2) meet all applicable regulatory requirements, and (3) meet the applicable acceptance criteria in NUREG-1537, Part 2. Based on these findings, the staff makes the following conclusions regarding issuance of a CP in accordance with 10 CFR 50.35 and 50.40:

- Kairos has described the proposed design of the reactor coolant system, including, but not limited to, the principal engineering criteria for the design, and has identified the major features or components incorporated therein for the protection of the health and safety of the public.

- Such further technical or design information as may be required to complete the safety analysis of the reactor coolant system, and which can reasonably be left for later consideration, will be provided in the FSAR.

- Safety features or components which require research and development have been described by Kairos and a research and development program (see SE Section 1.1.5) will be conducted that is reasonably designed to resolve any safety questions associated with such features or components.

- There is reasonable assurance that safety questions will be satisfactorily resolved at or before the latest date stated in the application for completion of construction of the proposed facility.

- There is reasonable assurance: (i) that the construction of the facility will not endanger the health and safety of the public, and (ii) that construction activities can be conducted in compliance with the Commission's regulations.

- The issuance of a permit for the construction of the Hermes facility would not be inimical to the common defense and security or to the health and safety of the public.

5.3 References

American Society of Mechanical Engineers (ASME) B31.3, "Process Piping." ASME: Two Park Avenue, New York, NY. June 2021

-----. Section VIII. "BPVC Section VIII-Rules for Construction of Pressure Vessels Division 1." ASME: Two Park Avenue, New York, NY. 2021

Kairos Power LLC. "Submittal of the Preliminary Safety Analysis Report for the Kairos Power Fluoride Salt-Cooled, High Temperature Non-Power Reactor (Hermes), Revision 3," May 31, 2023, Pkg. ML23151A743.

-----. KP-TR-003-NP-A, "Principal Design Criteria for the Kairos Power Fluoride Salt-Cooled, High Temperature Reactor," Revision 1, June 2020, ML20167A174.

-----. "Enclosure 2: Response to NRC Request for Additional Information 350," September 2022, ML22251A400 (redacted version).

-----. "Reactor Coolant for the Kairos Power Fluoride Salt-Cooled High Temperature Reactor Topical Report." KP-TR-005-NP-A, Revision 1. July 2020. ML20219A591. (redacted version).

-----. "Mechanistic Source Term Methodology Topical Report." KP-TR-012-NP-A, Revision 3. March 2022. ML22136A2918 (redacted version).

-----. “Metallic Materials Qualification for the Kairos Power Fluoride Salt-Cooled High-Temperature Reactor.” KP-TR-013-NP, Revision 4. September 2022. ML22263A456. (redacted version).

-----. “Graphite Material Qualification for the Kairos Power Fluoride Salt-Cooled High-Temperature Reactor.” KP-TR-014-NP, Revision 4. September 2022. ML22259A142 (redacted version).

The U. S. Nuclear Regulatory Commission (NRC). NUREG-1537, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors,” Part 1, “Format and Content,” and Part 2, “Standard Review Plan and Acceptance Criteria.” NRC: Washington, D.C. February 1996. ADAMS Accession Nos. ML042430055 and ML042430048.

6 ENGINEERED SAFETY FEATURES

Engineered safety features (ESFs) are features designed to mitigate the consequences of accidents and to keep radiological exposures within acceptable values. For this reason, ESFs must be designed to function during a full range of conditions, from normal operation to accident conditions. The need for ESFs in a test reactor is design-specific and determined through an applicant's accident analyses.

This chapter of the Kairos Power LLC (Kairos) Hermes construction permit (CP) safety evaluation (SE) describes the U.S. Nuclear Regulatory Commission (NRC) staff's (the staff's) technical review and evaluation of the preliminary information provided in Chapter 6, "Engineered Safety Features," of the Hermes preliminary safety analysis report (PSAR), Revision 3, as supplemented. The staff reviewed Chapter 6 of the Hermes PSAR, as supplemented, against applicable regulatory requirements using regulatory guidance and standards to assess the sufficiency of the preliminary information on the Hermes ESFs for the issuance of a CP in accordance with Title 10, *Code of Federal Regulations* (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities." As part of this review, the staff evaluated information on the Hermes ESFs, with special attention given to design and operating characteristics, unusual or novel design features, and principal safety considerations. The staff evaluated the preliminary design of the Hermes ESFs to ensure the design criteria, design bases, and information relative to construction is sufficient to provide reasonable assurance that the final design will conform to the design basis. In addition, the staff reviewed Kairos's identification and justification for the selection of those variables, conditions, or other items which are determined to be probable subjects of technical specifications (TS) for the facility, with special attention given to those items which may significantly influence the final design.

In its review of areas relevant to PSAR Chapter 6, the staff considered the information in Revision 1, dated September 29, 2022, of the technical report KP-TR-017, "KP-FHR Core Design and Analysis Methodology," and Revision 2, dated February 24, 2023, of the technical report KP-TR-018, "Postulated Event Analysis Methodology," which are part of the Hermes CP application, as supplemented, and which are referenced in the PSAR, Revision 3.

The staff's reviews and evaluations for areas relevant to PSAR Chapter 6, including regulations and guidance used, a summary of the application information reviewed, and evaluation findings and conclusions, are discussed in the SE sections below for each specific review area. A summary and overall conclusions on the staff's technical evaluation of the Hermes ESFs are provided in SE Section 6.4, "Summary and Conclusions on Engineered Safety Features."

6.1 <u>Summary Description</u>

PSAR Section 6.1, "Summary Description," provides a high-level overview of the Hermes ESFs. The ESFs for the Hermes non-power test reactor consist of the functional containment and the decay heat removal system (DHRS), both of which are credited in PSAR Chapter 13, "Accident Analysis." The functional containment includes the tristructural isotropic (TRISO) fuel particles and the Flibe coolant. The fuel design is the primary means of containing radionuclides for the Hermes reactor. The DHRS removes heat from the reactor vessel (RV) to ensure RV and fuel integrity when the normal heat rejection system is not available.

NUREG-1537, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors,” Part 1, “Format and Content,” and Part 2, “Standard Review Plan and Acceptance Criteria,” Section 6.1, “Summary Description,” do not stipulate any specific review findings for this section; therefore, the staff did not make any findings relative to PSAR Section 6.1. PSAR Sections 6.2, “Functional Containment,” and 6.3, “Decay Heat Removal System,” provide detailed descriptions of the functional containment and DHRS, respectively. The corresponding sections of this SE document the staff’s review findings on these ESFs.

6.1.1 Common Regulatory Evaluation for Engineered Safety Features

Common regulatory requirements for ESFs are identified below. Any additional requirements or guidance specific to a system are identified in the subsection for that system. The applicable regulatory requirements for the evaluation of the Hermes non-power test reactor ESFs are:

- 10 CFR 50.34, “Contents of applications; technical information,” paragraph (a), “Preliminary safety analysis report.”
- 10 CFR 50.34(a)(3)(ii) requires “The design bases and the relation of the design bases to the principal design criteria.”
- 10 CFR 50.34(a)(3)(iii) requires “Information relative to materials of construction, general arrangement, and approximate dimensions, sufficient to provide reasonable assurance that the final design will conform to the design bases with adequate margin for safety.”
- 10 CFR 50.34(a)(4) requires “A preliminary analysis and evaluation of the design and performance of structures, systems, and components [SSCs] of the facility…”
- 10 CFR 50.34(a)(5) requires “An identification and justification for the selection of those variables, conditions, or other items which are determined as the result of preliminary safety analysis and evaluation to be probable subjects of technical specifications for the facility.”
- 10 CFR 50.35, “Issuance of construction permits.”
- 10 CFR 50.40, “Common standards.”

6.2 Functional Containment

6.2.1 Introduction

Instead of using a traditional containment to limit the potential release of radioactive material, the Hermes test reactor uses a functional containment consisting of physical barriers, operating conditions, coolant design, and fuel form. PSAR Section 6.2, “Functional Containment,” describes the approach.

PSAR Section 6.2 states that the TRISO fuel particles retain most of the radioactive material at risk for release. The TRISO particles consist of several layers, as described in PSAR Section 4.2.1, “Reactor Fuel,” each of which forms a barrier that can prevent the release of radionuclides. In addition, PSAR Section 6.2 states that significant margin to the TRISO fuel design temperature of 1,600 °C will be maintained under transient conditions. Furthermore, the TRISO particles are contained within an annular shell inside a spherical pebble, which provides physical protection for the TRISO particles against mechanical damage.

PSAR Section 6.2 further states that the Flibe coolant in which the fuel pebbles are submerged is also credited for retaining radionuclides that are not aerosolized or evaporated during an event. In addition, the near-atmospheric primary system pressure precludes the type of high-energy releases associated with highly pressurized primary systems.

The individual components of the functional containment are described in PSAR Chapter 4, “Reactor Description,” and PSAR Chapter 5, “Heat Transport System.” PSAR Chapter 13 describes accident analyses using the integral functional containment approach. In addition, PSAR Chapter 14, “Technical Specifications,” discusses variables and conditions that are probable subjects of TSs associated with the fuel, coolant, and reactor.

6.2.2 Regulatory Evaluation

The requirements in the common regulatory evaluation for ESFs apply to the Hermes functional containment. There are no additional regulatory requirements for the functional containment.

The applicable guidance for the evaluation of the Hermes functional containment design is as follows:

- NUREG-1537, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors,” Part 1, “Format and Content,” and Part 2, “Standard Review Plan and Acceptance Criteria,” Section 6.2.1, “Confinement,” and Section 6.2.2, “Containment.”
- SECY-18-0096, “Functional Containment Performance Criteria for Non-Light-Water-Reactors” and its approval in SRM-SECY-18-0096, “Staff Requirements – SECY-18-0096 - Functional Containment Performance Criteria for Non-Light-Water-Reactors.”

6.2.3 Technical Evaluation

In SECY-18-0096, the staff recognized that non-light-water reactor (non-LWR) technologies may allow or require approaches different from those of LWRs to fulfill the safety function of limiting the release of radioactive materials. Therefore, the staff proposed a methodology for establishing functional containment performance criteria for non-LWRs. SECY-18-0096 defines “functional containment” as “a barrier, or a set of barriers taken together, that effectively limits the physical transport of radioactive materials to the environment.” The methodology calls for designers to establish performance criteria and specific functions to be performed by SSCs for each event category (normal operations, anticipated operational occurrences, design basis events, beyond design basis events, and design basis accidents). The design of each SSC would then be based on the aggregate of performance requirements from all event categories and fundamental safety functions, as well as any other roles chosen for the SSC. The Commission approved the staff’s proposed approach in SRM-SECY-18-0096.

The staff notes that the Hermes CP application does use a functional containment approach but does not follow the event categorization scheme in SECY-18-0096. Instead, the Hermes CP application takes a maximum hypothetical accident (MHA) approach, described in PSAR Chapter 13, intended to bound all postulated events in terms of dose consequences, consistent with the guidance for non-power reactors in NUREG-1537. PSAR Chapter 13 states that the MHA analysis demonstrates dose consequences of the MHA are within the accident dose criteria of 10 CFR 100.11(a) as shown in PSAR Table 13.22, “Maximum Hypothetical Accident Dose Consequences.” PSAR Section 6.2 describes the components and operating conditions that define the Hermes functional containment, which include the TRISO fuel particle, Flibe coolant, and low primary system pressure. The PSAR then identifies key performance criteria on specific SSCs to ensure the MHA remains bounding: specified acceptable system radionuclide release design limits for the fuel (discussed in PSAR Section 4.2.1) and circulating activity limits for the Flibe coolant (discussed in PSAR Section 5.1.1). The acceptability of the functional containment is demonstrated through design and analysis of these individual features as well as their combined capability, as evaluated in PSAR Chapter 13 accident analyses (particularly, the MHA analysis).

The staff evaluations of the functional containment features and their integral performance are provided in the following SE sections, which correspond with PSAR sections of the same numbering:

- Section 4.2.1, "Reactor Fuel"
- Section 4.3, "Reactor Vessel System"
- Section 5.1, "Primary Heat Transport System"
- Section 13.1.1, "Maximum Hypothetical Accident"
- Section 13.2.1, "Maximum Hypothetical Accident"

In addition, the staff notes that the proposed subjects of TS on fuel and coolant systems are necessary to ensure that the reactor remains within analyzed conditions and that actual dose consequences remain within those calculated as part of the MHA analysis.

NUREG-1537, Part 2, Chapter 6 provides guidance for evaluating "typical" ESFs, including the confinement, containment, and emergency core cooling system. However, it does not provide guidance for evaluating a functional containment. NUREG-1537, Part 2, Chapter 6 states that not all the ESFs it discusses may be found in a given design and that systems it does not discuss may be considered ESFs. In the latter case, the reviewer should evaluate these ESFs in a manner similar to that for the ESFs explicitly discussed in NUREG-1537. The staff notes that the objectives of a functional containment are effectively the same as those of a confinement or containment. Therefore, the staff considered applicable portions of the related NUREG-1537 acceptance criteria from Section 6.2.1, "Confinement," and Section 6.2.2, "Containment," in its evaluation.

The staff notes that Kairos has identified the need for a functional containment as an ESF based on its accident analyses and credits the functional containment for mitigating the consequences of accident scenarios. The staff notes that the functional containment does not interfere with normal operations or safe reactor shutdown because it is part of the normal and inherent reactor design. The goal of the functional containment is to maintain potential radiological exposures to the facility staff and members of the public below regulatory limits. Kairos's preliminary MHA analysis suggests that the Hermes reactor maintains radiological consequences within the accident dose criteria of 10 CFR Part 100, and the staff will confirm this when it evaluates the operating license (OL) application. The staff notes that safety related instrumentation to monitor coolant temperature, vessel temperature, and coolant activity will be used to monitor components of the functional containment. The staff also notes that Kairos identified the probable subjects of TSs associated with the functional containment, which, along with the fact that the functional containment features are part of normal operations, will ensure the functional containment is available and operable when needed to mitigate accident consequences. Therefore, the staff finds that the preliminary information on the Hermes functional containment is consistent with the applicable criteria of NUREG-1537.

6.2.4 Conclusion

Based on its findings above, the staff concludes the information in Hermes PSAR Section 6.2 is sufficient, is consistent with the applicable guidance, and meets the regulatory requirements identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. In addition, the staff finds the preliminary information on the functional containment approach is consistent with the approach described in SECY-18-0096 and SRM–SECY-18-0096. Further information as may be required to complete the review of the Hermes functional containment (e.g., final safety analyses) can reasonably be left for later consideration at the OL stage since this information is not necessary to be provided as part of a CP application.

6.3 Decay Heat Removal System

6.3.1 Introduction

PSAR Section 6.3, “Decay Heat Removal System,” describes the DHRS, which is an ex-vessel system that removes decay heat from the reactor core during normal and off-normal conditions. Its safety function is to remove decay heat during and after postulated events, including the MHA, that assume unavailability of the normal heat rejection system. PSAR Section 6.1 states that this heat removal is necessary to maintain reactor vessel temperatures below the design limit and helps to ensure fuel integrity.

PSAR Section 6.3.1, “Description,” states that the DHRS includes four independent trains comprised of annular thermosyphon thimbles, steam separators, and water storage tanks. Heat is transferred from the reactor vessel to the water-based thermosyphons through radiation and convection. Water in the thermosyphons, supplied by the water storage tanks, boils off and vents to the atmosphere. The PSAR states that the DHRS provides sufficient cooling for up to 7 days as needed after a postulated event in which normal cooling is unavailable. PSAR Section 6.3.1 further states that all portions of the DHRS credited in Chapter 13 are safety related and passive, and the DHRS does not require electrical power or operator action to perform its safety function during a postulated event.

6.3.2 Regulatory Evaluation

The requirements in the common regulatory evaluation for ESFs apply to the Hermes DHRS. There are no additional regulatory requirements for the DHRS.

The applicable guidance for the evaluation of Hermes DHRS design are as follows:

- NUREG-1537, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors,” Part 1, “Format and Content,” and Part 2, “Standard Review Plan and Acceptance Criteria,” Section 5.3, “Secondary Coolant System,” and Section 6.2.3, “Emergency Core Cooling System.”

6.3.3 Technical Evaluation

PSAR Section 3.1.1, “Design Criteria,” describes the principal design criteria (PDC) that are applicable to the Hermes reactor. These PDC were reviewed and approved by the staff in KP-TR-003-NP-A, Revision 1, “Principal Design Criteria for the Kairos Power Fluoride Salt-

Cooled, High Temperature Reactor." PSAR Section 6.3.2, "Design Bases," identified the design bases for the DHRS. The PSAR states that the following PDCs are applicable to the fuel:

- PDC 1, "Quality standards and records," which requires SSCs that are safety related be designed, fabricated, erected, and tested to appropriate quality standards, and to identify generally recognized codes and standards that are used.
- PDC 2, "Design bases for protection against natural phenomena," which requires safety related SSCs be designed to withstand the effects of natural phenomena.
- PDC 3, "Fire protection," which requires safety related SSCs to be designed and located to minimize the probability and effect of fires and explosions.
- PDC 4, "Environmental and dynamic effects design bases," which requires that SSCs that are safety related be designed to accommodate the effects of environmental conditions.
- PDC 10, "Reactor design," which requires the reactor core be designed to ensure Specified Acceptable Radiological Release Design Limit (SARRDLs) are not exceeded.
- PDC 34, "Residual Heat Removal," which requires a system to remove residual heat at a rate such that SARRDLs and the design conditions of safety related elements of the reactor coolant boundary are not exceeded.
- PDC 35, "Passive residual heat removal," which requires a system to assure sufficient core cooling during postulated events and to remove residual heat following postulated events.
- PDC 36, "Inspection of the passive residual heat removal system," which requires the system to permit appropriate periodic inspection of important components.
- PDC 37, "Testing of the passive residual heat removal system," which requires the system to permit appropriate periodic functional testing.

NUREG-1537, Part 2, Chapter 6, provides guidance for evaluating "typical" ESFs, including the confinement, containment, and emergency core cooling systems. However, it does not provide guidance for evaluating a passive, safety related DHRS. NUREG-1537, Part 2, Chapter 6, states that not all of the ESFs it discusses may be found in a given design and that systems it does not discuss may be considered ESFs. In the latter case, the guidance states that the reviewer should evaluate these ESFs in a manner similar to that for the ESFs explicitly discussed in NUREG-1537. The closest NUREG-1537 analogs to the Hermes DHRS are the secondary coolant system and emergency core cooling system. Therefore, the staff considered applicable portions of NUREG-1537 acceptance criteria from Section 5.3, "Secondary Coolant System," and Section 6.2.3, "Emergency Core Cooling System," in its evaluation.

The staff reviewed PSAR Section 6.3, focusing on the following areas of review:

- DHRS design bases and required capability, as derived from postulated event analyses
- DHRS design features to ensure it provides adequate cooling
- Tests and inspections to ensure continued operability of the DHRS

6.3.3.1 PSAR Design Description

Each of the four independent DHRS trains consists of one water storage tank, one steam separator, and six thimbles, as illustrated in PSAR Figure 6.3-1, "Functional Diagram of the DHRS." PSAR Figure 6.3-2, "Notional Diagram of the DHRS Separator and Float Valve," illustrates the concept of the steam separator and its connections in additional detail, and PSAR

Figure 6.3-3, “Annular Thimble Geometry,” shows the annular thermosyphon concept. PSAR Section 6.3.1.1, “Water Storage Tanks,” states that each water storage tank supplies cooling water via gravity-driven flow through a feedwater line to the thimbles and steam separators. The water storage tanks are supplied by the treated water system, described in PSAR Section 9.7.2, “Treated Water System.” This ensures chemistry control for the DHRS, helping to protect against performance issues such as fouling. The staff notes that the water tanks hold sufficient capacity to support up to seven days of operation, as needed, which the staff confirmed via a hand calculation.

PSAR Section 6.3.1.2, “Steam Separators,” states that the feedwater line connects to the steam separator, which serves as the interface between the water storage tank and the six thimbles in that particular DHRS train. A float valve on the thimble feedwater line controls the volume of water in the steam separator, maintaining a controlled free surface. Therefore, according to the PSAR, the flow of water to the thimbles is a function of the boil-off rate in the thimbles, which is in turn a function of reactor vessel temperature. PSAR Section 6.3.1.3, “Thimbles,” states that water enters the thimbles via the central thimble feedwater inlet and downward through the guide tube, then turns upward into the annular evaporator section and evaporates due to heat transfer from the reactor vessel. The less dense two-phase mixture is ejected into the steam separator via the two-phase outlet, and steam exits the steam separator via the steam return line.

PSAR Section 6.3.1 describes the DHRS operating modes. During low decay power operation with reactor power less than the threshold power (~10 megawatts for a fresh core), cooling is provided by parasitic losses to the reactor cavity with the thimbles dry and isolated from the rest of the DHRS. For high decay power operation with reactor power greater than the threshold power, the DHRS is in continuous operation with thimble boil-off replenished by the water from the storage tanks, whose levels are monitored. As reactor power increases above the threshold power core and parasitic cooling is no longer sufficient, the DHRS is placed in service. PSAR Section 6.3.1 states that during this transition phase, the water fills the guide thimble and evaporator tube, which causes them to decrease from the standby temperature (550 °C) to the nominal boil-off operating temperature (100 °C).

6.3.3.2 Staff Evaluation of DHRS Design

The staff asked Kairos during the Decay Heat Removal System audit (ML23115A480) if DHRS qualification testing included low pressure quenching tests to ensure that stable heat removal can be established because the guide thimble and evaporator tube will initially be empty and hence relatively hot prior to its startup (upon reaching the threshold power). In a docketed audit response KP-NRC-2209-003, “Transmittal of Response to NRC Question on DHRS Testing from PSAR Section 6.3 Audit on Hermes Preliminary Safety Analysis Report”, Kairos stated that two-phase flow dynamics associated with quenching at low pressure is included in the qualification testing. Similarly, the staff asked if a thimble feedwater float valve failing to close as heat demand decreases was included in the DHRS qualification testing. The staff notes that the float valve failing to close could potentially flood the steam separator leading to the potential for inadequate heat removal and/or placing large dynamic loads on the various DHRS components. As described in KP-NRC-2209-003, Kairos stated that float valve failure to close is included in the DHRS qualification testing. KP-NRC-2209-003 also addressed other DHRS qualification tests of interest to the staff including the effects of two-phase natural circulation instabilities and potential evaporator tube fouling on the ability to maintain adequate heat removal.

KP-NRC-2212-003, “Transmittal of Changes to Preliminary Safety Analysis Report Chapter 6 and Response to NRC Question on DHRS Testing,” further states that the DHRS design verification process will address important aspects of DHRS materials and mechanical performance, including “thermal shock effects on material properties, flow-induced vibration effects on DHRS components, and metal fatigue effects due to stress and thermal cycling.” Finally, KP-NRC-2209-003 also states that “Qualification testing for the safety-related portion of the DHRS will be defined in a test plan that includes appropriate acceptance criteria and demonstrates the system reliability and adequacy of performance under conditions that simulate the most adverse design basis conditions." The staff notes that the planned DHRS qualification testing covers several broad areas that could challenge adequate heat removal and DHRS structural integrity and performance, such as two-phase flow dynamics associated with quenching at low pressure, two-phase natural circulation instabilities, thermal shock to DHRS components, flow-induced vibrations, metal fatigue, and evaporator tube fouling.

The staff notes that the passive nature of the DHRS also makes overcooling and freezing of the Flibe a possibility. Kairos has proposed, as discussed in KP-TR-018-NP, “Postulated Event Analysis Methodology,” Section 3.2.1, “Postulated Event Categories and Duration of Evaluation,” that freezing of the Flibe is prevented for at least 72 hours without operator action. The staff notes that there may be scenarios where the DHRS is placed in service for adequate cooling but a reactor trip from this condition could cause freezing before 72 hours assuming no operator action. Therefore, the final DHRS design needs to balance adequate heat removal for high and low residual heat loads. The ability of the DHRS to prevent Flibe freezing within 72 hours without operator action will be evaluated by the staff during the OL application review.

PSAR Section 6.3.3, “System Evaluation,” relates the design bases to the design criteria and identifies how the DHRS satisfies the PDC applicable to the design of the system. In the following paragraphs, the staff addresses each PDC by summarizing the information presented in the PSAR and explaining the staff’s evaluation of the adequacy of the preliminary information in the PSAR relative to NUREG-1537 acceptance criteria.

6.3.3.3 PDC 1, Quality Standards and Records:

PSAR Table 6.3-4 identifies the applicable design codes and standards for the DHRS, including American Society of Mechanical Engineers (ASME) Section III, Division 5, for metallic pressure boundary components, ASCE 43-19, “Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities” and ASCE 4-16, “Seismic Analysis of Safety-Related Nuclear Structures” for seismic analysis, and American Concrete Institute (ACI) 349-13, “Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary” for cavity support structures for the DHRS. The staff finds that the preliminary information on the DHRS design is consistent with PDC 1 because Kairos states that it will design safety related portions of the DHRS in conformance with appropriate codes and standards and the quality assurance program. The staff’s evaluation of the quality assurance program is described in SE Chapter 12. The staff’s evaluation of reactor components designed to ASME Section III, Division 5, ASCE 43-19, ASCE 4-16, and ACI 349-13 is described SE Chapters 3 and 4. The staff will review the final DHRS design at the OL stage for conformance with PDC 1.

6.3.3.4 PDC 2, Design Bases for Protection Against Natural Phenomena:

PSAR Section 6.3.3 states that the DHRS is primarily located in the safety related portion of the reactor building. The non-safety related steam vent lines may cross the isolation moat and experience differential displacements as part of a seismic event, as discussed in PSAR

Section 3.5. PSAR Section 6.3.3 states that the steam vent lines are designed such that a failure due to differential displacement does not preclude any safety related SSCs from performing their safety functions. The staff finds that that the preliminary information on the DHRS design is consistent with PDC 2 because of its location in the safety related portion of the reactor building, which provides protection of safety related components from external hazards as described in SE Sections 3.4 and 3.5, and because the steam vent lines are designed to allow safety related SSCs to perform their safety functions in the event of failure due to differential displacement. The staff will review the final DHRS design at the OL stage for conformance with PDC 2.

6.3.3.5 PDC 3, Fire Protection:

PSAR Section 6.3.3 states that the DHRS is designed with the use of low combustible materials and physical separation to minimize fire and explosion risk. PSAR Section 9.4 describes a fire protection program designed to provide protection against fire hazards for safety related SSCs. The staff finds that the preliminary information on the DHRS design is consistent with PDC 3 since the design incorporates low combustible materials and physical separation and because a fire protection program will be implemented. The staff's evaluation of the fire protection plan is described in SE Section 9.4.

6.3.3.6 PDC 4, Environmental and Dynamic Effects Design Bases:

PSAR Section 6.3.3 states that the DHRS will be constructed with materials that can withstand conditions of normal operation, maintenance, testing, and postulated events, including irradiation effects and temperatures up to 750 °C. The staff notes that the design temperature for the DHRS is 750 °C, consistent with the limitation in Regulatory Guide 1.87 relative to the use of ASME Section III, Division 5. The PSAR further states that the low pressure design of the DHRS and use of restraints minimize the likelihood of dynamic effects. In addition, PSAR Section 6.3.1.4 describes how the leak barrier feature of the DHRS provides protection from Flibe-water interactions within the reactor cavity caused by either a failure in the DHRS system or a failure in the Primary Heat Transport System during normal operation or a postulated event. The leak barrier is designed to meet the same pressure and temperature conditions as the DHRS pressure boundary, as described in PSAR Table 6.3-3. Based on the DHRS design parameters, planned qualification testing, and leak barrier features, the staff finds that the preliminary information on the DHRS design is consistent with PDC 4. In addition, the staff finds that the preliminary information is consistent with NUREG-1537 criteria, which state that the design should limit corrosion or other degradation. The staff will review the final DHRS design at the OL stage for conformance with PDC 4.

6.3.3.7 PDCs 10, 34, and 35, Reactor Design, Residual Heat Removal, and Passive Residual Heat Removal:

PDCs 10, 34, and 35 address adequate heat removal under normal operation and postulated events. PSAR Section 6.3.1 states that the DHRS removes residual heat from the reactor core during normal and off-normal conditions. During normal operation, the Primary Heat Transport System is the primary means to remove heat, as discussed in PSAR Chapter 5. During off-normal conditions or following postulated events, the DHRS serves as the primary heat sink to remove residual heat. PSAR Section 6.3.3 states that the system is designed such that three trains are sufficient to remove residual heat with the fourth train assumed to be inoperable to account for the single failure criterion.

The ability of the DHRS to adequately remove residual heat to meet PDCs 10, 34, and 35 is informed by the staff's audit of the DHRS sizing calculation and the illustrative examples in Figures A1-2, A4-1 and A4-2 of KP-TR-018-NP, which demonstrate the various temperature acceptance criteria are met up to at least 72 hours. Based on meeting these acceptance criteria, the staff finds that the preliminary information on the DHRS design is consistent with PDC 10, 34, and 35. In addition, the staff finds that the preliminary information is consistent with NUREG-1537 criteria, which state that the design should be capable of dissipating all necessary fission and decay heat at the appropriate rate for all potential reactor conditions, including postulated events. The staff notes that the events represented in Figures A1-2, A4-1 and A4-2 of KP-TR-018-NP all start at hot full power, steady-state conditions, which is limiting from a maximum temperature and decay heat perspective but may not be limiting from an overcooling perspective as described above in the staff's evaluation of the DHRS design regarding Flibe freezing and overcooling. The staff will review the final DHRS design at the OL stage for conformance with PDC 10, 34, and 35.

6.3.3.8 PDCs 36 and 37, Inspection and Testing of the Passive Residual Heat Removal System:

PDCs 36 and 37 address inspection of the DHRS system and functional system testing, respectively. PSAR Section 6.3.3 states that the DHRS has the capability for online monitoring of water storage tank levels and leaks between the evaporator and thimble. The PSAR also states that the DHRS is designed to allow sufficient access to perform inspections. Finally, PSAR Section 6.3.3 states that the transition from normal to postulated event operation can be functionally tested and the DHRS is in an "always on" operating condition as a demonstration of system availability.

The staff notes that DHRS components will be designed to facilitate inspections. In addition, leak detection and tank level monitoring provide a means to ensure system performance between potential inspection intervals. Based on this design enabling inspection, leak detection, and monitoring, the staff finds the preliminary information on the DHRS design is consistent with PDC 36 because the system is designed to allow for periodic inspections and online monitoring to ensure system integrity and capability to perform its safety function. In addition, the staff finds the preliminary information on the DHRS design is consistent with PDC 37 because of the continuous online monitoring of the system while in service and the ability to perform functional testing. The staff will review the final DHRS design at the OL stage for conformance with PDC 36 and 37.

6.3.3.9 Other NUREG-1537 Criteria

The staff notes that Kairos has identified the need for the DHRS as an ESF based on the Hermes accident analyses and credits the DHRS to mitigate the consequences of accident scenarios. The DHRS does not interfere with normal operations or safe reactor shutdown because the DHRS is outside the reactor vessel and designed to be on during normal operations. The staff notes that the goal of the DHRS is to remove decay heat in order to maintain potential radiological exposures to the facility staff and members of the public below regulatory limits. Kairos's preliminary MHA analysis suggests that the Hermes reactor maintains radiological consequences below regulatory limits, and the staff will confirm this when it evaluates the OL application. The staff notes that the DHRS is designed to be passive without a need for power to perform its safety function. The staff also notes that Kairos identified the probable subjects of TSs associated with the DHRS, which, along with the fact that the DHRS will already be on during normal operations, will ensure the DHRS is available and operable when needed to mitigate the potential consequences of an accident. Therefore, in addition to the NUREG-1537 criteria discussed alongside PDC above, the staff finds that the preliminary information on the Hermes DHRS is consistent with the applicable criteria of NUREG-1537.

6.3.3.10 Testing and Inspection

PSAR Section 6.3.4 states that any tests and inspections of the DHRS will be included with the submission of the OL. However, the staff notes that the PSAR states that the design of the DHRS allows for access for monitoring, inspection, and maintenance, which is important for demonstrating consistency with PDC 36 and 37 as noted in those PDCs above.

The testing and surveillance program will be submitted as part of the Hermes OL application and evaluated at the OL stage. These programs will be tracked in Appendix A of this SE and evaluated during the OL review.

6.3.4 Conclusion

Based on the information provided by Kairos and the staff evaluation documented above, the staff finds that Kairos provided sufficient preliminary information on development of a DHRS design that will perform its safety function of passive residual heat removal, in accordance with 10 CFR 50.34(a)(3). The staff concludes that the preliminary information provided for the DHRS is adequate at this stage of the design and is consistent with PDCs 1, 2, 3, 4, 10, 34, 35, 36, and 37 and with the acceptance criteria of NUREG-1537, Part 2, Section 5.3, “Secondary Coolant System,” and Chapter 6, “Engineered Safety Features.”

Based on its findings above, the staff concludes the information in Hermes PSAR Section 6.3, as supplemented, is sufficient and meets the applicable guidance and regulatory requirements identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Further information as may be required to complete the review of Hermes DHRS can reasonably be left for later consideration at the OL stage since this information is not necessary for the review of a CP application.

6.4 <u>Summary and Conclusions on the Engineered Safety Features</u>

The staff evaluated the information on the Hermes ESFs as described in PSAR Chapter 6, as supplemented, and finds that the preliminary information on, and design criteria of, the ESFs, including the PDC, design bases, and information relating to materials of construction, general arrangement, and approximate dimensions: (1) provide reasonable assurance that the final design will conform to the design bases, (2) meet all applicable regulatory requirements, and (3) meet the applicable acceptance criteria in NUREG-1537, Part 2. Based on these findings, the staff makes the following conclusions regarding issuance of a CP in accordance with 10 CFR 50.35 and 10 CFR 50.40:

- Kairos has described the proposed design of the ESFs, including, but not limited to, the principal engineering criteria for the design, and has identified the major features or components incorporated therein for the protection of the health and safety of the public.

- Such further technical or design information as may be required to complete the safety analysis of the ESFs, and which can reasonably be left for later consideration, will be provided in the FSAR.

- There is reasonable assurance: (i) that the construction of the Hermes facility will not endanger the health and safety of the public, and (ii) that construction activities can be conducted in compliance with the Commission's regulations.

- The issuance of a permit for the construction of the Hermes facility would not be inimical to the common defense and security or to the health and safety of the public.

6.5 References

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7 INSTRUMENTATION AND CONTROL SYSTEMS

Chapter 7 of the Kairos Power LLC (Kairos) Hermes construction permit (CP) safety evaluation (SE) describes the U.S. Nuclear Regulatory Commission (NRC) staff technical review and evaluation of the preliminary design of the Hermes non-power test reactor structures, systems, and components (SSCs) as presented in Chapter 7.0, "Instrumentation and Controls," of the Hermes Preliminary Safety Analysis Report (PSAR), Revision 3.

As part of this review, the staff evaluated information on Hermes PSAR's Instrumentation and Control (I&C) systems, with special attention to design and operating characteristics, unusual or novel design features, and principal safety considerations. The preliminary design of Hermes PSAR's I&C systems was evaluated to ensure the appropriate Principal Design Criteria (PDC) and design bases have been established and information relative to materials of construction, general arrangement, and approximate dimensions are sufficient to provide reasonable assurance that the final design will conform to the design basis.

Areas of review for this section included I&C process control systems, reactor protection system, main control room (MCR), remote onsite shutdown panel (ROSP), display information, and sensors. Within these review areas, the staff assessed the preliminary design of the I&C systems needed to monitor key parameters and variables, maintain parameters and variables within prescribed operating ranges, alert operators when operating ranges are exceeded, and assure safety limits are not exceeded.

7.1 Instrumentation and Controls Overview

Hermes PSAR, Section 7.1.1, "Summary Description," states that the I&C systems monitor and control plant operations during normal operations and planned transients. The systems also monitor and actuate protection systems in the event of unplanned transients. The I&C is comprised of four parts, described in the bulleted list below. Each of the four parts are described in further detail in subsequent subsections of this SE. The architectural design of the system accounts for interconnection interfaces for plant I&C SSCs. PSAR Figure 7.1-1, "Instrumentation and Controls System Architecture," provides an overview of the I&C system architecture.

- The plant control system (PCS) provides the capability to reliably control the plant systems during normal, steady state, and planned transient power operations, including normal plant startup, power maneuvering, and shutdown. The PCS is evaluated in Section 7.2 of this SE.
- The reactor protection system (RPS) provides protection for reactor operations by initiating signals to mitigate the consequences of postulated events and to ensure safe shutdown.
- The RPS is evaluated in Section 7.3 of this SE.
- The MCR and ROSP provide the capability for plant operators to monitor plant systems, control plant systems, and to initiate plant shutdown. The MCR and ROSP are evaluated in Section 7.4 of this SE.
- Sensors provide input to multiple control and protection systems. Sensors are evaluated in Section 7.5 of this SE.

As stated in the PSAR, the I&C system implements the Institute of Electrical and Electronics Engineers (IEEE) Standard 603-2018, "Standard Criteria for Safety Systems for Nuclear Power

Generating Stations," IEEE Standard 7-4.3.2-2003, "IEEE Standard Criteria for Programmable Digital Devices in Safety Systems of Nuclear Power Generating Stations," and other consensus standards for safety related I&C functions. The I&C system is designed to incorporate the principles of independence, redundancy and diversity. Features reflecting those principles are discussed in the specific subsystem descriptions.

The RPS is the safety related system credited for tripping the reactor and actuating engineered safety features. Accordingly, the RPS is isolated and independent from the other I&C systems and uses input signals from independent instrumentation. RPS instrumentation signals are provided to the PCS via a data diode, which is part of the RPS hardware platform. As described in PSAR Section 7.3, "Reactor Protection System," the RPS is isolated from other I&C systems, including the MCR and the ROSP, using safety-related isolation hardware. Isolation is achieved through features built into the hardware platform or through separate isolation devices. The I&C system includes the capability for both manual and automatic control. The sensors for temperature, pressure, neutron count rates, level, flow, radiation level, and other analog and digital field detectors provide input to the RPS and PCS.

The PSAR states that the RPS includes sensors, trips and interlocks to shut down the reactor when operating parameters exceed operational limits. This includes release of the control and shutdown elements within a set of defined parameters after the onset of a postulated event. As shown on PSAR Figure 7.1-1, the RPS sensors are separate from the PCS sensors, which input into the PCS. Specific trips and interlocks are discussed in Section 7.3. The PSAR states that RPS actuate setpoints for trips and interlocks are calculated based on the following design approaches:

- Simulation models: Time to reach operational limits based on system qualification (environments, process conditions, etc.) as demonstrated by actual empirical data collected during simulation testing.
- RPS Technical Specifications: Measurement time, process parameters as informed by safety case assumptions and bounded by Technical Specification limits.
- Mechanical design and testing - response time for actuation to complete: Time to detect, process, and actuate the required controls; this time should be less than the time between event onset and parameter reaching a limiting condition for continued operation.
- Tiered (graded) approach to protection: The RPS utilizes highly reliable safety related parameters as the final level of protection for public health and safety.

The PDC for the facility SSCs are described in PSAR Chapter 3, "Design of Structures, Systems and Components," and are based on those specified in the NRC-approved Kairos Power Topical Report, KP-TR-003-NP-A, "Principal Design Criteria for the Kairos Power Fluoride Salt-Cooled, High Temperature Reactor."

7.2 <u>Plant Control System</u>

7.2.1 Introduction

Hermes PSAR, Section 7.2.1, "Description," states that the PCS is a non-safety -related control system which controls reactor startup, changes in power levels, and shuts down the reactor. The PCS is made up of three subsystems:

- reactor control system (RCS)
- reactor coolant auxiliary control system (RCACS)
- primary heat transport control system (PHTCS)

The PCS maintains plant parameters within the normal operating envelope and provides data to the control consoles located in the main control room.

As described in the PSAR, the Hermes PCS is a microprocessor-based distributed control system that individually controls plant systems using applicable inputs. The subsystems listed above are integrated into the PCS using non-safety related signal wireways which are terminated at local cabinets and use redundant, non-safety, real time data highways. The plantwide sensor inputs are used to verify interlock and permissive rules for the various plant states. The sensor data is also used to provide feedback and alarms to the operators via the control consoles. The PCS is powered by alternating current and direct current (DC) power supplies which are discussed in Hermes PSAR Chapter 8, "Electric Power System." The PCS uses non-safety related sensor inputs as well as safety related sensor inputs from the RPS as described in PSAR Section 7.3.3.

7.2.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of Hermes PSAR Section 7.2 are as follows:

- 10 CFR 50.34, "Contents of applications; technical information," paragraph (a), "Preliminary safety analysis report."
    - 10 CFR 50.34(a)(3)(ii) requires "The design bases and the relation of the design bases to the principal design criteria."
    - 10 CFR 50.34(a)(3)(iii) requires "Information relative to materials of construction, general arrangement, and approximate dimensions, sufficient to provide reasonable assurance that the final design will conform to the design bases with adequate margin for safety."
    - 10 CFR 50.34(a)(4) which requires "A preliminary analysis and evaluation of the design and performance of structures, systems, and components [SSCs] of the facility…"
    - 10 CFR 50.34(a)(5) requires "…identification and justification for the selection of those variables, conditions, or other items which are determined as a result of preliminary safety analysis and evaluation to be probable subjects of technical specifications for the facility…"
- 10 CFR 50.35, "Issuance of construction permits."
- 10 CFR 50.40, "Common standards."

The applicable guidance for the evaluation of Hermes PCS design is as follows:

- NUREG-1537, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors," Part 1, "Format and Content," and Part 2, "Standard Review Plan and Acceptance Criteria," Section 7.3, "Reactor Control System."

The Design Specific Review Standard (DSRS) for NuScale Small Modular Reactor Design, Chapter 7, “Instrumentation and Controls,” was used to evaluate I&C design principles of independence, redundancy and diversity, and the I&C architecture for the PCS.

7.2.3 Technical Evaluation

Hermes PSAR, Section 3.1, Table 3.1-3, “Principal Design Criteria” identifies PDC 13 as applicable to I&C systems.

7.2.3.1 Architecture

The PCS is made up of three subsystems: RCS, RCACS, and PHTCS. As shown in Figure 7.1-1 in the PSAR, each of the subsystems are independent from one another. The PCS is independent from the MCR, isolated via a gateway, and is independent and isolated from the RPS sensor inputs via a one-way data diode. The non-safety sensors provide input signals using non-safety related signal wireways that are terminated at local cabinets using redundant, non-safety, real time data highways.

PSAR Section 7.2.1.1 states that the RCS controls and monitors systems and components that support normal operation, planned transients, and normal shutdown of the reactor. The RCS controls the reactor systems, primary heat transport systems, and coolant auxiliary systems identified in Figure 7.1-1 of the PSAR. The RCS controls reactivity for normal operations and normal shutdown using reactor control elements and reactor shutdown elements in the reactivity control and shutdown system (RCSS). The RCS is capable of incrementally changing the position of reactor control elements and of releasing the control and shutdown elements. The RCS inputs include reactor outlet and inlet temperature sensors and source and power range neutron excore detectors. The RCS provides a reactor monitoring function to monitor plant components that are associated with reactor functions. The RCS uses source and power range sensors that are located outside the reactor vessel for reactor control. The RCS controls pebble insertion and extraction, in-vessel pebble handling, and ex-vessel pebble handling in the pebble handling and storage system (PHSS), and is capable of counting linearized pebbles external to the vessel, controlling the rate of pebble insertion and removal from the vessel, and controlling pebble distribution within the PHSS. Additionally, the RCS controls the reactor thermal management system (RTMS), which monitors the temperature of the primary system to maintain it within the normal operating envelope and to implement planned transients. The RCS also controls external heating elements in the RTMS to prevent overcooling.

PSAR Section 7.2.1.2 states that the RCACS controls the chemistry control system that monitors reactor coolant chemistry. The RCACS also controls the coolant inventory management system. The monitoring systems provide information to facilitate maintaining coolant purity and circulating activity within specifications for the system. The RCACS also controls the inert gas system and tritium management system.

For the PHTCS, PSAR Section 7.2.1.3 states that the PHTCS controls and monitors systems and components that support normal operation of the primary heat transport system (PHTS). The purpose of the PHTCS is to control the transport of primary coolant through the PHTS, to maintain the primary coolant in a liquid state, to control the rejection of heat from the PHTS, and to monitor the inventory of primary coolant in the PHTS. The PHTCS maintains the parameters in the PHTS within the normal operating envelope. The PHTCS controls the primary salt pump, the primary loop thermal management subsystem, and the heat rejection subsystem. The PHTCS does not provide a safety function; however, as discussed in Section 7.3 of this SE, the

RPS trips the primary salt pump (PSP) on a reactor trip, as a protection feature for the reactor system related to the pump.

DSRS Chapter 7, Sections 7.1.2, 7.1.3, and 7.1.5 provide guidance to review the I&C principles of independence, redundancy, and diversity. DSRS Appendix B provides guidance for reviewing I&C architectures. The architecture shown in Figure 7.1-1 and the descriptions provided in Section 7.2 of the Hermes PSAR shows appropriate electrical isolation and communication independence for demonstrating independence. The preliminary design contains multiple channels for safety related functions, giving appropriate redundancy. The preliminary design includes both functional and component diversity. Because of these preliminary design features, the staff finds that the information provided by Kairos demonstrates an adequate design basis for the preliminary design of the PCS to meet the I&C design principles of independence, redundancy and diversity and maintain the plant within its normal operation, and is consistent with the guidance found in the DSRS and in Appendix B of the DSRS. Further information can reasonably be left for later consideration at the operating license (OL) stage.

7.2.3.2 Communications

As shown on PSAR Figure 7.1-1 and described in PSAR Section 7.2.1, there is no communication from the PCS to the RPS; communication is from the RPS to the PCS through safety related isolation and data diode. Additionally, the RPS provides interlocks that remove the power from the RCSS control, PHSS, RTMS, PSP, Primary Loop Thermal Management Control System, and Heat Rejection Control System controllers. The description of communication paths between the PCS and RPS provided by Kairos is consistent with the guidance in DSRS Section 7.1.2. on independence because the proposed design exhibits communication independence between safety and non-safety systems. The staff finds the information to be adequate at this stage of the licensing process and that further information can reasonably be left for later consideration at the OL stage.

7.2.3.3 Codes and Standards

Hermes PSAR, Table 7.2-2, “Standards Applicable to the Plant Control System” states that the Hermes software development process will follow Annex C, Sections C.2.2.2, C.2.2.3 and C.2.3 of IEEE Std. 7-4.3.2-2003, International Electrotechnical Commission (IEC) 61131 for the programable controllers, and IEC 62443 for cybersecurity. The staff reviewed PSAR Table 7.2-2, which lists the standards for the digital platform. The staff finds that the standards provided by Kairos are adequate for the design of the PCS because the standards listed provide sufficient guidance for software development, hardware/software for controllers, and cybersecurity and are consistent with the applicable acceptance criteria in NUREG-1537, Part 2, Section 7.3. The staff finds the information to be adequate at this stage of the licensing process and that further information can reasonably be left for later consideration at the OL stage.

7.2.3.4 Technical Specifications

PSAR Table 14.1-1, “Proposed Variables and Conditions for Technical Specifications” states that the RCS “objective is to infer or calculate reactivity coefficients during normal plant operation to limit the severity of a reactivity transient.” The staff reviewed the information provided in PSAR Section 7.2.1.1 that describes how the RCS controls reactivity for normal operations and limits rapid reactivity insertion via the reactor control elements. Additionally, PSAR Section 7.2.3 describes the PCS, which is designed to monitor plant parameters and maintain systems with normal operation and to control planned transients associated with anticipated operational occurrences. The staff finds the information provided is adequate to support the preliminary development of the technical specifications and is consistent with the applicable acceptance criteria in NUREG-1537, Part 2, Section 7.3 because setpoints are adjusted automatically based on plant modes or adjusted by operators to limit the severity of reactivity transients, thus maintaining reactivity coefficients within limits over the allowable range of operation. The staff finds the information to be adequate at this stage of the licensing process, and that further information can reasonably be left for later consideration at the OL stage.

7.2.3.5 Logic, Displays, and Alarms

As stated in Hermes PSAR Section 7.2.1, the PCS includes trips, interlocks, and annunciations to monitor the operation of the PCS. The staff reviewed PSAR Sections 7.2.1.1, 7.2.1.2, 7.2.1.3, 7.2.1.4, Tables 7.2-1 and 7.2-3. Because the trips, interlocks, and annunciations as described in the PSAR are able to monitor and maintain variables and systems over their anticipated ranges for normal operation and over the range defined in postulated events, the staff finds that the preliminary design is consistent with the applicable acceptance criteria in NUREG-1537, Part 2, Section 7.3. The staff finds the information to be adequate at this stage of the licensing process and that further information can reasonably be left for later consideration at the OL stage.

7.2.3.6 Failure Modes

Hermes PSAR, Section 7.2.3, states that the PCS is designed so that it cannot interfere with the RPS's ability to perform its safety functions. This is accomplished by isolating the RPS from the PCS and other non-safety SSCs. Additionally, the PSAR states that the RPS deactivates non-safety related SSCs controlled by the PCS that would affect the RPS from performing its safety functions. The isolation and deactivation of non-safety SSCs are described and evaluated in Section 7.3 of this SE. Because of these isolation and deactivation features, the failure modes of the PCS do not interfere with the RPS performance of its safety functions, and the staff finds that the preliminary design is consistent with the applicable acceptance criteria in NUREG-1537, Part 2, Section 7.3. The staff finds the information to be adequate at this stage of the licensing process and that further information can reasonably be left for later consideration at the OL stage.

7.2.4 Conclusion

The staff finds that the level of detail provided on PCS, including its RCS, is consistent with the applicable acceptance criteria in NUREG-1537, Part 2, Section 7.3, "Reactor Control System," and demonstrates an adequate design basis for a preliminary design.

A more detailed evaluation of information (e.g., ranges of transient and steady-state conditions, requirements for multiple setpoints and trip criteria, PCS platform) will occur during the review of the Hermes OL application, at which time the staff will confirm that the final design conforms to PDC 13 for the facility SSCs based on the NRC-approved Kairos Power Topical Report, KP-TR-003-NP-A and applicable regulations.

Based on its review, the staff finds that the preliminary design of the Hermes PCS, as described in Hermes PSAR Section 7.2, is sufficient and meets the applicable regulatory requirements and guidance identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 10 CFR 50.40.

7.3 Reactor Protection System

7.3.1 Introduction

Hermes PSAR, Section 7.3.1, "Description," states that the RPS provides protection for reactor operations by initiating signals to mitigate the consequences of postulated events and to ensure safe shutdown. The RPS is the only portion of the I&C system that is safety related and that is credited for tripping the reactor and actuating engineered safety features. The purpose of the RPS is to actuate upon receipt of a trip signal in response to out-of-normal conditions and provide automatic initiating signals to protection functions. There are three possible trip sources that can cause the RPS to actuate:

- process variables reach or exceed specified setpoints, as measured by RPS sensors;
- manual initiation from the MCR or ROSP; and
- plant electric power is lost (with a time delay).

There are three protection functions that result from RPS actuation:

- actuate the RCSS that inserts control and shutdown elements into the reactor core;
- inhibit actions from the PCS so that it does not interfere with the functioning of the RPS; and
- ensure an actuation of the decay heat removal system (DHRS) that passively removes heat from the PHTS to the atmosphere.

Actuation of the RPS to trip the reactor includes several actuations that stop specific non-safety related SSCs, normally controlled by PCS, to ensure that those non-safety related SSCs do not prevent a safety related SSC from performing its safety function. The non-safety related functions that are stopped via removal of power to controllers are shown in Hermes PSAR, Figure 7.1-1. The RCSS element withdrawal is inhibited after a loss of power to prevent inadvertent positive reactivity insertion when power returns. The PSP is stopped to maintain a low-pressure Flibe salt coolant inventory in the core. The heat rejection subsystem blower is stopped to prevent potential forced air ingress into the PHTS and inadvertent overcooling. Pebble extraction and insertion in the PHSS is stopped to prevent removing pebbles from the core in the event of a PHSS extraction line break. Finally, RTMS actuation is prohibited to prevent a challenge to the heat removal capability of the DHRS. These inhibitions are accomplished through safety related trip devices as shown in PSAR Figure 7.1-1.

The RPS is built on a logic-based platform that does not utilize software or microprocessors for operation. It is composed of logic implementation using discrete components and field programmable gate array (FPGA) technology. The RPS is isolated from other I&C systems, including MCR and the ROSP, using safety related isolation hardware. Isolation is achieved through features built into the hardware platform or through separate isolation devices.

Reactor trip functions are hardcoded into FPGA logic and are not dependent on plant operating state. Operating conditions are compared against the trip setpoints and actuate protection functions according to established programmable logic. The RPS cabinets are located within the safety related portion of the reactor building within an environmentally separated enclosure.

The RPS uses inputs from the reactor core temperature, reactor vessel level, and source and power range neutron excore detectors.

7.3.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of Hermes PSAR Section 7.3 are as follows:

- 10 CFR 50.34, "Contents of applications; technical information," paragraph (a), "Preliminary safety analysis report."
  - 10 CFR 50.34(a)(3)(ii) requires "The design bases and the relation of the design bases to the principal design criteria."
  - 10 CFR 50.34(a)(3)(iii) requires "Information relative to materials of construction, general arrangement, and approximate dimensions, sufficient to provide reasonable assurance that the final design will conform to the design bases with adequate margin for safety."
  - 10 CFR 50.34(a)(4) which requires "A preliminary analysis and evaluation of the design and performance of structures, systems, and components [SSCs] of the facility…"
  - 10 CFR 50.34(a)(5) requires "…identification and justification for the selection of those variables, conditions, or other items which are determined as a result of preliminary safety analysis and evaluation to be probable subjects of technical specifications for the facility…"
- 10 CFR 50.35, "Issuance of construction permits."
- 10 CFR 50.40, "Common standards."

The applicable guidance for the evaluation of Hermes RPS design is as follows:

- NUREG-1537, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors," Part 1, "Format and Content," and Part 2, "Standard Review Plan and Acceptance Criteria," Section 7.4, "Reactor Protection System."

DSRS for NuScale Small Modular Reactor Design, Chapter 7 was used to evaluate I&C design principles of independence, redundancy and diversity, plant safety function allocation, communication between safety related and non-safety related I&C systems, and the I&C architecture for the Hermes RPS.

7.3.3 Technical Evaluation

Hermes PSAR, Section 3.1, Table 3.1-3 identifies the following PDCs as applicable to the RPS:

- PDC 1, "Quality Standards and Records,"
- PDC 2, "Design bases for protection against natural phenomena,"
- PDC 3, "Fire Protection,"
- PDC 4, "Environmental and dynamic effects design bases,"
- PDC 10, "Reactor design,"
- PDC 13, "Instrumentation and Control,"
- PDC 15, "Reactor coolant system design,"
- PDC 20, "Protection system functions,"
- PDC 21, "Protection system reliability and testability,"
- PDC 22, "Protection System Independence,"

- PDC 23, “Protection system failure modes,”
- PDC 24, “Separation of protection and control systems,”
- PDC 25, “Protection system requirements for reactivity control malfunctions,”
- PDC 28, “Reactivity limits,”
- PDC 29, “Protection against anticipated operation occurrences.”

7.3.3.1 Architecture

Hermes overall I&C architecture is shown in Hermes PSAR, Figure 7.1-1 and the specific RPS architecture is shown in Hermes PSAR, Figure 7.3-1. The staff reviewed the Hermes I&C architecture using the guidance found in DSRS Chapter 7, Sections 7.1.2, 7.1.3, and 7.1.5 and DSRS Appendix B. The I&C architecture for the RPS demonstrates adherence to the fundamental I&C design principles by having four channels, with separate sensors for each channel, identifies trip outputs, and isolation devices, either data diodes or safety related isolation devices for signals going in and out of the RPS. The staff finds that the architecture shown in Figure 7.1-1, Figure 7.3-1 and the descriptions provided in Section 7.3 of the Hermes PSAR demonstrate an adequate design basis for the preliminary design of the RPS to meet the fundamental I&C design principles of independence, redundancy, and diversity for a safety system. The descriptions provided by Kairos are consistent with the guidance found in the DSRS and in Appendix B of the DSRS and the staff finds the information to be adequate at this stage of the licensing process and that further information can reasonably be left for later consideration at the OL stage.

7.3.3.2 Protective Functions

Hermes PSAR, Section 7.3.1 states that the three Kairos Power Fluoride Salt-Cooled High Temperature Reactor (KP-FHR) protection functions resulting from RPS actuation have separate channels of sensor electronics and input devices, redundant and separate groups of signal conditioning, and redundant and separate groups for trip determination to ensure that the three KP-FHR protection functions that result from RPS actuation: 1) actuate the RCSS that inserts control and shutdown elements into the reactor core, 2) inhibit actions from the PCS so that it does not interfere with the functioning of the RPS, and 3) ensure an actuation of the DHRS that passively removes heat from the PHTS to the atmosphere can be met. The staff finds that the preliminary design is adequate and consistent with the applicable acceptance criteria found in NUREG-1537, Part 2, Section 7.4 because of the separation and redundancy in the three protection functions described in PSAR Section 7.3.1. The staff finds that the information provided is adequate at this stage of the licensing process and that further information can reasonably be left for later consideration at the OL stage.

7.3.3.3 Communications

As shown in Figure 7.1-1, all communications between safety related and non-safety related I&C systems are accomplished using a data diode or a safety related isolation device. Actuation of the RPS to trip the reactor includes several actuations that stop specific non-safety related SSCs actuations, normally controlled by the PCS, to ensure that those non-safety related SSCs do not prevent a safety related SSC from performing its safety function. The staff finds that the communications scheme for the RPS demonstrates an adequate design basis for the preliminary design of the RPS to provide independence for the communication between safety and non-safety systems. The descriptions provided by Kairos are consistent with the guidance found in the DSRS Section 7.1.2 and the staff finds the information to be adequate at this stage of the licensing process and that further information can reasonably be left for later consideration at the OL stage.

7.3.3.4 Codes and Standards

Hermes PSAR, Sections 7.3.2, “Design Bases,” and 7.3.3, “System Evaluation,” identify regulatory requirements applicable to the RPS. The RPS is to be designed in accordance with IEEE Std 603-2018. Additional design-related information for the RPS is shown in PSAR Table 7.3-1, “Codes and Standards Applied to the Reactor Protection System.” The staff reviewed Table 7.3-1 and Sections 7.3.2 and 7.3.3 and finds that the codes and standards and descriptions, provided by Kairos, are adequate because sufficient guidance is provided in the codes and standards for development of the safety related RPS and the codes and standards are consistent with the applicable acceptance criteria in NUREG-1537, Part 2, Section 7.4. The staff finds the information to be adequate at this stage of the licensing process and that further information can reasonably be left for later consideration at the OL stage.

7.3.3.5 Logic and Schematics

Hermes PSAR, Figure 7.3-1, “Reactor Protection System Trip Logic Schematic,” and PSAR Sections 7.3.1, 7.3.2, and 7.3.3 provide the information, including system logic and schematic diagrams, showing all instruments, computer hardware and software, electrical, and electro-mechanical equipment used in detecting reactor conditions requiring scram or other reactor protective action and in initiating of the actions. The staff reviewed Figure 7.3-1 and PSAR Sections 7.3.1, 7.3.2, and 7.3.3. The staff finds that the descriptions provided by Kairos are consistent with the applicable acceptance criteria in NUREG-1537, Part 2, Section 7.4 because the trip logic scheme provides protection for reactor operations by initiating signals to mitigate the consequences of postulated events and to ensure safe shutdown. The staff finds the information to be adequate at this stage of the licensing process and that further information can reasonably be left for later consideration at the OL stage.

7.3.3.6 Trip Functions

Hermes PSAR Figure 7.3-1 and Section 7.3.1 describe three possible trip sources, which are: 1) process variables reach or exceed specified setpoints, as measured by the RPS sensors; 2) manual initiation from the MCR or ROSP; and 3) plant electric power is lost (with a time delay). The three protection functions that result from RPS actuation are: 1) activate the RCSS that inserts control and shutdown elements into the reactor core; 2) inhibit actions from the PCS so that it does not interfere with the functioning of the RPS; and 3) ensure activation of the DHRS that passively removes heat from the PHTS to the atmosphere. The staff reviewed the adequacy of the preliminary design to perform the functions necessary to ensure reactor safety for the three protective functions specified in the safety analysis and the design of hardware and software relevant to trip functions using relevant guidance, including IEEE standards and guidance listed by Kairos in PSAR Table 7.3-1. The staff finds that the descriptions provided by Kairos are consistent with the applicable acceptance criteria in NUREG-1537, Part 2, Section 7.4 and the relevant IEEE standards because the trip functions, as described, will be able to perform the functions necessary to ensure reactor safety. The staff finds the information to be adequate at this stage of the licensing process and that further information can reasonably be left for later consideration at the OL stage.

7.3.3.7 Accident Mitigation

PSAR Chapters 5, "Heat Transport System," 6, "Engineered Safety Features," and 13, "Accident Analysis," describe the systems, safety features, and safety functions necessary to mitigate the consequences of postulated events. PSAR Sections 7.3.1.1 and 7.3.1.2 describe the I&C components and logic to actuate those systems and safety features necessary to mitigate the consequences of postulated events and to ensure safe shutdown. The staff finds that PSAR Sections 7.3.1.1 and 7.3.1.2 adequately describe the RPS safety features to ensure initiation of the three protective functions. The preliminary design is consistent with the applicable acceptance criteria in NUREG-1537, Part 2, Section 7.4 because the components and logic are designed to reliably and rapidly initiate automatic actions to achieve the protective functions. The staff finds the information to be adequate at this stage of the licensing process and that further information can reasonably be left for later consideration at the OL stage.

7.3.3.8 Safety Settings

Hermes PSAR Chapter 7 does not provide specific information for proposed trip setpoints, time delays, and accuracy criteria. The Hermes PSAR does not identify the I&C platform or sensors; therefore, the staff cannot verify trip setpoints, time delays, and accuracy criteria. However, the staff finds that the information provided in PSAR Section 7.1.2 is adequate for the preliminary design of the RPS to support tripping of the reactor when called upon because of the architecture and descriptions to perform the functions necessary to ensure reactor safety and the use of ANSI/ISA 67.04.01-2018, to establish the safety related setpoints. Once the design is final, sensors with appropriate ranges established to protect the analytical limits specified in the plant safety analysis will be selected as shown in PSAR Table 7.5-1 and setpoints will be established using methodology described in PSAR Section 7.1.2. The descriptions provided by Kairos are consistent with the applicable acceptance criteria in NUREG-1537, Part 2, Section 7.4 and the staff finds the information to be adequate at this stage of the licensing process and that further information can reasonably be left for later consideration at the OL stage.

7.3.3.9 Response Time

Hermes PSAR, Chapters 7 and 13, do not provide specific information on the RPS equipment response times to satisfy the time allocated from trip initiation to trip completion for the I&C equipment. However, PSAR Section 7.1.2 states that RPS setpoints are calculated considering time to detect, process, and actuate the required controls. Also, Chapter 13, "Transient Assumption," in various sections, states that the postulated event analysis assumes conservative trip and actuation delays to account for any uncertainty in the signal time associated with the RPS. The staff finds the assumption for response time in Chapter 13, to be acceptable as an adequate design basis for the preliminary design because the assumed conservative trip will account for all I&C response times. The descriptions provided by Kairos are consistent with the applicable acceptance criteria in NUREG-1537, Part 2, Section 7.4 and the staff finds the information to be adequate at this stage of the licensing process and that further information can reasonably be left for later consideration at the OL stage.

7.3.3.10 Technical Specifications

The technical specifications described in PSAR Chapter 14 are evaluated by the staff in Section 14 of this SE to verify appropriate safety limits, LSSS, LCOs, surveillance tests and intervals. PSAR Section 7.3.1 describes the RPS features required to be in the technical specifications that are credited for tripping the reactor and actuating engineered safety features. PSAR Section 7.3.4 states that the RPS parameters to which operability controls are applied are reactor core temperature, reactor vessel level, source and power range neutron detectors. Surveillance intervals are established based on operating experience, engineering judgment, and available vendor recommendations. The staff finds that the information provided in Section 7.3 describing operational limits, design parameters, and surveillance/testing information to be adequate for the preliminary development of technical specifications and safety related trip settings, as necessary, for the RPS. Once the design is final and the I&C equipment requirements have been specified, the staff will be able to verify that appropriate safety limits, LSSS, LCOs, surveillance tests and intervals are adequate to ensure reactor safety. The descriptions provided by Kairos are consistent with the applicable acceptance criteria in NUREG-1537, Part 2, Section 7.4 because they identify the parameters which will likely be the subject of technical specifications and also the design principles for operational limits and surveillance. The staff finds the information to be adequate at this stage of the licensing process and that further information can reasonably be left for later consideration at the OL stage.

7.3.3.11 I&C Platform

Hermes PSAR, Section 7.3.1, states that the RPS is built on a logic-based platform that does not utilize software or microprocessors for operation and is composed of logic implementation using discrete components and FPGA technology. The staff reviewed the descriptions provided in PSAR Section 7.3.1 and finds they are consistent with the applicable acceptance criteria in NUREG-1537, Part 2, Section 7.4 because they describe the appropriate software development guidance documents, including verification and validation, that are necessary when developing FPGA-based systems. When the RPS logic-based platform has been identified and more information is provided in the OL application, the staff can confirm the implementation and evaluate if the platform can perform its safety related functions. The staff finds the information to be adequate at this stage of the licensing process and that further information can reasonably be left for later consideration at the OL stage.

7.3.3.12 Single Failure

Hermes PSAR Section 7.3.3 states that no single failure results in loss of the RPS protective functions and PSAR Tables 3.1-3 and 7.3-1, list the codes and standards applicable to the RPS. IEEE Std. 603-2018, specifically Section 5, specifies that the RPS is designed to perform its safety function after a single failure and to meet seismic and environmental qualification, redundancy, diversity, and independence criteria. Additionally, IEEE Std. 379-2014, “IEEE Standard Application of the Single-Failure Criterion to Nuclear Power Generating Station Safety Systems,” is also listed in Table 7.3-1, as a means to meet the single failure criterion. The staff reviewed PSAR Section 7.3.3 and PSAR Tables 3.1-3 and 7.3-1 and finds they provide sufficient descriptions of design principles to ensure that the RPS can be designed to perform its safety function after a single failure and to meet seismic and environmental qualification, redundancy, diversity, and independence criteria. Therefore, the descriptions provided by Kairos are consistent with the applicable acceptance criteria in NUREG-1537, Part 2, Section 7.4, and the staff finds the information to be adequate at this stage of the licensing process and that further information can reasonably be left for later consideration at the OL stage.

7.3.4 Conclusion

The staff finds that the level of detail provided on RPS satisfies the acceptance criteria in NUREG-1537, Part 2, Section 7.4, "Reactor Protection System," and demonstrates an adequate design basis for a preliminary design.

A more detailed evaluation of information (e.g., ranges of transient and steady-state conditions, requirements for multiple setpoints and trip criteria, and RPS platform) will occur during the review of the Hermes OL application, at which time the staff will confirm that the final design conforms to the PDCs 1, 2, 3, 4, 10, 13, 15, 20, 21, 22, 23, 24, 25, 28, and 29 for the facility SSCs, based on in the NRC-approved Kairos Power Topical Report, KP-TR-003-NP-A and applicable regulations.

Based on its review, the staff finds that the design of the Hermes RPS, as described in Hermes PSAR Section 7.3, is sufficient to meet the applicable regulatory requirements and guidance identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 10 CFR 50.40.

7.4 Main Control Room and Remote Shutdown Panel

7.4.1 Introduction

Hermes PSAR, Section 7.4.1, "Description," states that the MCR provides means for operators to monitor the behavior of the plant, control performance of the plant, and manage the response to postulated event conditions in the plant. The ROSP provides separate means to shut down the plant and monitor plant parameters in response to postulated event conditions.

Hermes PSAR, Section 7.4.1.1, states that the MCR contains equipment related to normal operation of the plant. This equipment includes operator and supervisor workstation terminals, which provide alarms, annunciations, personnel and equipment interlocks, and process information. This equipment is the main point of interaction (human/system interface (I)) between operators and the PCS and the information coming from the RPS. The terminals are connected to the main plant network through a network switch. The system uses redundant fiber optic communication channels between the PCS and the MCR. Communication from the RPS to the MCR utilizes a data diode for one-way communication. The MCR console displays plant parameters to allow operators to monitor conditions during and following postulated events. The MCR console contains a manual trip switch that propagates through safety related isolation, which allows operators to initiate a plant trip, but this is not a safety related function nor credited in the accident analyses. The MCR also contains a central alarm panel for the fire protection system so that operators can monitor the status of fire protection equipment inside the reactor building. The central alarm panel includes controls for the ventilation and extinguishing systems related to the response to fires.

Hermes PSAR, Section 7.4.1.2, states that the ROSP provides a human/system interface for plant staff to monitor indications from the reactor protection system including operating status of the RPS and the DHRS in the event that the MCR becomes inaccessible or uninhabitable. The ROSP communicates (one-way, read-only) with the RPS instrumentation using a safety related isolation device, with the ability to initiate a trip signal from a manual trip button that actuates RPS. The ROSP is not safety related and is located in the safety related portion of the reactor building.

7.4.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of Hermes PSAR Section 7.4 are as follows:

- 10 CFR 50.34, “Contents of applications; technical information,” paragraph (a), “Preliminary safety analysis report.”
  - 10 CFR 50.34(a)(3)(ii) requires “The design bases and the relation of the design bases to the principal design criteria.”
  - 10 CFR 50.34(a)(3)(iii) requires “Information relative to materials of construction, general arrangement, and approximate dimensions, sufficient to provide reasonable assurance that the final design will conform to the design bases with adequate margin for safety.”
  - 10 CFR 50.34(a)(4) which requires “A preliminary analysis and evaluation of the design and performance of structures, systems, and components [SSCs] of the facility…”
  - 10 CFR 50.34(a)(5) requires “…identification and justification for the selection of those variables, conditions, or other items which are determined as a result of preliminary safety analysis and evaluation to be probable subjects of technical specifications for the facility…”
- 10 CFR 50.35, “Issuance of construction permits.”
- 10 CFR 50.40, “Common standards.”

The applicable guidance for the evaluation of Hermes MCR and ROSP design is as follows:

- NUREG-1537, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors,” Part 1, “Format and Content,” and Part 2, “Standard Review Plan and Acceptance Criteria,” Section 7.6, “Control Console and Display Instruments.”

The DSRS for NuScale Small Modular Reactor Design, Chapter 7 was used to evaluate I&C design principles of independence, redundancy and diversity, the I&C architecture, and communication between safety and non-safety system for the MCR, ROSP, and other I&C Platforms.

7.4.3 Technical Evaluation

Hermes PSAR, Section 3.1, Table 3.1-3 identifies PDC 19, “Control room,” as applicable to the MCR and ROSP.

7.4.3.1 Architecture

The staff reviewed the overall I&C architecture as shown in Hermes PSAR, Figure 7.4-1, “Architecture of the Main Control Room and the Remote Shutdown Onsite Panel,” for the MCR and ROSP for adherence to the fundamental I&C design principles. DSRS Chapter 7, Sections 7.1.2, 7.1.3, and 7.1.5 provide guidance to review the I&C principles of independence, redundancy, and diversity. Appendix B of the DSRS provides guidance for reviewing I&C architectures. The MCR and ROSP are physically separated from one each other, and both are physically separated from the PCS and RPS as shown in Figure 7.4-1 and described in Hermes PSAR Section 7.4. Therefore, the staff finds that the design of the MCR and ROSP, as described by Kairos, is consistent with the guidance found in the DSRS and in Appendix B of the DSRS. The staff finds the information to be adequate at this stage of the licensing process and that further information can reasonably be left for later consideration at the OL stage.

7.4.3.2 Communication

As shown on PSAR Figures 7.1-1 and 7.4-1 and PSAR Section 7.4.1.1, the communication scheme uses redundant fiber optic communication channels between the PCS and MCR. Data diodes and safety related isolation devices are used between safety related and non-safety related I&C systems. A non-safety related gateway is used to control the flow of data between the I&C systems. The data flow can be either bi-directional or one way between systems. The staff reviewed PSAR Figures 7.1-1 and 7.4-1 and Section 7.4.1.1 and finds that the MCR, ROSP, PCS and the RPS have sufficient isolation between all systems. The staff finds the design of the MCR and ROSP is sufficient because it adheres to independence requirements for communication between safety and non-safety systems. Therefore, the staff finds that the descriptions provided by Kairos are consistent with the guidance found in the DSRS, Section 7.1.2 and the staff finds the information to be adequate at this stage of the licensing process and that further information can reasonably be left for later consideration at the OL stage.

7.4.3.3 Codes and Standards

Hermes PSAR, Table 7.4-1, “Codes and Standards Applied to the Main Control Room and Remote Onsite Shutdown Panel,” identifies ten consensus organization standards or guidance to be used for the design of MCR and ROSP for developing computer software and software verification and validation programs for reactor designs that use computerized protection subsystems. The staff reviewed the codes and standards provided in PSAR Table 7.4-1 and finds that they are sufficient for developing and controlling the software design for the MCR and ROSP. The staff finds this information to be adequate for the preliminary design of the MCR and ROSP because appropriate consensus organization guidance will be followed in developing software necessary for the controls, displays, and alarms. Therefore, the descriptions provided by Kairos are consistent with the applicable acceptance criteria in NUREG-1537, Part 2, Section 7.6 and the staff finds the information to be adequate at this stage of the licensing process and that further information can reasonably be left for later consideration at the OL stage.

7.4.3.4 Controls, Displays, and Alarms

Hermes PSAR, Sections 7.4.1.1 and 7.4.1.2 describe the controls, displays, and alarms to perform the necessary control and protection actuation and information management, storage, and display functions. Hermes PSAR, Section 7.4.3 describes the system evaluation for both the MCR and the ROSP. The staff finds that the information in Section 7.4.3 is adequate in describing the displays and organization of consoles for both MCR and ROSP because design objectives are specified that allow operators to manipulate plant parameters to control the reactor within an acceptable envelope during normal operating conditions. PSAR Section 7.4.3.1 also states that no operator actions are required to mitigate the consequences of postulated events. Because the systems are passive and no operator actions are required to mitigate the consequences of postulated events, no safety related displays are required for the Hermes design. The staff reviewed the elements described in PSAR Sections 7.4.1.1 and 7.4.1.2 for the MCR and ROSP and finds this information to be adequate because the PSAR identifies features for performing the necessary control and protection actuation, and information management, storage, and display functions. Based on the review described in this paragraph, the staff finds that the descriptions provided by Kairos are consistent with the applicable acceptance criteria in NUREG-1537, Part 2, Section 7.6. The staff finds the information to be adequate at this stage of the licensing process and that further information can reasonably be left for later consideration at the OL stage.

7.4.3.5 Technical Specifications

The MCR is described in PSAR Sections 7.4.1.1 and 7.4.3.1. PSAR Chapter 14, Table 14.1-1, Item 3.0, contains proposed Technical Specifications for controls and monitoring systems to ensure the safe operation of the facility. The staff reviewed the above sections and finds that the MCR controls, displays, and alarms descriptions are adequate because they provide the necessary information to support the preliminary development of the technical specifications, specifically Table 14.1-1, Item 3.0, for controls and monitoring systems to ensure the safety operation of the facility. Because the PSAR provides information for the development of appropriate technical specifications, the descriptions provided by Kairos are consistent with the applicable acceptance criteria in NUREG-1537, Part 2, Section 7.6. The staff finds the information to be adequate at this stage of the licensing process and that further information can reasonably be left for later consideration at the OL stage.

7.4.4 Conclusion

The staff evaluated the sufficiency of the preliminary design of Hermes's MCR and ROSP, as described in Hermes PSAR Section 7.4, in part, by reviewing the operator interface description, operator interface data entry, display interface hardware and software human factors engineering, static annunciator and fixed status display, alarm and event display, human machine interface, and display independence using the applicable acceptance criteria from Section 7.6, "Control Console and Display Instruments," of NUREG-1537, Part 2. The staff finds the level of detail provided is consistent with the applicable acceptance criteria in NUREG-1537, Part 2, Section 7.6 and demonstrates an adequate design basis for a preliminary design.

A more detailed evaluation of information (e.g., ranges of transient and steady-state conditions, requirements for multiple setpoints and trip criteria, and MCR and ROSP consoles) will occur during the review of the Hermes OL application, at which time the staff will confirm that the final design conforms to PDC 19 for the facility SSCs based on the NRC-approved Kairos Power Topical Report, KP-TR-003-NP-A and applicable regulations.

Based on its review, the staff finds that the preliminary design of the Hermes control console and display information, as described in Hermes PSAR Section 7.4, is sufficient and meets the applicable regulatory requirements and guidance identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 10 CFR 50.40.

7.5 <u>Sensors</u>

7.5.1 Introduction

Hermes PSAR, Section 7.5.1, "Description," states that sensors are used to provide information about temperature, pressure, neutron count rates, level, flow of the primary coolant and area radiation levels as input to multiple control and protection subsystems. Independent sensors are provided to the RPS and the PCS. Sections in PSAR Chapter 7 provide information on specific I&C subsystems including a discussion of the sensors that support that subsystem and the type of sensor used (i.e., analog or digital).

Temperature, pressure, level, and flow sensors measure and monitor plant operating process parameters and are used to control operations and to initiate reactor protective actions. Neutron source range sensors provide indication of power level during the initial stages of startup. Gamma radiation monitors provide information about area radiation levels during all plant modes of operation.

7.5.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of Hermes PSAR Section 7.5 are as follows:

- 10 CFR 50.34, "Contents of applications; technical information," paragraph (a), "Preliminary safety analysis report."
    - 10 CFR 50.34(a)(3)(ii) requires "The design bases and the relation of the design bases to the principal design criteria."
    - 10 CFR 50.34(a)(3)(iii) requires "Information relative to materials of construction, general arrangement, and approximate dimensions, sufficient to provide reasonable assurance that the final design will conform to the design bases with adequate margin for safety."
    - 10 CFR 50.34(a)(4) which requires "A preliminary analysis and evaluation of the design and performance of structures, systems, and components [SSCs] of the facility…"
    - 10 CFR 50.34(a)(5) requires "…identification and justification for the selection of those variables, conditions, or other items which are determined as a result of preliminary safety analysis and evaluation to be probable subjects of technical specifications for the facility…"
- 10 CFR 50.35, "Issuance of construction permits."
- 10 CFR 50.40, "Common standards."

The applicable guidance for the evaluation of Hermes sensor design is as follows:

- NUREG-1537, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors," Part 1, "Format and Content," and Part 2, "Standard Review Plan and Acceptance Criteria," Section 7.3, "Reactor Control System" and Section 7.4, "Reactor Protection System."

The DSRS for NuScale Small Modular Reactor Design, Chapter 7 was used to evaluate I&C design principles of independence, redundancy and diversity, the I&C architecture, and communication between safety and non-safety sensors and other I&C Platforms.

7.5.3 Technical Evaluation

Hermes PSAR, Section 3.1, Table 3.1-3 identifies the following PDCs as applicable to sensors.

- PDC 1, "Quality Standards and Records,"
- PDC 2, "Design bases for protection against natural phenomena,"
- PDC 3, "Fire Protection,"
- PDC 13, "Instrumentation and Control,"
- PDC 21, "Protection system reliability and testability,"

- PDC 22, “Protection System Independence,”
- PDC 24, “Separation of protection and control systems,”
- PDC 29, “Protection against anticipated operation occurrences.”

7.5.3.1 Architecture

The overall I&C architecture as shown in Hermes PSAR, Figure 7.1-1 provides a set of independent safety related sensors for each RPS channel. PSAR Section 7.3.1.1 states that the RPS receives input from sensors through hardwired, analog, safety related wireways. Once the signal inputs are converted to digital, these safety related signals are sent to the PCS via a one-way data diode. The non-safety related sensors signals are sent to their respective non-safety local cabinets via non-safety wireways. The signals are then sent to the PCS in redundant, non-safety, real time data highways. The staff reviewed PSAR Figure 7.1-1 and PSAR Section 7.3.1.1 and finds that the description of overall I&C architecture is adequate because it demonstrates adherence to the fundamental I&C design principles of independence, redundancy, and diversity for sensors. The descriptions provided by Kairos of the overall I&C architecture are consistent with the guidance found in the DSRS and in Appendix B of the DSRS and the staff finds the information to be adequate at this stage of the licensing process. Further information can reasonably be left for later consideration at the OL stage.

7.5.3.2 Codes and Standards

As shown on Figure 7.1-1, both the non-safety and safety related sensors input directly to their respective PCS and RPS platforms. Accordingly, the codes and standards, as evaluated in Sections 7.2 and 7.3 of this SE, apply to the respective sensors of each platform. The staff reviewed PSAR Sections 7.5.2 and 7.5.3, in conjunction with the review of codes and standards, as they apply to sensors per NUREG-1537, Part 2, in Sections 7.2 and 7.3 of this SE, and finds the information adequate because the sensors are designed to monitor and maintain variables and systems over their anticipated ranges for normal operation, and over the range defined in postulated events. The descriptions provided by Kairos are consistent with the applicable acceptance criteria in NUREG-1537, Part 2 and the staff finds the information to be adequate at this stage of the licensing process and that further information can reasonably be left for later consideration at the OL stage.

7.5.3.3 Sensors

Hermes PSAR, Table 7.5-1, “Parameter Range for Safety-Related Sensors” Table 7.5-2, “Parameter Range for Non-Safety Related Sensors,” and PSAR Section 7.5.1 provide the temperature range of operation for both the safety related and non-safety related sensors and descriptions. The remaining sensor channels (vessel level, area radiation, source range neutronics, intermediate range neutronics, and power range neutronics) are to be provided in the OL application. Section 7.5.3 and Table 7.5-1 provide the temperature safety related sensors range of 450^{o}C–750^{o}C, which are designed to monitor temperatures between the freezing temperature of the primary coolant, and up to the highest design temperature determined by the safety analysis, 750°C. For the non-safety related temperature sensors, the staff reviewed Section 7.5.3 and Table 7.5-2. Table 7.5-2 provides a range of 550°C–650°C, which as described in Section 7.5.3 are designed to monitor process variables to reflect the range for postulated events and bounds, with margin, the range for normal operation.

The staff reviewed PSAR Tables 7.5-1 and 7.5.2, and Sections 7.5.1 and 7.5.3 and finds that the proposed ranges for the safety related temperature sensor are adequate because the range bounds, with margin, to monitor normal operation and postulated temperature events. Additionally, the staff finds the proposed ranges for the non-safety related temperature sensor are adequate because the range bounds, with margin, to monitor normal operation. The descriptions provided by Kairos are consistent with the applicable acceptance criteria in NUREG-1537, Part 2 and the staff finds the information to be adequate at this stage of the licensing process and that further information can reasonably be left for later consideration at the OL stage.

7.5.3.4 Technical Specifications

As shown in PSAR Figure 7.1-1 and described in Section 7.5.1 and 7.5.3, both the non-safety and safety related sensors input exclusively to the PCS or the RPS, to support the respective trips described in Table 14.1-1. TS evaluated in Sections 7.2 and 7.3 of this SE apply to the respective sensors. The staff finds the descriptions provided by Kairos are consistent with the applicable acceptance criteria in NUREG-1537, Part 2 and that the information to be adequate at this stage of the licensing process and that further information can reasonably be left for later consideration at the OL stage.

7.5.4 Conclusion

The staff finds the level of detail provided on safety related and non-safety related sensors, as described in Hermes PSAR Section 7.5, is consistent with the applicable acceptance criteria in Sections 7.2, “Design of Instrumentation and Control Systems,” and 7.3, “Reactor Control System,” of NUREG-1537, Part 2 and demonstrates an adequate design basis for a preliminary design.

A more detailed evaluation of information (e.g., ranges of transient and steady-state conditions and requirements for both non-safety and safety related sensors) will occur during the review of the Hermes OL application, at which time the staff will confirm that the final design conforms to PDCs 1, 2, 3, 13, 21, 22, 24 and 29 for the facility SSCs based on the NRC-approved Kairos Power Topical Report, KP-TR-003-NP-A and applicable regulations.

Based on its review, the staff finds that the preliminary design of the safety related and non-safety related sensors, as described in Hermes PSAR Section 7.5, is sufficient and meets the applicable regulatory requirements and guidance identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 10 CFR 50.40.

7.6 Summary and Conclusions on Instrumentation and Control Systems

The staff evaluated the information on the Hermes instrumentation and control systems as described in PSAR Chapter 7 and finds that the preliminary information on, and design criteria of, the instrumentation and control systems, including the PDC, design bases, and information relating to materials of construction, general arrangement, and approximate dimensions: (1) provide reasonable assurance that the final design will conform to the design bases, (2) meet all applicable regulatory requirements, and (3) meet the applicable acceptance criteria in NUREG-1537, Part 2. Based on these findings, the staff makes the following conclusions regarding issuance of a CP in accordance with 10 CFR 50.35 and 50.40:

- Kairos has described the proposed design of the instrumentation and control systems, including, but not limited to, the principal engineering criteria for the design, and has identified the major features or components incorporated therein for the protection of the health and safety of the public.

- Such further technical or design information as may be required to complete the safety analysis of the instrumentation and control systems, and which can reasonably be left for later consideration, will be provided in the FSAR.

- Safety features or components which require research and development have been described by Kairos and a research and development program (see SE Section 1.1.5) will be conducted that is reasonably designed to resolve any safety questions associated with such features or components.

- There is reasonable assurance that safety questions will be satisfactorily resolved at or before the latest date stated in the application for completion of construction of the proposed facility.

- There is reasonable assurance: (i) that the construction of the facility will not endanger the health and safety of the public, and (ii) that construction activities will be conducted in compliance with the Commission’s regulations.

- The issuance of a permit for the construction of the Hermes facility would not be inimical to the common defense and security or to the health and safety of the public.

7.7 References

Institute of Electrical and Electronics Engineers (IEEE). Standard 7-4.3.2, "IEEE Standard Criteria for Programmable Digital Devices in Safety Systems of Nuclear Power Generating Stations." New York. 2003.

-----. Standard 379, “IEEE Standard Application of the Single-Failure Criterion to Nuclear Power Generating Station Safety Systems.” New York. 2014.

-----. Standard 1012-2017, “System, Software, and Hardware Verification and Validation.” New York. 2017

-----. Standard 603, “Standard Criteria for Safety Systems for Nuclear Power Generating Stations.” New York. 2018.

Institute of Electrical and Electronics Engineers, Instrument Society of America, ANSI/ISA-67.04.01, “Setpoints for Nuclear Safety-Related Instrumentation.” New York. 2018.

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-----. “Submittal of the Preliminary Safety Analysis Report for the Kairos Power Fluoride Salt-Cooled, High Temperature Non-Power Reactor (Hermes), Revision 3,” May 31, 2023, Pkg. ML23151A743.

The U. S. Nuclear Regulatory Commission (NRC). NUREG-1537, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors,” Part 2, “Standard Review Plan and Acceptance Criteria.” NRC: Washington, D.C. February 1996. ADAMS Accession Nos. ML042430048.

-----. Regulatory Issue Summary 2006-17, “The Staff Position on The Requirements of 10 CFR 50.36, ‘Technical Specifications,’ Regarding Limiting Safety System Settings During Periodic Testing and Calibration of Instrument Channels.” NRC: Washington, D.C. August 2006. ADAMS Accession Nos. ML051810077.

-----. “Design-Specific Review Standard for NuScale SMR Design.” NRC: Washington, D.C. June 2016. ML15355A295.

-----. “Design Review Guide (DRG): Instrumentation and Controls for Non-Light-Water Reactor (non-LWR) Reviews.” NRC: Washington, D.C. February 2021. ML21011A140.

8 ELECTRICAL POWER SYSTEMS

This chapter of the Hermes construction permit safety evaluation (SE) describes the technical review and evaluation by the U.S. Nuclear Regulatory Commission (NRC) staff (the staff) of the preliminary design of the Kairos Power LLC (Kairos) Hermes Non-Power Reactor facility as presented in Chapter 8, "Electric Power Systems," of the Hermes preliminary safety analysis report (PSAR), Revision 3. The staff reviewed Hermes PSAR Chapter 8 against applicable regulatory requirements using regulatory guidance and standards to assess the sufficiency of the preliminary design of the Hermes facility. The following sections of the SE describe the areas reviewed as specified in NUREG-1537, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors," Part 2, "Standard Review Plan and Acceptance Criteria."

8.1 Electrical Systems

Hermes PSAR Section 8.1, "Summary Description," states that the purpose of the electrical system is to provide power to plant equipment for operation and that the electrical system consists of the non-Class 1E normal power system and the backup power system. Further, Kairos states that, due to the passive design of Hermes, safety related structures, systems, and components (SSCs) do not require electric power to perform safety related functions following a design basis event. The design has no emergency electrical power systems as described in NUREG-1537, Part 2, Section 8.2. In addition, Kairos states that alternating current (AC) power from offsite or backup power sources is not required to mitigate a design basis event.

8.2 Normal Power System

8.2.1 Introduction

Hermes PSAR Section 8.2, "Normal Power System," states that the normal power system is supplied by an offsite power source from the local utility, which provides a medium voltage feeder. Further, Kairos states that the nominal bus voltage of 480 volts (V) is distributed to plant loads and a loss of voltage or a degraded voltage condition on the normal power system does not adversely affect the performance of safety related functions.

8.2.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of Hermes normal power systems are as follows:

- 10 CFR 50.34, "Contents of applications; technical information," paragraph (a), "Preliminary safety analysis report," including:
    - 10 CFR 50.34(a)(3)(ii) which requires "The design bases and the relation of the design bases to the principal design criteria."
    - 10 CFR 50.34(a)(3)(iii) which requires "Information relative to materials of construction, general arrangement, and approximate dimensions, sufficient to provide reasonable assurance that the final design will conform to the design bases with adequate margin for safety."
    - 10 CFR 50.34(a)(4), which requires "[a] preliminary analysis and evaluation of the design and performance of structures, systems, and components [SSCs] of the facility…"; and

- 10 CFR 50.35, “Issuance of construction permits.”
- 10 CFR 50.40, “Common standards.”

The applicable guidance for the evaluation of the Hermes normal power systems is as follows:

- NUREG-1537, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors,” Part 1, “Format and Content,” and Part 2, “Standard Review Plan and Acceptance Criteria,” Section 8.1, “Normal Electrical Power Systems.”

8.2.3 Technical Evaluation

The Principal Design Criteria (PDC) for the facility SSCs are described in Hermes PSAR Section 3.1 and are based on those specified in the NRC-approved Kairos Power Topical Report, KP-TR-003-NP-A, “Principal Design Criteria for the Kairos Power Fluoride Salt-Cooled, High Temperature Reactor”. Hermes PSAR, Section 3.1, Table 3.1-3, “Principal Design Criteria” identifies PDC 17 and 18 as applicable to Chapter 8.

The normal power system provides AC and direct current (DC) electrical power by an offsite power source and is designed in accordance with National Fire Protection Association (NFPA) 70, “National Electrical Code 2020,” as stated in PSAR Section 8.2.3, “System Evaluation.”

In PSAR Section 8.2.1.1, “AC Electrical Power,” Kairos states that AC electrical power components include the following:

- A single incoming feeder from the utility to the normal power system with nominal feeder voltage of 4.16 kilovolt (kV),
- A 4.16 kV/480 V step down transformer, and
- The low voltage AC electrical power distribution with nominal bus voltages of 480 V and 120 V.

Further, Kairos stated that selected loads are supplied continual AC power via uninterruptible power supplies (UPS), which provide power during normal operations and backup power during loss of normal electrical power.

In PSAR Section 8.2.1.2, “DC Electrical Power,” Kairos states that 24 VDC is provided to instrumentation and control (I&C) functions during normal operations and for a specified maximum duty cycle following a loss of AC power.

In PSAR Section 8.2.2, “Design Bases,” Kairos states that the normal power system does not perform any safety related functions, is not credited for the mitigation of postulated events, and is not credited with performing safe shutdown functions. Further, Kairos states in PSAR Section 8.2.3, “System Evaluation” that malfunction of the normal power system will not cause reactor damage or prevent safe reactor shutdown. Section 8.2.3 also states that adequate independence is maintained between the non-safety normal power system and Class 1E I&C System. The I&C system is evaluated in Chapter 7 of this document. In the staff’s review of PSAR Chapter 8 and, particularly, Figure 8.1-1, “Electrical Configuration Diagram,” the staff notes a dedicated connection from the utility to the normal power system.

PDC 17, “Electric power systems,” requires that “electric power systems shall be provided when required to permit functioning of SSCs.” PDC 18, “Inspection and testing of electric power systems,” requires that “electric power systems which are safety related shall be designed to permit appropriate inspection and testing.” During the General Audit (ML23160A287), the staff requested clarification on the electrical systems that Kairos stated met PDC 17 and 18. Kairos affirmed the information in Section 8.2, that no electrical systems were required for performing any safety related function for safe shutdown of the plant or to keep the plant in the safe shutdown condition. The staff notes that there are no Class 1E electric power systems based on the PSAR statements that the normal power system is not credited for accident mitigation or safe shutdown; that the normal power system is classified as non-Class 1E or non-safety; and that no technical specifications for the normal power system are required. Because of this, the staff finds that PDCs 17 and 18 are not applicable to this design..

8.2.4 Conclusion

The staff finds that the level of detail provided on the normal power system meets the applicable criteria of NUREG-1537,” Part 2, Section 8.1, and demonstrates an adequate design basis for a preliminary design. Because AC power from offsite sources will not be required to perform safe shutdown functions in the preliminary design, the reactor can be safely shut down in the event of a loss or interruption of the normal electrical power system. A more detailed evaluation of information will occur during the review of the Hermes operating license application, at which time the staff will confirm that the final design conforms to this design basis.

Based on its review, the staff finds that the design of the Hermes normal power system, as described in Hermes PSAR Section 8.2, is sufficient and meets the applicable regulatory requirements and guidance identified in this section for the issuance of a construction permit in accordance with Title 10, Code of Federal Regulations (10 CFR), 50.35 and 50.40. The staff also finds that PDCs 17 and 18 are not applicable since there are no Class 1E electrical power systems.

8.3 Backup Power System

8.3.1 Introduction

While there are no emergency electrical power systems, Hermes PSAR Section 8.3, “Backup Power System (BPS),” states the backup power system’s design function is to provide AC electrical power to the essential facility loads when the normal AC power supply is not available and includes backup generators and UPS, as well as electrical equipment and circuits used to interconnect the backup generators to the low voltage AC electrical power distribution. The PSAR further states that the facility is equipped with a plug-in connection for use with a portable 480 VAC generator to provide power to essential loads in the event the backup generators are unavailable.

8.3.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of Hermes backup power systems are as follows:

- 10 CFR 50.34, “Contents of applications; technical information,” paragraph (a), “Preliminary safety analysis report,” including:

- 10 CFR 50.34(a)(3)(ii) which requires “The design bases and the relation of the design bases to the principal design criteria.”
    - 10 CFR 50.34(a)(3)(iii) which requires “Information relative to materials of construction, general arrangement, and approximate dimensions, sufficient to provide reasonable assurance that the final design will conform to the design bases with adequate margin for safety.”
    - 10 CFR 50.34(a)(4), which requires “[a] preliminary analysis and evaluation of the design and performance of structures, systems, and components [SSCs] of the facility…”; and
- 10 CFR 50.35, “Issuance of construction permits.”
- 10 CFR 50.40, “Common standards.”

The applicable guidance for the evaluation of the Hermes backup power systems is as follows:

- NUREG-1537, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors,” Part 1, “Format and Content,” and Part 2, “Standard Review Plan and Acceptance Criteria,” Section 8.1, “Normal Electrical Power Systems.”

The staff notes that NUREG-1537 contains guidance for emergency electrical power systems in Parts 1 and 2, Section 8.2, “Emergency Electrical Power Systems.” However, because Kairos’s backup power system is not an emergency power system and does not perform any safety related functions but rather provides a backup to normal electric power for selected loads as discussed below, the staff determined that NUREG-1537, Parts 1 and 2, Section 8.1, “Normal Electrical Power Systems,” is the applicable guidance for the staff’s review of Hermes backup power systems.

8.3.3 Technical Evaluation

The PDC for the facility SSCs are described in PSAR Section 3.1 and are based on those specified in the NRC-approved Kairos Power Topical Report, KP-TR-003-NP-A. Hermes PSAR, Chapter 3, Table 3.1-3, “Principal Design Criteria” identifies the PDC 17 and 18 as applicable to electrical power systems.

PSAR Section 8.3.1.1, “Backup generators,” states that the backup generators automatically start in the event of a loss of offsite power and provide power to essential facility loads. Further, Kairos states that there will be at least one redundant generator. In addition, PSAR Section 8.3.1.2, “Uninterruptible Power Supplies,” states that selected loads are supplied with AC power via UPS and the UPS provides backup power during a loss of normal electrical power. Kairos stated in PSAR Section 8.3.2, “Design Bases,” that the BPS does not perform any safety related functions, is not credited for the mitigation of postulated events, and is not credited with performing safe shutdown functions. The BPS, as stated in Section 8.3.3, “System Evaluation,” is designed according to NFPA 70, National Electric Code 2020, so that postulated failures of SSCs in the system do not preclude a safety related SSC from performing its safety function. In the PSAR, Kairos addressed the classification and design attributes of the BPS and the staff finds that PDCs 17 and 18 are not applicable since there are no Class 1E electric power systems.

The staff finds that the level of detail provided on the backup power system satisfies the applicable acceptance criteria of NUREG-1537, Part 2, Section 8.1, and demonstrates an adequate design basis for a preliminary design. A more detailed evaluation of information will occur during the review of the Hermes operating license application, at which time the staff will confirm that the final design conforms to this design basis.

8.3.4 Conclusion

Based on its review, the staff finds that the description of the Hermes backup power system, as described in Hermes PSAR Section 8.3, is sufficient and meets the applicable regulatory requirements and guidance identified in this section for the issuance of a construction permit in accordance with 10 CFR 50.35 and 50.40. The staff also finds that PDCs 17 and 18 are not applicable since there are no Class 1E electrical power systems.

8.4 Summary and Conclusions on Electrical Power Systems

The staff evaluated the information on the Hermes electrical power systems as described in PSAR Chapter 8 and finds that the preliminary information on, and design criteria of, the electrical power systems, including the PDC, design bases, and other design information: (1) provide reasonable assurance that the final design will conform to the design bases, (2) meet all applicable regulatory requirements, and (3) meet the applicable acceptance criteria in NUREG-1537, Part 2. Based on these findings, the staff concludes the following regarding issuance of a construction permit in accordance with 10 CFR 50.35 and 50.40:

- Kairos has described the proposed design for the electrical power systems, including, but not limited to, the principal engineering criteria for the design, and has identified the major features or components incorporated therein for the protection of the health and safety of the public.
- Such further technical or design information as may be required to complete the safety analysis of the electrical power systems, and which can reasonably be left for later consideration, will be provided in the operating license application.
- There is reasonable assurance: (i) that the construction of the facility will not endanger the health and safety of the public, and (ii) that construction activities will be conducted in compliance with the Commission’s regulations.
- The issuance of a permit for the construction of the Hermes facility would not be inimical to the common defense and security or to the health and safety of the public.

8.5 References

Kairos Power LLC. KP-TR-003-NP-A, "Principal Design Criteria for the Kairos Power Fluoride Salt-Cooled, High Temperature Reactor," Revision 1, June 2020, ML20167A174.

-----. “Submittal of the Preliminary Safety Analysis Report for the Kairos Power Fluoride Salt-Cooled, High Temperature Non-Power Reactor (Hermes), Revision 3,” May 31, 2023, Pkg. ML23151A743.

National Fire Protection Association (NFPA) 70, “National Electrical Code 2020.”

Nuclear Regulatory Commission (U.S.) (NRC). NUREG-1537, Part 2, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors Standard Review Plan and Acceptance Criteria." NRC: Washington, D.C. February 1996. ML042430048.

-----. “Summary Report for the Regulatory Audit of Kairos Power LLC Hermes Construction Permit Preliminary Safety Analysis Report – General Audit,” June 2023, ML23160A287.

9 AUXILIARY SYSTEMS

The auxiliary systems of the Hermes non-power test reactor consist of the reactor coolant auxiliary systems (the chemistry control system, the inert gas system, the tritium management system, the inventory management system, and the reactor thermal management system); the reactor building heating, ventilation and air conditioning system (RBHVAC); the pebble handling and storage system (PHSS); the fire protection systems; the communication system; facilities for possession and use of byproduct, source, and special nuclear material; the plant water systems (service water system, Treated Water System, Component Cooling Water System, Chilled Water System); and other auxiliary systems (remote maintenance and inspection system, Spent Fuel Cooling System, Compressed Air System, cranes and rigging, and auxiliary site services).

This chapter of the Hermes construction permit safety evaluation (SE) describes the technical review and evaluation by the U.S. Nuclear Regulatory Commission (NRC) staff (the staff) of the preliminary design of the Kairos Power LLC (Kairos) Hermes Non-Power Reactor facility as presented in Chapter 9, "Auxiliary Systems," of the Hermes preliminary safety analysis report (PSAR), Revision 3. The staff reviewed Hermes PSAR Chapter 9 against applicable regulatory requirements using regulatory guidance and standards to assess the sufficiency of the preliminary design of the Hermes facility. The following sections of the SE describe the areas reviewed as specified in NUREG-1537, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors," Part 2, "Standard Review Plan and Acceptance Criteria", as appropriate.

The principal design criteria (PDC) for the facility structures, systems, and components (SSCs) are described in Section 3.1 of the Preliminary Safety Analysis Report (PSAR). The PDC are based on the NRC approved Kairos Power Topical Report, KP-TR-003-NP-A, "Principal Design Criteria for the Kairos Power Fluoride Salt-Cooled, High Temperature Reactor, Revision 1." Each of the sections below identify the applicable PDC for the system being evaluated.

9.1 <u>Reactor Coolant Auxiliary Systems</u>

The reactor coolant auxiliary systems are five systems providing support for the functionality and performance of the Flibe coolant. Each of the five systems is evaluated in a separate section below.

9.1.1 Chemistry Control System

9.1.1.1 Introduction

The PSAR describes the chemistry control system (CCS) as being used to monitor coolant chemistry in the reactor vessel system and primary heat transport system (PHTS) for compliance with Flibe specifications found in KP-TR-005, "Reactor Coolant for the Kairos Power Fluoride Salt-Cooled High Temperature Reactor Topical Report," Revision 1. The CCS allows for offline analysis of Flibe chemistry and can remove and replace a sufficient amount of coolant to restore conformance with the Flibe specification via the inventory management system (IMS). The CCS does not perform any safety related functions, nor is it credited to mitigate postulated events.

9.1.1.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of the Hermes CCS are as follows:

- 10 CFR 50.34, “Contents of applications; technical information,” paragraph (a), “Preliminary safety analysis report.”
    - 50.34(a)(3)(ii) requires “The design bases and the relation of the design bases to the principal design criteria.”
    - 50.34(a)(3)(iii) requires “Information relative to materials of construction, general arrangement, and approximate dimensions, sufficient to provide reasonable assurance that the final design will conform to the design bases with adequate margin for safety.”
    - 50.34(a)(4) which requires “A preliminary analysis and evaluation of the design and performance of structures, systems, and components [SSCs] of the facility…”
    - 50.34(a)(5) requires “An identification and justification for the selection of those variables, conditions, or other items which are determined as the result of preliminary safety analysis and evaluation to be probable subjects of technical specifications for the facility.”
- 10 CFR 50.35, “Issuance of construction permits.”
- 10 CFR 50.40, “Common standards.”

As provided in § 20.1002, “Scope,” the regulations in 10 CFR Part 20, “Standards for Protection Against Radiation,” “apply to persons licensed by the Commission to receive, possess, use, transfer, or dispose of byproduct, source, or special nuclear material or to operate a production or utilization facility.” Kairos has applied for a construction permit (CP) and has not specifically requested approval of any design information. A CP does not provide a license to operate the facility. In its Hermes CP application, Kairos also has not applied for licenses to receive, possess, use, transfer, or dispose of byproduct, source, or special nuclear material at the facility. Therefore, the staff did not evaluate whether requirements in 10 CFR Part 20 would be met for the construction of the Hermes reactor. Instead, the staff assessed whether Kairos had identified the relevant requirements for an operating facility and provided descriptions of the preliminary facility design to determine whether the PSAR provides an acceptable basis for the development of the auxiliary systems and whether there is reasonable assurance that Kairos will comply with the regulations in 10 CFR Part 20 during Hermes facility operation. This is consistent with 10 CFR 50.40(a), which provides that in determining whether a CP may be issued, the Commission will be guided by consideration of reasonable assurance that Kairos will comply with the regulations, including the regulations in 10 CFR Part 20, and that the health and safety of the public will not be endangered.

The applicable guidance for the evaluation of the CCS is NUREG-1537, Parts 1 and 2, Section 5.4, “Primary Coolant Cleanup System.” This guidance was developed for water chemistry and does not contain specific guidance for molten salts. However, the rationale for maintaining coolant purity (e.g., limit corrosion, minimize radioactivity release) remains the same. The staff’s review was based on the guidance in NUREG-1537 but did not use portions of the guidance only applicable to water chemistry (e.g., pH ranges).

9.1.1.3 Technical Evaluation

The PDC for Hermes are described in PSAR Chapter 3, “Design of Structures, Systems and Components,” and are based on those specified in the NRC approved Kairos Power Topical Report, KP-TR-003-NP-A, “Principal Design Criteria for the Kairos Power Fluoride Salt-Cooled, High Temperature Reactor.” The PDC applicable to the Hermes CCS are:

- PDC 2, Design Bases for Protection Against Natural Phenomena
- PDC 4, Environmental and Dynamic Effects Design Bases
- PDC 70, Reactor Coolant Purity Control.

The staff evaluated the preliminary design of the CCS to determine whether it can meet its design functions stated above. Section 9.1.1.3, “System Evaluation,” of the PSAR states that the CCS may be located near safety related SSCs but that the safety related SSCs will be protected from failure of the CCS. The staff’s evaluation of seismic damage and effects of natural phenomena are contained in Sections 3.4 and 3.5, respectively, of this safety evaluation (SE). Therefore, consistent with the evaluations in SE Sections 3.4 and 3.5, the staff finds that the preliminary design of the CCS is consistent with PDC 2 because the PSAR describes potential methods which will be employed to ensure that a postulated failure of the CCS does not impact safety related SSCs.

PDC 4 requires that safety related systems accommodate the environmental conditions from normal operations and postulated events. The PSAR states that safety related systems in the area of the CCS are protected against failures of the CCS equipment by being physically separate, the use of barriers, or by the design of the safety related components. The staff finds that the preliminary design is consistent with PDC 4 and that the CCS will not adversely impact safety related SSCs. Final design details in the operating license (OL) application will allow the staff to verify any potential impacts of failures of the CCS.

PDC 70 addresses the ability to monitor and correct coolant chemistry. Section 9.1.1.3, “System Evaluation,” of the PSAR states that the CCS can periodically monitor the reactor coolant chemistry. It describes some of the impurities that can be examined and states that if specifications are only marginally met then the IMS can remove and replace enough coolant to increase the margin of conformance to specifications. The staff finds that the preliminary design is consistent with PDC 70 because the CCS can monitor coolant chemistry and because removing coolant and replacing it with cleaner coolant provides a way to maintain coolant purity.

The guidance in NUREG-1537, Part 2, Section 5.4, states that coolant purity should be maintained consistent with limits established in Chapters 4 and 11 of the safety analysis report. The staff will review specific coolant purity limits in the operating license (OL) application. The management of coolant purity limits is part of Operational Programs and is appropriate to review at the OL stage. The staff reviewed the description of CCS capabilities in the PSAR and finds that the CCS will be able to achieve the necessary functions. Details of specific required actions to be taken if the purity limits are not met, and time limits to complete required actions can be provided in the OL application. Additionally, as confirmed in the response to Request for Confirmation of Information (RCI) 349, the OL application will describe how the CCS measures a well-mixed representative sample of the reactor coolant. This will allow the staff to ensure that purity specifications can be met throughout the primary system. The provisions for representative sampling support proposed technical specifications to measure various aspects of coolant purity and composition. The staff will evaluate the specific methods to monitor and maintain coolant specifications during the OL application review.

The PSAR states that the CCS is designed to meet 10 CFR 20.1406. As a sampling system, the CCS is not credited to correct coolant chemistry and therefore should not experience a buildup of radionuclides within the system relative to the bulk reactor coolant. Additionally, because the CCS is not credited to remove radionuclides from the coolant, the generation of radioactive waste should be minimized. The staff finds that based on the preliminary design, the CCS will be consistent with the requirements of 10 CFR 20.1406 because the CCS is designed, in conjunction with the IMS, to contain radionuclides from the reactor coolant. The staff will review the final details of how the CCS minimizes contamination in the OL application.

Chapter 14, "Technical Specifications," of the PSAR describes proposed technical specifications to be contained in the Hermes OL. Some of the proposed technical specifications relate to reactor coolant purity requirements (e.g., LiF to BeF2 ratio, circulating activity). The staff finds that the preliminary design of the CCS will be able to support the proposed technical specifications related to the reactor coolant chemistry because the CCS has the ability to analyze and correct coolant chemistry (via the IMS). The staff will evaluate the required samples and frequencies needed to meet the technical specification as part of its review of the OL application.

9.1.1.4 Conclusion

Based on the discussion above, the staff concludes that the information in Hermes PSAR Section 9.1.1 is sufficient and meets applicable guidance and regulatory requirements identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. The information provided gives the staff reasonable assurance that the CCS will not lead to radiation exposure or releases that exceed limits in 10 CFR Part 20, and that the CCS can support proposed technical specifications related to coolant chemistry. The staff finds that the CCS design will conform with guidance in NUREG-1537 to monitor and maintain coolant purity in order to limit degradation of essential components in the primary system. Further information will be required before approving operation of the Hermes CCS (e.g., basis of sampling location to provide a well-mixed and representative chemistry sample, ability of CCS to correct coolant chemistry within specified timeframes) and will be reviewed at the OL stage.

9.1.2 Inert Gas System

9.1.2.1 Introduction

Section 9.1.2 of the PSAR describes the inert gas system (IGS). The design functions of the IGS are to:

- Maintain an inert environment for components using argon
- Provide inert gas purge flow
- Remove impurities from cover gas
- Provide transport for tritium for treatment
- Provide reactor coolant motive force during filling and draining

The PSAR also states that the IGS does not perform any safety related functions.

9.1.2.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of the Hermes IGS are as follows:

- 10 CFR 50.34, “Contents of applications; technical information,” paragraph (a), “Preliminary safety analysis report.”
  - 50.34(a)(3)(ii) requires “The design bases and the relation of the design bases to the principal design criteria.”
  - 50.34(a)(3)(iii) requires “Information relative to materials of construction, general arrangement, and approximate dimensions, sufficient to provide reasonable assurance that the final design will conform to the design bases with adequate margin for safety.”
  - 50.34(a)(4) which requires “A preliminary analysis and evaluation of the design and performance of structures, systems, and components [SSCs] of the facility…”
  - 50.34(a)(5) requires “An identification and justification for the selection of those variables, conditions, or other items which are determined as the result of preliminary safety analysis and evaluation to be probable subjects of technical specifications for the facility.”
- 10 CFR 50.35, “Issuance of construction permits.”
- 10 CFR 50.40, “Common standards.”

As described in subsection 9.1.1 above, the staff did not evaluate whether requirements in 10 CFR Part 20 would be met for the construction of the Hermes reactor. Instead, the staff assessed whether Kairos identified the relevant requirements for an operating facility and provided descriptions of the preliminary facility design. The staff assessed this to determine whether the PSAR provides an acceptable basis for the development of systems and whether there is reasonable assurance that Kairos will comply with the regulations in 10 CFR Part 20 during Hermes facility operation.

Section 9.6, “Cover Gas Control in Closed Primary Coolant Systems,” of NUREG-1537, Parts 1 and 2, provides the guidance for evaluating cover gas systems. Although the staff used the NUREG-1537 guidance in its review, this guidance was developed for reactors that use water as a coolant and does not contain specific guidance for cover gas systems for reactors with a molten salt coolant. However, the rationale for cover gas control (e.g., providing required pressure differential, assessing purity, processing and storing gases) remains the same. The staff used concepts from the guidance and did not use portions of the guidance only applicable to water chemistry (e.g., recombination of hydrogen and oxygen from radiolysis of the coolant).

9.1.2.3 Technical Evaluation

The PDC applicable to the Hermes IGS are as follows:

- PDC 2, Design Bases for Protection Against Natural Phenomena
- PDC 4, Environmental and Dynamic Effects Design Bases
- PDC 64, Monitoring Radioactivity Releases.

The staff evaluated the preliminary design of the IGS to determine whether it can meet its design functions stated above. These functions include maintaining the primary coolant system as a closed system, helping to prevent the uncontrolled release of radionuclides, maintaining cover gas purity, allowing for tritium to move downstream for treatment, and providing the motive force for reactor coolant during filling and draining operations. Kairos described the the preliminary design information in PSAR Section 9.1.2, and stated that the IGS will be able to ensure the required type of gas, concentrations of constituents, and design basis pressure. Additionally, the IGS will be able to provide an appropriate purging flow to system components because gas flow rates, temperature, and pressures will be individually regulated to meet design requirements for each component. The IGS will be able to provide Flibe vapor/aerosol control because it will allow for the forced flow of gas to different components and systems to prevent Flibe deposits. The IGS only provides a pathway for tritium to be transported to the tritium management system and the IGS does not perform any tritium management functions. Tritium capture is discussed and evaluated in Section 9.1.3, "Tritium Management System," of this SE.

The staff reviewed the preliminary design of the IGS to ensure the purity of the gas can be assessed, and the gas can be processed, decontaminated and stored. The IGS will allow for management of the inert gas because Figure 9.1.2-1, "Process Flow Diagram for the Inert Gas System," shows the appropriate subsystems needed to achieve these functions. Additionally, in the response to RCI 349, Kairos confirmed that the IGS will be capable of measuring both air and moisture in the cover gas. Therefore, based on the preliminary design of the IGS, the staff finds that the IGS can ensure purity of the argon cover gas consistent with operational limits and proposed technical specifications. This is consistent with the guidance in NUREG-1537 which states the staff should review systems for assessing the required purity of contained gases as well as systems for processing and storing the contained gases.

Section 9.1.2.3 of the PSAR states that although the IGS is not safety related, it may be in proximity or connect to safety related SSCs. These safety related SSCs will be protected from seismic failures of the IGS such that postulated failures of the IGS do not prevent safety related SSCs from performing safety functions. The staff's evaluation of seismic damage and effects of natural phenomena are contained in Sections 3.4 and 3.5, respectively, of this SE. Therefore, consistent with the evaluations in Sections 3.4 and 3.5 of this SE, the staff finds that the preliminary design of the IGS is consistent with PDC 2 because the PSAR describes potential methods which will be employed to ensure that a postulated failure of the IGS does not impact safety related SSCs.

The PSAR states that the IGS is a low pressure system, thus precluding pipe whip. The IGS contains argon gas which is inert and will not adversely affect safety related SSCs. Because failures of the IGS will not affect safety related SSCs, he staff finds that the preliminary design of the IGS is consistent with PDC 4. The staff will review the final design details in the OL application to assess any potential impacts of pipe whip on safety related SSCs. The staff finds that argon is an inert gas, and its release will not cause damage to other SSCs.

The PSAR states that the IGS includes sampling systems that can evaluate gas radioactivity levels. Additionally, Figure 9.1.2-1 of the PSAR shows subsystems that will be able to measure radioactivity in, and remove radioactive particles from, the cover gas. Based on this information, the staff finds that the preliminary design of the IGS is consistent with PDC 64 because the IGS will be able to monitor for radioactivity that can potentially be released. Additionally, the staff finds it acceptable to include a technical specification on circulating activity to support the determination of the specified acceptable radiological release design limit. This is consistent with PDC 64 which requires a means to monitor for radioactivity that may be released, and also consistent with the guidance in NUREG-1537 which states systems should assess purity of gases.

Section 9.1.2.4, "Testing and Inspection," of the PSAR states that the IGS backup argon system will be periodically checked for quantity and leakage. The argon volumes and gas purity will be included in the technical specifications. Additionally, the Kairos response to RCI 349 confirmed that the entirety of the IGS can be periodically checked for leakage. The staff finds that these capabilities will allow the IGS to meet its design functions to maintain an inert environment. The staff also finds the proposed technical specifications for argon volume and purity acceptable as this is consistent with the guidance in NUREG-1537 that gas purity should be assessed. Based on the preliminary design, the staff finds that leaks from the system that could release radionuclides, or introduce contaminants (e.g., air or moisture), can be detected and appropriate action taken prior to exceeding operational limits. This is consistent with NUREG-1537 guidance which states that systems should be designed to ensure control and detection of leaks so there is no uncontrolled release of radioactive material.

The staff finds that the IGS will be consistent with 10 CFR 20.1406 based on its preliminary design, as there are systems provided to remove radioactive material from the IGS if necessary, and because the IGS can be monitored for leaks which would allow for action to limit release of radioactivity. The staff will verify the capability to monitor activity and releases with the design details provided in the OL application.

9.1.2.4 Conclusion

Based on the review described above, the staff concludes that the information in Hermes PSAR Section 9.1.2, as supplemented by the response to RCI 349, is sufficient and meets applicable guidance and regulatory requirements identified in this section for issuance of a CP in accordance with 10 CFR 50.35 and 50.40. The information provided gives the staff reasonable assurance that the IGS can meet its design functions and will not lead to radiation exposure or releases that exceed limits in 10 CFR Part 20. The staff also finds that the IGS will be designed consistent with the guidance in NUREG-1537 to assess and maintain cover gas purity and meet any technical specification applicable to the IGS. Further information will be required to approve operation of the Hermes IGS (e.g., limit on circulating activity in the cover gas, details for allowable impurities, leakage detection) and will be reviewed at the OL stage.

9.1.3 Tritium Management System

9.1.3.1 Introduction

PSAR Section 9.1.3, "Tritium Management System," describes a preliminary design for the tritium management system (TMS), which monitors and removes tritium from the vapor spaces of the reactor coolant system and the reactor building during normal operation. PSAR Section 9.1.3 states that the system does not perform safety related functions.

9.1.3.2 Regulatory Evaluation

The applicable regulatory requirements for evaluation of the Hermes TMS are as follows:

- 10 CFR 50.34, "Contents of applications; technical information," paragraph (a), "Preliminary safety analysis report."
    - 50.34(a)(3)(ii) requires "The design bases and the relation of the design bases to the principal design criteria."

    - 50.34(a)(3)(iii) requires “Information relative to materials of construction, general arrangement, and approximate dimensions, sufficient to provide reasonable assurance that the final design will conform to the design bases with adequate margin for safety.”
    - 50.34(a)(4) which requires “A preliminary analysis and evaluation of the design and performance of structures, systems, and components [SSCs] of the facility…”
    - 50.34(a)(5) requires “An identification and justification for the selection of those variables, conditions, or other items which are determined as the result of preliminary safety analysis and evaluation to be probable subjects of technical specifications for the facility.”
- 10 CFR 50.35, “Issuance of construction permits.”
- 10 CFR 50.40, “Common standards.”

As described in subsection 9.1.1 above, the staff did not evaluate whether requirements in 10 CFR Part 20 would be met for the construction of the Hermes reactor. Instead, the staff assessed whether Kairos identified the relevant requirements for an operating facility and provided descriptions of the preliminary facility design. The staff assessed this to determine whether the PSAR provides an acceptable basis for the development of systems and whether there is reasonable assurance that Kairos will comply with the regulations in 10 CFR Part 20 during Hermes facility operation.

The applicable guidance for the staff’s evaluation of the Hermes TMS is as follows:

- NUREG-1537, Parts 1 and 2, Section 9.7, “Other Auxiliary Systems.” The guidance notes that the design, functions, and potential malfunctions of the auxiliary systems should not result in reactor accidents or uncontrolled release of radioactivity and no function or malfunction of the auxiliary systems should interfere with or prevent safe shutdown of the reactor.

9.1.3.3 Technical Evaluation

Principal design criteria applicable to the TMS are:

- PDC 2, Design Bases for Protection Against Natural Phenomena
- PDC 60, Control of Releases of Radioactive Materials to the Environment
- PDC 64, Monitoring Radioactivity Releases

PSAR Section 9.1.3 states that the TMS does the following: (1) provides tritium separation from argon in the IGS, (2) provides tritium separation from air in the reactor building cells, and (3) provides final collection and disposal of tritium. The system captures tritium to reduce environmental releases. The system is integrated into other Hermes systems based on expected tritium distribution among possible transport pathways and the feasibility of tritium capture in each environment. To accomplish these functions, getter alloy capture beds are used to separate tritium from argon, and molecular sieve capture beds are used to separate tritium from air. Following their inservice duty cycles, the tritium capture materials are stored in sealed canisters.

PSAR Section 9.1.3 states that the TMS's functions are not safety related. However, portions of the TMS may be near safety related SSCs. Therefore, PSAR Section 9.1.3 states that TMS components will be designed and positioned to preclude adverse interactions with safety related SSCs, consistent with PDC 2. Consistent with the evaluations in Sections 3.4 and 3.5 of this SE, the staff finds that the TMS will be designed consistent with PDC 2 because the PSAR describes potential methods which will be employed to ensure that a postulated failure of the TMS does not impact safety related SSCs.

PSAR Section 9.1.3 states that, consistent with PDC 13, "Instrumentation and control," tritium inventories will be monitored to comply with the inventory limits set by Maximum Hypothetical Accident (MHA) assumptions. This will ensure that the dose due to accidental releases from the TMS are bounded by the MHA and would therefore meet the accident dose criteria in 10 CFR 100.11 (see SE Chapter 13). PSAR Section 9.1.3 states that the TMS maintains a minimum level of overall tritium capture capacity to minimize tritium releases from the plant and satisfy PDC 60. PSAR Section 9.1.3 states that radiation monitoring is provided in the TMS for the evaluation of tritium levels in TMS subsystems which satisfies, in part, PDC 64. PSAR 9.1.3 states that, because the system contains radiological contaminants, the system is designed to minimize contamination and support eventual decommissioning consistent with 10 CFR 20.1406. Based on the preliminary design of the TMS, the staff has reasonable assurance that the TMS will be consistent with the requirements of 10 CFR 20.1406 because the TMS is designed, in conjunction with other systems, to collect and contain tritium generated from reactor operation.

For the TMS, the staff used the guidance and acceptance criteria in NUREG-1537, Parts 1 and 2, Section 9.7, "Other Auxiliary Systems," to review the TMS preliminary design description in PSAR Section 9.1.3, "Tritium Mitigation System." As part of its review, the staff assessed whether PSAR Section 9.1.3 identifies the appropriate PDC for the TMS. Based on the staff's evaluation of the preliminary design features described above, the staff finds that Kairos has described the design bases for the TMS and that the preliminary information on the design and functional description of the TMS provides reasonable assurance that the TMS will conform to the design bases. The staff finds that the TMS is a non-safety related system that will be designed such that it will (1) not result in reactor accidents, (2) not prevent safe shutdown of the reactor, and (3) not result in unacceptable radioactivity releases or exposures. Therefore, based on its review, the staff determined that the level of detail provided on the TMS, including the design bases, and identification of relevant PDC, is adequate for a preliminary design and is consistent with the applicable acceptance criteria of NUREG-1537, Part 2, Section 9.7.

9.1.3.4 Conclusion

Based on the review described above, the staff concludes that the information on the TMS in PSAR Section 9.1.3 is sufficient and meets applicable guidance and regulatory requirements identified in this section for issuance of a CP in accordance with 10 CFR 50.35 and 50.40. The staff concludes that the preliminary design features intended to minimize contamination, support eventual decommissioning, and control releases to the environment will help ensure compliance with 10 CFR Part 20. Based on the information provided, the staff concludes that the TMS will be designed to collect and contain tritium, consistent with the guidance in NUREG-1537 to prevent uncontrolled release of radioactivity, to limit potential radiation exposures to within 10 CFR Part 20 requirements, and for no function or malfunction of the TMS to interfere with or prevent safe shutdown of the reactor.

9.1.4 Inventory Management System

9.1.4.1 Introduction

PSAR Section 9.1.4, "Inventory Management System," describes a preliminary design for the IMS, which adds and removes reactor coolant to maintain the desired level and volume within reactor-coolant-containing systems and components (e.g., reactor vessel, CCS). PSAR Section 9.1.4 states that the system does not perform safety related functions.

9.1.4.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of the Hermes IMS are as follows:

- 10 CFR 50.34, "Contents of applications; technical information," paragraph (a), "Preliminary safety analysis report."
    - 50.34(a)(3)(ii) requires "The design bases and the relation of the design bases to the principal design criteria."
    - 50.34(a)(3)(iii) requires "Information relative to materials of construction, general arrangement, and approximate dimensions, sufficient to provide reasonable assurance that the final design will conform to the design bases with adequate margin for safety."
    - 50.34(a)(4) which requires "A preliminary analysis and evaluation of the design and performance of structures, systems, and components [SSCs] of the facility…"
    - 50.34(a)(5) requires "An identification and justification for the selection of those variables, conditions, or other items which are determined as the result of preliminary safety analysis and evaluation to be probable subjects of technical specifications for the facility."
- 10 CFR 50.35, "Issuance of construction permits."
- 10 CFR 50.40, "Common standards."

As described in subsection 9.1.1 above, the staff did not evaluate whether requirements in 10 CFR Part 20 would be met for the construction of the Hermes reactor. Instead, the staff assessed whether Kairos identified the relevant requirements for an operating facility and provided descriptions of the preliminary facility design. The staff assessed this to determine whether the PSAR provides an acceptable basis for the development of systems and whether there is reasonable assurance that Kairos will comply with the regulations in 10 CFR Part 20 during Hermes facility operation.

The applicable guidance for the staff's evaluation of the Hermes IMS is as follows:

- NUREG-1537, Parts 1 and 2, Section 9.7, "Other Auxiliary Systems." The guidance notes that the design, functions, and potential malfunctions of the auxiliary systems should not result in reactor accidents or uncontrolled release of radioactivity and no function or malfunction of the auxiliary systems should interfere with or prevent safe shutdown of the reactor.

9.1.4.3 Technical Evaluation

Principal design criteria applicable to the IMS are:

- PDC 2, Design Bases for Protection Against Natural Phenomena
- PDC 4, Environmental and Dynamic Effects Design Bases
- PDC 33, Reactor Coolant Inventory Maintenance
- PDC 70, Reactor Coolant Purity Control

PSAR Section 9.1.4 states that the IMS does the following: (1) adds and removes reactor coolant to maintain the desired level and volume within the reactor vessel and the CCS and (2) provides an interface for new reactor coolant delivery and used reactor coolant removal. The free volume in the system is filled with inert gas from the IGS. The IGS can apply inert gas pressure or vacuum on the IMS tanks to circulate cover gas through the TMS or initiate reactor coolant transfers between tanks. Electrical heating and thermal insulation of the tanks, pumps, and piping is provided to maintain the reactor coolant in a liquid phase for system operations. Process sensors are included for use by the plant control system to monitor the reactor coolant inventory (e.g., load cells and coolant level sensors) and temperature in the system tanks.

The IMS reactor coolant transfer lines will be constructed of stainless steel and designed per American Society of Mechanical Engineers (ASME) B31.3 2016. The IMS tanks will be constructed of stainless steel and designed per ASME BPVC, Section VIII 2015. The tanks and reactor coolant transfer lines are being designed and fabricated to meet the pressure, mechanical loads, corrosion, and the temperature requirements of the system.

The reactor vessel coolant level management tank provides a means to maintain the level of reactor coolant in the reactor vessel through a transfer line, a dip tube, and an overflow weir. The transfer into the reactor vessel is pump driven through the dip tube. The return flow is collected by an overflow weir and the transfer is gravity driven back into the reactor vessel coolant level management tank.

The reactor vessel fill/drain tank provides a means of filling and draining the reactor vessel through a transfer line and a dip tube. The transfer to the reactor vessel is pump driven, and the transfer out of the reactor vessel is gravity driven. The reactor vessel fill/drain tank transfer line is equipped with a passive reactor vessel isolation system to prevent unintentional draining. The reactor vessel fill/drain tank is sized to hold the reactor vessel coolant inventory.

The system is being designed to preclude the inadvertent draining of the reactor vessel via siphoning. PSAR Section 9.1.4.3 describes the anti-siphoning function.

PSAR Section 9.1.4 states that the IMS's functions are not safety related. However, portions of the IMS may be near safety related SSCs. Therefore, PSAR Section 9.1.4 states that IMS components will be designed and positioned to preclude adverse interactions with safety related SSCs, consistent with PDC 2. Consistent with the evaluations in Sections 3.4 and 3.5 of this SE, the staff finds that the preliminary design of the IMS is consistent with PDC 2 because the PSAR describes potential methods which will be employed to ensure that a postulated failure of the IMS does not impact safety related SSCs.

PSAR Section 9.1.4 states that the IMS will be designed such that safety related systems near the IMS are protected against the dynamic effects potentially created by the failure of IMS equipment, consistent with PDC 4. Safety related portions of the reactor coolant boundary are limited to the reactor vessel, such that failures of other SSCs containing reactor coolant do not result in unacceptable consequences, consistent with PDC 33. The CCS will be used to monitor the coolant chemistry, and the IMS may be used to replace coolant to restore conformance to the Flibe specification, consistent with PDC 70. PSAR Section 9.1.4 states that the system will be designed to minimize contamination and support eventual decommissioning, consistent with 10 CFR 20.1406, “Minimization of Contamination.”

For the IMS, the staff used the guidance and acceptance criteria in NUREG-1537, Parts 1 and 2, Section 9.7, “Other Auxiliary Systems,” to review the IMS preliminary design description in PSAR Section 9.1.4, “Inventory Management System.” As part of its review, the staff assessed whether PSAR Section 9.1.4 identifies the appropriate PDCs for the IMS. Based on the staff’s evaluation of the preliminary design features described above, the staff finds that Kairos has provided the design bases for the IMS and that the preliminary information on the design and functional description of the IMS provides reasonable assurance that the IMS will conform to the design bases. The staff finds that the IMS is a non-safety related system that will be designed such that it will 1) not result in reactor accidents, 2) not prevent safe shutdown of the reactor, and 3) not result in unacceptable radioactivity releases or exposures. Therefore, based on its review, the staff determined that the level of detail provided on the IMS, including the design bases and identification of relevant PDC, is adequate for a preliminary design and is consistent with the applicable acceptance criteria of NUREG-1537, Part 2, Section 9.7.

The staff’s technical evaluation of the anti-siphoning function is in Section 5.1.3.2.5 of this SE.

9.1.4.4 Conclusion

Because of the review of IMS features to maintain coolant level, volume, and purity described above, the staff concludes that the information on the IMS in PSAR Section 9.1.4 is sufficient and meets the applicable guidance and regulatory requirements identified in this section for issuance of a CP in accordance with 10 CFR 50.35 and 50.40. The staff concludes that the preliminary design features intended to minimize contamination and support eventual decommissioning will comply with the requirements of 10 CFR 20.1406. Based on the information provided, the staff concludes that the preliminary design of the IMS satisfies the applicable acceptance criteria in NUREG-1537 to prevent uncontrolled release of radioactivity and for no function or malfunction of the IMS to interfere with or prevent safe shutdown of the reactor.

9.1.5 Reactor Thermal Management System

9.1.5.1 Introduction

PSAR Section 9.1.5, “Reactor Thermal Management System,” describes a preliminary design for the reactor thermal management system (RTMS) which consists of two subsystems: the equipment and structural cooling subsystem (ESCS) and the reactor auxiliary heating system (RAHS). The purpose of the ESCS is to remove heat from SSCs in the reactor cavity to maintain the temperatures within operational limits. The purpose of the RAHS is to preheat the reactor vessel and to ensure Flibe in the vessel is maintained above a minimum operating temperature. PSAR Section 9.1.5 states that the RTMS does not perform safety related functions.

9.1.5.2 Regulatory Evaluation

The applicable regulatory requirements for evaluation of the RTMS are as follows:

- 10 CFR 50.34, “Contents of applications; technical information,” paragraph (a), “Preliminary safety analysis report.”
    - 50.34(a)(3)(ii) requires “The design bases and the relation of the design bases to the principal design criteria.”
    - 50.34(a)(3)(iii) requires “Information relative to materials of construction, general arrangement, and approximate dimensions, sufficient to provide reasonable assurance that the final design will conform to the design bases with adequate margin for safety.”
    - 50.34(a)(4) which requires “A preliminary analysis and evaluation of the design and performance of structures, systems, and components [SSCs] of the facility…”
    - 50.34(a)(5) requires “An identification and justification for the selection of those variables, conditions, or other items which are determined as the result of preliminary safety analysis and evaluation to be probable subjects of technical specifications for the facility.”
- 10 CFR 50.35, “Issuance of construction permits.”
- 10 CFR 50.40, “Common standards.”

As described in subsection 9.1.1 above, the staff did not evaluate whether requirements in 10 CFR Part 20 would be met for the construction of the Hermes reactor. Instead, the staff assessed whether Kairos identified the relevant requirements for an operating facility and provided descriptions of the preliminary facility design. The staff assessed this to determine whether the PSAR provides an acceptable basis for the development of systems and whether there is reasonable assurance that Kairos will comply with the regulations in 10 CFR Part 20 during Hermes facility operation.

The applicable guidance for the staff’s evaluation of the RTMS is as follows:

- NUREG-1537, Parts 1 and 2, Section 9.7, “Other Auxiliary Systems.” The guidance notes that the design, functions, and potential malfunctions of the auxiliary systems should not result in reactor accidents or uncontrolled release of radioactivity and no function or malfunction of the auxiliary systems should interfere with or prevent safe shutdown of the reactor.

9.1.5.3 Technical Evaluation

Principal design criteria applicable to the RTMS are:

- PDC 2, Design Bases for Protection Against Natural Phenomena
- PDC 44, Structural and Equipment Cooling
- PDC 45, Inspection of Structural and Equipment Cooling Systems
- PDC 46, Testing of Structural and Equipment Cooling Systems
- PDC 71, Reactor Coolant Heating Systems

PSAR Section 9.1.5 states the ESCS removes heat from SSCs in the reactor cavity area to maintain the operational temperature limits of those structures and components. This is accomplished by active heat removal features (see below) as well as high temperature, load bearing, irradiation-hardened insulation on SSCs. Heat removed by the subsystem is transferred to the Component Cooling Water System.

The systems that are actively cooled by the ESCS during normal operation are the steel liner of the concrete structure, the reactivity control and shutdown system, and the primary salt pump. The steel liner of the concrete structure is water cooled. The primary salt pump is gas cooled by active components (fans, blowers, pumps) in a closed loop system.

PSAR Section 9.1.5 states the RAHS pre-heats the reactor vessel and ensures coolant is maintained above a minimum operating temperature. This is accomplished by electric heaters adjacent to the heated surface. The system provides the initial startup heating required to achieve and maintain operational temperature for the reactor vessel, primary salt pump, reactor vessel internals, IMS, IGS, and PHSS reactor vessel head penetrations prior to the availability of nuclear heating. For initial commissioning, the system will be used to evaporate residual moisture out of the reactor vessel, internal graphite structures, and the reactor vessel, to preclude corrosion upon contact with the introduction of the molten salt coolant. Because the reactor coolant melting point is high, preheating of the vessel and internals prevents thermal shock damage to the reactor.

PSAR 9.1.5 states that the RTMS's functions are not safety related. However, portions of the RTMS may be near safety related SSCs. Therefore, PSAR Section 9.1.5 states that RTMS components will be designed and positioned to preclude adverse interactions with safety related SSCs, consistent with PDC 2. Consistent with the evaluations in Sections 3.4 and 3.5 of this SE, the staff finds that the preliminary design of the RTMS is consistent with PDC 2 because the PSAR describes potential methods which will be employed to ensure that a postulated failure of the RTMS does not impact safety related SSCs.

PSAR 9.1.5 states that the ESCS will be designed to detect gas and water leaks and isolate breaches in the system via the plant control system, and that the ESCS will be designed to permit inspection and testing to ensure the capability of the ESCS to cool SSCs and interface with the Component Cooling Water System (CCWS) to transfer heat to the ultimate heat sink, consistent with PDC 44, PDC 45, and PDC 46.

PSAR Section 9.1.5 states that the RAHS will ensure sufficient heat is added to components to compensate for parasitic heat loss during periods when the reactor is not supplying fission heat and to heat the vessel and vessel head components uniformly to prevent thermal shock, consistent with PDC 71.

PSAR Section 9.1.5. states that the RTMS will be designed to minimize contamination and support eventual decommissioning, consistent with 10 CFR 20.1406.

For the RTMS, the staff used the guidance and acceptance criteria in NUREG-1537, Parts 1 and 2, Section 9.7, "Other Auxiliary Systems," to review the RTMS preliminary design description in PSAR Section 9.1.5, "Reactor Thermal Management System." As part of its review, the staff assessed whether PSAR Section 9.1.5 identifies the appropriate PDC for the RTMS. Based on staff's evaluation of the preliminary design features described above, the staff finds that Kairos has described the design bases for the RTMS and that the preliminary information on the design and functional description of the RTMS provides reasonable assurance that the RTMS will conform to the design bases. The staff finds that the RTMS is a non-safety related system that will be designed such that it will 1) not result in reactor accidents, 2) not prevent safe shutdown of the reactor, and 3) not result in unacceptable radioactivity releases or exposures. Therefore, based on its review, the staff determined that the level of detail provided on the RTMS, including the design bases, and identification of relevant PDC, is adequate for a preliminary design and is consistent with the applicable acceptance criteria of NUREG-1537, Part 2, Section 9.7.

9.1.5.4 Conclusion

Based on the review of RTMS features described above to maintain Flibe above a minimum operating temperature and cool nearby structures and equipment, the staff concludes that the information on the RTMS in PSAR Section 9.1.5 is sufficient and meets applicable guidance and regulatory requirements identified in this section for issuance of a CP in accordance with 10 CFR 50.35 and 50.40. The staff concludes that the preliminary design features intended to minimize contamination and support eventual decommissioning are consistent with the requirements of 10 CFR 20.1406. Based on the information provided, the staff concludes that the preliminary design of the RTMS satisfies the applicable acceptance criteria in NUREG-1537 to not result in accidents or unacceptable radioactivity releases and for no function or malfunction of the RTMS to interfere with or prevent safe shutdown of the reactor.

9.2 Reactor Building Heating, Ventilation, and Air Conditioning System

9.2.1 Introduction

Section 9.2 of the Hermes PSAR describes the RBHVAC. The RBHVAC is not proposed to provide any safety related function or support any safety related SSCs. Although radiation monitoring and filtration will be provided, the RBHVAC is not needed to mitigate any postulated event. No technical specifications are proposed for the RBHVAC. The RBHVAC performs the following non-safety related functions:

- Maintain environmental conditions (air quality, temperature, humidity, pressure, and noise levels) for personnel health, habitability, and for SSC operability
- Provide a means to control and monitor tritium, beryllium, and other controlled effluents
- Monitor exhaust air vented from the reactor building for controlled effluents
- Ensure ventilation flow from areas of low hazard to areas of higher hazard potential
- Minimize contamination of facility areas

9.2.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of the Hermes non-power test reactor RBHVAC are as follows:

- 10 CFR 50.34, “Contents of applications; technical information,” paragraph (a), “Preliminary safety analysis report.”
    - 50.34(a)(3)(ii) requires “The design bases and the relation of the design bases to the principal design criteria.”
    - 50.34(a)(3)(iii) requires “Information relative to materials of construction, general arrangement, and approximate dimensions, sufficient to provide reasonable assurance that the final design will conform to the design bases with adequate margin for safety.”
    - 50.34(a)(4) which requires “A preliminary analysis and evaluation of the design and performance of structures, systems, and components [SSCs] of the facility…”
- 10 CFR 50.35, “Issuance of construction permits.”

- 10 CFR 50.40, “Common standards.”

As described in subsection 9.1.1 above, the staff did not evaluate whether requirements in 10 CFR Part 20 would be met for the construction of the Hermes reactor. Instead, the staff assessed whether Kairos identified the relevant requirements for an operating facility and provided descriptions of the preliminary facility design. The staff assessed this to determine whether the PSAR provides an acceptable basis for the development of systems and whether there is reasonable assurance that Kairos will comply with the regulations in 10 CFR Part 20 during Hermes facility operation.

Guidance used by the staff to support this review includes:

- NUREG-1537, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors, Parts 1 and 2.” Specifically, Section 9.1 “Heating, Ventilation, and Air Conditioning Systems” provides review criteria and procedures. The guidance notes that heating ventilation and air conditioning (HVAC) systems will support functions like the as low as is reasonably achievable (ALARA) program, radiation monitoring, and contamination control which are described in Chapter 11, “Radiation Protection Program and Waste Management,” of the PSAR and this SE.
- Regulatory Guide 4.20, “Constraint on Releases of Airborne Radioactive Materials to the Environment for Licensees Other than Power Reactors,” Revision 1. The constraint of 10 CFR 20.1101(d) may be interpreted as that fraction of the public dose limit allocated to airborne emissions to ensure that doses are ALARA through this particular release pathway. Licensees are required to design their facilities and structure operations such that airborne emissions of radioactive materials generated from operations result in doses to the public that are below the constraint. The constraint serves as a starting point, or upper level, for ALARA assessments. If licensees exceed the constraint on airborne emissions, they are required to report the radiation dose to the NRC and to take corrective actions to lower the dose below the constraint value.

9.2.3 Technical Evaluation

Principal design criteria applicable to the RBHVAC are:

- PDC 2, Design Bases for Protection Against Natural Phenomena
- PDC 60, Control of Releases of Radioactive Materials to the Environment
- PDC 64, Monitoring Radioactivity Releases

The staff reviewed material presented in the PSAR against acceptance criteria of NUREG-1537, Part 2 Section 9.1. The PSAR describes the design of the RBHVAC but does not provide details of design features. The staff expects that the OL application will provide details on design features.

The RBHVAC supplies filtered fresh air to the reactor building and monitors and filters air that is exhausted to the environment. The RBHVAC contains return airflow paths throughout the reactor building, including from the reactor and PHSS cells. The TMS (described in Section 9.1.3 of the PSAR and evaluated in Section 9.1.3 of this SE) has a subsystem within the RBHVAC to collect airborne tritium and convert it to water. The tritiated water is collected and handled as radioactive waste (described in Section 11.2.2 of the PSAR and evaluated in

Section 11.2 of this SE). This process assures that normal sources of airborne radioactive material are diverted and filtered to maintain occupational doses and that doses to the public are ALARA. The staff finds that Kairos has shown that the preliminary Hermes design is consistent with the requirements of 10 CFR 20.1101(b) because of RBHVAC design features, including the supply of fresh air to the reactor building, the filtering of exhaust air, and the integration of the TMS with the RBHVAC.

The RBHVAC is designed to direct flow and leakage toward areas of higher radioactivity to minimize diffusion or other uncontrolled release of airborne radioactive material from the reactor cell and the PHSS cell. The staff finds that the description and level of detail on the RBHVAC provides reasonable assurance that the RBHVAC is consistent with the requirements of 10 CFR 20.1101(b) and 10 CFR 20.1406 based on the design of the system to move contaminated air to areas of higher radioactivity.

The design of the reactor building and the RBHVAC minimize the uncontrolled release of airborne radioactive material to the environment. All exhaust paths will be monitored, filtered with high efficiency particulate air filters, and can be isolated. Final details of the design and isolation capability will be provided in the operating license application. Higher radiation areas will be sealed to minimize leakage and will be fully contained within lower radiation areas.

A preliminary screening analysis of effluent emissions described in PSAR Section 11.1.5 demonstrates that planned releases of airborne radioactive material to the environment will be within regulatory limits. The analysis calculates a peak dose of 1.4 mrem/year at a nearby location accessible to the public. This dose is well within the constraint of 10 mrem/year required by 10 CFR 20.1101(d). Because Kairos demonstrated a peak dose of 1.4 mrem/year to the public, the staff finds that Kairos has shown, based on preliminary analyses, that the Hermes design will be able to meet the requirements of 10 CFR 20.1101(d) during operation.

9.2.4 Conclusion

In the PSAR Sections 9.1.3, 9.2, and 11.2.2, Kairos has identified design features for the RBHVAC and the TMS. Based on the review described above, the staff concludes that the information in Hermes PSAR Section 9.2 is sufficient and meets the applicable guidance and regulatory requirements identified in this section for issuance of a CP in accordance with 10 CFR 50.35 and 50.40. On the basis of its review, the staff has determined that the level of detail provided regarding the RBHVAC demonstrates an adequate basis for a preliminary design and satisfies the applicable acceptance criteria of NUREG-1537 to support the ALARA program, radiation monitoring and contamination control functions. Based on the staff review and findings above, the staff concludes that the design features and analyses described in the PSAR provide reasonable assurance that Kairos will meet 10 CFR 20.1101(b), 10 CFR 20.1101(d), and 10 CFR 20.1406.

9.3 Pebble Handling and Storage System

9.3.1 Introduction

PSAR Section 9.3, "Pebble Handling and Storage System," describes a preliminary design for the PHSS, which provides for handling and storing fuel and other pebbles. The system encompasses receipt and inspection of new fuel upon delivery, core loading, sensing, inspection and sorting during downstream circulation, re-insertion, core unloading, and removal and transfer to storage.

9.3.2 Regulatory Evaluation

The applicable regulatory requirements are as follows:

- 10 CFR 50.34, "Contents of applications; technical information," paragraph (a), "Preliminary safety analysis report."
  - 50.34(a)(3)(ii) requires "The design bases and the relation of the design bases to the principal design criteria."
  - 50.34(a)(3)(iii) requires "Information relative to materials of construction, general arrangement, and approximate dimensions, sufficient to provide reasonable assurance that the final design will conform to the design bases with adequate margin for safety."
  - 50.34(a)(4) which requires "A preliminary analysis and evaluation of the design and performance of structures, systems, and components [SSCs] of the facility…"
  - 50.34(a)(5) requires "An identification and justification for the selection of those variables, conditions, or other items which are determined as the result of preliminary safety analysis and evaluation to be probable subjects of technical specifications for the facility."
- 10 CFR 50.35, "Issuance of construction permits."
- 10 CFR 50.40, "Common standards."

As described in subsection 9.1.1 above, the staff did not evaluate whether requirements in 10 CFR Part 20 would be met for the construction of the Hermes reactor. Instead, the staff assessed whether Kairos identified the relevant requirements for an operating facility and provided descriptions of the preliminary facility design. The staff assessed this to determine whether the PSAR provides an acceptable basis for the development of systems and whether there is reasonable assurance that Kairos will comply with the regulations in 10 CFR Part 20 during Hermes facility operation.

Similarly, with regard to the PHSS, the staff also did not evaluate whether requirements in 10 CFR 70.24, "Criticality accident requirements," would be met for the construction of Hermes because a Hermes CP would not authorize Kairos to possess SNM. Instead, the staff assessed whether Kairos identified relevant requirements and descriptions of the preliminary facility design, to determine whether the PSAR provides an acceptable basis for the development of systems and whether there is reasonable assurance that Kairos will comply with 10 CFR 70.24 during Hermes operation.

The applicable guidance for the staff's evaluation is NUREG-1537, Parts 1 and 2, Section 9.2, "Handling and Storage of Reactor Fuel."

9.3.3 Technical Evaluation

Principal design criteria applicable to the PHSS are:

- PDC 2, Design Bases for Protection Against Natural Phenomena
- PDC 3, Fire Protection
- PDC 4, Environmental and Dynamic Effects Design Bases
- PDC 33, Reactor Coolant Inventory Maintenance

- PDC 61, Fuel Storage and Handling and Radioactivity Control
- PDC 62, Prevention of Criticality in Fuel Storage and Handling
- PDC 63, Monitoring Fuel and Waste Storage

PSAR Section 9.3 states the PHSS provides for receipt and inspection of new fuel upon delivery; performs core loading, sensing, inspection and sorting during downstream circulation; re-insertion; core unloading; and removal and transfer to storage. Major components, features, and functions include the pebble extraction machine, debris removal, off-head conveyance line, pebble processing, pebble inspection, pebble insertion, inert gas boundary, pebble storage, and new pebble introduction.

The spent fuel storage portion of the system is composed of stainless steel storage canisters and a transporter device to move canisters. Individual storage canisters will be designed to hold 1900 to 2100 pebbles. After the canister is filled with pebbles, the canister's fill valve is closed, and the canister is moved via an automated transfer system for sealing. After sealing, the canister is moved with a canister transporter to a water-filled cooling pool for initial spent fuel storage. After cooling in pool storage, the canister is moved to an air-cooled storage bay.

Consistent with PDC 2, the concrete structures associated with the storage bay, pool, and support restraints in the pool are being designed as Seismic Design Category 3 structures to ensure the geometry of the storage area is maintained to prevent inadvertent criticality during a design basis earthquake. For a postulated earthquake, the tristructural isotropic (TRISO) fuel is passively cooled by the transporter and the pool which provides passive cooling and spacing to restrict pebble movement to prevent criticality. Other portions of the PHSS that do not perform a safety function will be either seismically mounted or physically separated to preclude adverse interactions with other safety related SSCs during a design basis earthquake.

Consistent with PDC 3, the PHSS is being designed to minimize the probability of a fire or explosion by limiting the accumulation of potentially combustible material such as graphite dust within the system. The PHSS is not located near nor interfaces with pneumatic systems with the potential for air leakage into the PHSS. The PHSS is filled with inert gas at a positive pressure to help prevent air ingress. Locations within the PHSS where pebbles are not submerged in coolant, such as the pebble extraction machine, will either not exceed temperatures that would induce pebble oxidation or are expected to quickly cool such that oxidation, if any, would be minimal and not affect the acceptability of the pebble for reuse.

Consistent with PDC 4, the pebble handling portion of the PHSS is protected from the effects of discharging fluids. There are no pressurized piping systems in or around the PHSS thus precluding the need to consider pipe whip and related dynamic effects in the design. A hypothetical water line break does not pose a criticality risk, because the storage system criticality analysis assumes complete submergence and internal flooding of canisters in water. The PHSS is designed to handle the high radiation environment. The PHSS accounts for the temperature within the system to preclude oxidation of pebbles. The canisters are designed for the internal pressure due to accumulation of radionuclides and thermal loads associated with the spent fuel loaded in each canister. The canisters are designed for the tensile stress exerted during transfer. The canister interior is designed to handle radiolysis products from spent fuel to ensure the integrity of the canister, seal, and weld precluding release of radionuclides from the canister.

Consistent with PDC 33, the design of the PHSS minimizes the coolant drained from the reactor system in the event of a PHSS failure. The pebble extraction machine elevation is near the free surface of the coolant so that only a small amount of coolant is lost if the extraction machine breaks. Similarly, the pebble insertion line elevation is no lower than the salt pump elevation, limiting the amount of coolant lost with an insertion line break.

Consistent with PDC 61, the safety related portions of the PHSS that contain reactivity will be designed to ensure (1) capability to permit appropriate inspection and testing of components, (2) suitable shielding for radiation protection, (3) appropriate containment, confinement, and filtering, (4) residual heat removal capability, and (5) precluding significant reduction in fuel storage cooling under postulated event conditions. Regarding the inspection and testing of components, pebbles exiting the core are inspected to identify abnormal wear, cracking, and missing surfaces due to pebble chipping, as well as to determine the burnup. Regarding shielding for radiation protection, the PHSS will be adequately shielded to limit worker dose, in accordance with the radiation protection program described in PSAR Chapter 11. Containment and confinement of radioactivity within the fuel is maintained for the limiting PHSS malfunction event as discussed in Section 13.1.5. Regarding residual heat removal capability, heat removal mechanisms within the system, such as thermal radiation and convection via natural circulation, are sufficient to remove decay heat produced by pebbles moving through the system. Regarding precluding significant reduction in fuel storage cooling under postulated event conditions, the PHSS is designed to ensure decay heat loads from pebbles in the spent fuel pool are passively cooled by water in the pool in the event of a loss of power. The canisters in the storage bay are cooled during postulated events by natural convection due to the spacing which allows sufficient airflow.

Consistent with PDC 62, the system design will incorporate design features needed to ensure criticality is prevented. Examples include (1) removing pebbles at a rate that prohibits formation of a critical configuration in the event a PHSS line breach spills pebbles outside the PHSS, (2) maintaining an inert gas environment precluding moisture intrusion in fuel handling areas, (3) including physical constraints and system interlocks in the fuel handling equipment, and (4) making conservative assumptions in determining spacing requirements for each spent fuel canister such as assuming the canisters are submerged under water and are flooded internally. A summary of the criticality analyses confirming the system design maintains a geometrically safe configuration will be provided in the OL application.

Consistent with PDC 63, the PHSS is designed to ensure thermal and mechanical loads to the pebble and oxidation during handling, inspection, and loading into canisters do not exceed pebble design limits. Pebble inspection and sorting performed by the PHSS ensures that damaged pebbles extracted from the reactor are removed from use. Monitoring of the cover gas and reactor coolant radioactivity provides early indication of potential TRISO failure.

The PHSS includes a monitoring system capable of detecting criticality which Kairos states will satisfy the requirement in 10 CFR 70.24(a)(1), “Criticality Accident Requirements.”

PSAR Section 9.3 states that the PHSS contains radiological contaminants and, therefore, the PHSS will be designed to minimize such contamination and support eventual decommissioning, consistent with the requirements of 10 CFR 20.1406, “Minimization of contamination.”

For the PHSS, the staff used the guidance and acceptance criteria in NUREG-1537, Parts 1 and 2, Section 9.2, “Handling and Storage of Reactor Fuel,” to review the PHSS preliminary design description in PSAR Section 9.3, “Pebble Handling and Storage System.” As part of its review, the staff assessed whether PSAR Section 9.3 identifies the appropriate PDC for the PHSS. The staff finds that Kairos has described the design bases for the PHSS and that the preliminary information on the design and functional description of the PHSS provides reasonable assurance that the PHSS will conform to the design bases. The staff finds that the PHSS will be designed such that 1) criticality will not occur, 2) fuel handling tools and procedures will be designed to avoid damaging fuel, 3) methods for assessing fuel radioactivity and potential exposure rates will be adequate to avoid personnel overexposure, and 4) shielding methods will ensure doses are below occupational exposure limits and as low as reasonably achievable. Therefore, based on its review, the staff determined that the level of detail provided on the PHSS, including the design bases, and identification of relevant PDC, is adequate for a preliminary design and is consistent with the applicable acceptance criteria of NUREG-1537, Part 2, Section 9.2.

9.3.4 Conclusion

On the basis of its review, the staff has determined that the level of detail provided regarding the Hermes PHSS demonstrates an adequate basis for a preliminary design and satisfies the applicable acceptance criteria of NUREG-1537 to support functions like maintaining subcriticality, preventing damage to pebbles, limiting radiation exposure, and material control and accounting. Based on the staff findings above, the staff concludes that the preliminary design of the PHSS, as described in the PSAR, is sufficient and meets the applicable regulatory requirements and guidance identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Based on the monitoring capability described above, the staff concludes that the preliminary design features related to criticality safety are consistent with the requirements of 10 CFR 70.24. The staff concludes that the preliminary design features intended to minimize contamination and support eventual decommissioning provide reasonable assurance that Kairos will acceptably meet the requirements of 10 CFR 20.1406(a). Further technical or design information required to approve operation of the PHSS will be evaluated in the review of the OL application.

9.4 Fire Protection Systems and Programs

9.4.1 Introduction

PSAR Section 9.4 “Fire Protection Systems and Programs,” describes a preliminary design for fire protection systems and related programs. The fire protection program integrates components, procedures, analysis, and personnel used to define and carry out all activities of fire protection. The fire protection system is designed to detect, control, and extinguish fires so that a continuing fire will not prevent safe shutdown or result in an uncontrolled release of radioactive material that exceeds acceptance criteria. Kairos stated that a description of the fire protection program and a fire hazards analysis will be provided with the application for an OL.

9.4.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of Hermes fire protection systems and programs are as follows:

- 10 CFR 50.34(a) “Contents of applications; technical information,” paragraph (a), “Preliminary safety analysis report.”
    - 50.34(a)(3)(ii) requires “The design bases and the relation of the design bases to the principal design criteria.”

    - 50.34(a)(3)(iii) requires "Information relative to materials of construction, general arrangement, and approximate dimensions, sufficient to provide reasonable assurance that the final design will conform to the design bases with adequate margin for safety."
    - 50.34(a)(4) which requires "A preliminary analysis and evaluation of the design and performance of structures, systems, and components [SSCs] of the facility…"
    - 50.34(a)(5) requires "An identification and justification for the selection of those variables, conditions, or other items which are determined as the result of preliminary safety analysis and evaluation to be probable subjects of technical specifications for the facility."
- 10 CFR 50.35, "Issuance of construction permits."
- 10 CFR 50.40, "Common standards."

The applicable guidance for the evaluation of the Hermes fire protection systems and programs is as follows:

- NUREG-1537, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors," Part 1, "Format and Content," and Part 2, "Standard Review Plan and Acceptance Criteria," Section 9.3, "Fire Protection Systems and Programs."

9.4.3 Technical Evaluation

Kairos states in PSAR Section 9.4.2.3 that the fire protection systems conform to local building and fire codes. Additionally, PSAR Section 9.4.2.3 states that the fire protection systems will be designed to ANSI/ANS 15.17, "Fire Protection Program Criteria for Research Reactors," and National Fire Protection Association 801, "Standard for Fire Protection for Facilities Handling Radioactive Materials," 2020 edition. Life safety provisions are included in the facility design in accordance with the National Fire Protection Association 101, "Life Safety Code," 2021 edition.

Kairos states in PSAR Section 9.2.2.2 that noncombustible and fire-resistant materials are used whenever practical, particularly in locations with SSCs that are safety related or required for safe shutdown. Safety related SSCs and equipment required for safe shutdown of the reactor are located within the reactor building. The floors, walls, and ceilings of the reactor building are constructed almost entirely of reinforced concrete.

According to PSAR Section 9.4.2.1, the fire protection system is designed to detect, control, and extinguish fires so that a continuing fire will not prevent safe shutdown or result in an uncontrolled release of radioactive material that exceeds acceptance criteria. Design features such as fire barriers and fire area penetration protection are also included to provide for life safety provisions and to minimize the spread of fire. Fire protection system elements and design features will be identified and installed in defined fire areas based on the results of the fire hazards analysis. Kairos states in PSAR Section 9.4.2.4 that functional tests of the fire protection system will be performed prior to startup.

Kairos states in PSAR Section 9.4.2.1 that the fire protection system includes fire detection and alarm systems as well as automatic and manual fire suppression systems. These fire detection and firefighting systems will be of appropriate capacity and capability and are designed to minimize the adverse effects of fires on SSCs that are safety related or required for safe shutdown. The PDC applicable to fire protection systems are evaluated below based on the information provided in PSAR Section 9.4.

9.4.3.1 PDC 2 "Design Bases for Protection Against Natural Phenomena"

Kairos states in PSAR Section 9.4.2.3 that fire water piping is routed such that a rupture or inadvertent operation of the fire protection system does not significantly impair safety related or safe shutdown functions. Kairos stated that the fire protection systems are not safety related but portions of these systems may cross the isolation moat discussed in Section 3.5 of the PSAR, and that SSCs that cross a base-isolation moat may experience differential displacements as a result of seismic events. Kairos stated that the fire protection systems are designed so that postulated failures of SSCs in these systems from differential displacements will not preclude a safety related SSC from performing its safety function. Based on these features of the fire protections systems, staff finds that the preliminary design is consistent with PDC 2.

9.4.3.2 PDC 3 "Fire Protection"

The staff reviewed Kairos's submittal against the four criteria described in PDC 3. The fire protection features described in the paragraphs above demonstrate that the preliminary design will 1) minimize the effect of fires, 2) will minimize the use of combustible materials, 3) will provide fire detection and fighting systems, and 4) will not impair the function of safety related SSCs and, therefore the staff finds that the preliminary design is consistent with PDC 3.

9.4.3.3 PDC 19 Control Room

The staff reviewed the PSAR as it applies to providing the capability both inside and outside the control room to operate plant systems necessary to achieve and maintain safe shutdown conditions. In Section 7.4 of the PSAR "Main Control Room and Remote Onsite Shutdown Panel," Kairos stated that the main control room provides the means for operators to monitor the behavior of the plant, control performance of the plant, and manage the response to postulated event conditions in the plant. The main control room also contains a central alarm panel for the fire protection system so that operators can monitor the status of fire protection equipment inside the reactor building. The central alarm panel includes controls for the ventilation and extinguishing systems related to the response to fires.

The remote onsite shutdown panel (ROSP) provides separate means to shut down the plant and monitor plant parameters in response to postulated event conditions. The ROSP is located in the safety related portion of the reactor building and is used in the event that the main control room becomes uninhabitable. Based on the capabilities to monitor and control the plant both inside and outside the control room in the event of a fire, the staff finds that the preliminary design is consistent with PDC 19.

9.4.3.4 PDC 23 Protection System Failure Modes

The staff reviewed the PSAR as it applies to the protection system being designed to fail into a safe state or into a state demonstrated to be acceptable on some other defined basis if the plant experiences adverse environments such as from a fire. In Section 4.2.2 of the PSAR, "Reactivity Control and Shutdown System," (RCSS) Kairos stated that the RCSS fails into a safe state in the event of adverse conditions or environments. In Section 7.3 of the PSAR, "Reactor Protection System," (RPS) Kairos stated that the RPS fails to a safe state upon detection of adverse environmental conditions, such as a fire. Because the RCSS and the RPS fail in a safe state in the event of a fire, the staff finds that the preliminary design is consistent with PDC 23.

9.4.4 Conclusion

On the basis of its review, the staff has determined that the level of detail provided regarding the fire protection program and fire protection systems demonstrates an adequate basis for a preliminary design and satisfies the applicable acceptance criteria of NUREG-1537: prevention of fires and limitation of combustible materials, methods to detect, control, and extinguish fires, and ensuring safe shutdown in the event of a fire. Therefore, the staff concludes that information provided in the PSAR meets the regulatory requirements and guidance identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Based on the information provided in the PSAR, the staff concludes that the preliminary description of the fire protection program and the fire protection systems demonstrate an adequate design basis for a preliminary design so that the requirements of 10 CFR 50.34(a) are met. Further programmatic, technical, or design information required to approve operation of the test reactor will be evaluated in the review of the OL application.

9.5 Communication Systems

9.5.1 Introduction

PSAR Section 9.5 “Communication,” describes a preliminary design for the Hermes communication systems. Hermes PSAR, Section 9.5.1, states that the communication system provides communications during normal and emergency conditions between essential areas of the facility and between locations remote to the facility. The communication system is not safety related; it is not credited for mitigation of design basis events and has no safe shutdown function.

9.5.2 Regulatory Evaluation

The applicable regulatory requirements are as follows:

- 10 CFR 50.34, “Contents of applications; technical information,” paragraph (a), “Preliminary safety analysis report.”
    - 50.34(a)(3)(ii) requires “The design bases and the relation of the design bases to the principal design criteria.”
    - 50.34(a)(3)(iii) requires “Information relative to materials of construction, general arrangement, and approximate dimensions, sufficient to provide reasonable assurance that the final design will conform to the design bases with adequate margin for safety.”
- 10 CFR 50.35, “Issuance of construction permits.”
- 10 CFR 50.40, “Common standards.”

The applicable guidance for the staff’s evaluation is NUREG-1537, Parts 1 and 2, Section 9.4, “Communication Systems.” The guidance notes the need for communication capabilities among plant operating staff.

9.5.3 Technical Evaluation

As stated in Hermes PSAR, Section 9.5.2, the communication system provides the capabilities for both normal and emergency communications and has the following subsystems: plant radio, public address and general alarm, communication capability in the event of a loss of normal power, distributed antenna, and security communications.

Two-way communication is provided between the main control room and other locations in the reactor facility. The communication system uses diverse voice over Internet protocol, commercial land, and cellular phone lines in combination in the control room and several other locations within and outside the reactor building to provide communications between key areas of the facility. The communication system is designed so that a failure of any one station does not impact the other stations. In an emergency, the public address system is used to alert personnel.

The staff evaluated the sufficiency of the preliminary information on Hermes communication systems, as described in PSAR Section 9.5, using the guidance and acceptance criteria from NUREG-1537, Parts 1 and 2. Based on its review, the staff determined that the level of detail provided on Hermes communication systems is adequate and meets the applicable acceptance criteria of NUREG-1537, Part 2, Section 9.4, because:

- The facility communication systems are designed to provide two-way communication between the main control room and all other locations necessary for safe reactor operation.
- The communication systems allow the reactor operator on duty to communicate with the supervisor on duty and with health physics personnel.
- The communication systems allow a facility-wide announcement of an emergency.
- The communication systems have provisions for summoning emergency assistance from designated personnel, as discussed in the physical security and emergency plans. Physical security and emergency plans will be evaluated as part of the operating license application review.

9.5.4 Conclusion

On the basis of its review, the staff has determined that the level of detail provided regarding the Hermes communication systems demonstrates an adequate basis for a preliminary design and satisfies the applicable acceptance criteria of NUREG-1537. Based on its findings above, the staff concludes the design of the Hermes communication systems, as described in Hermes PSAR Section 9.5, is sufficient and meets the applicable regulatory requirements and guidance identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40 and demonstrates an adequate design basis for a preliminary design. A more detailed evaluation of information will occur during the review of the Hermes OL application, at which time the staff will confirm that the final design conforms to this design basis.

9.6 Possession and Use of Byproduct, Source, and Special Nuclear Material

9.6.1 Introduction

PSAR Section 9.6, "Possession and Use of Byproduct, Source, and Special Nuclear Material," discusses radioactive materials, including byproduct material, source material, and special nuclear material (SNM) that will be present at the Hermes facility. PSAR Section 9.6 also discusses locations where these materials will be stored or used at the facility, systems that interact with these materials and controls for handling these materials. PSAR Section 9.6 states that the design bases for systems interacting with byproduct, source, or SNM are to prevent uncontrolled release of radioactive materials and to maintain any Kairos personnel exposures within 10 CFR Part 20 dose limits and ALARA objectives.

PSAR Section 9.6 states that Kairos's CP application does not request authorization to possess any radioactive material, and that amendments or applications for license(s) allowing such possession of such material would be submitted at later date(s). During the General Audit (ML23115A480), Kairos stated that it planned to possess byproduct, source and SNM associated with Hermes operation under a 10 CFR Part 50 OL for Hermes, but that it might also request authorization to possess such materials prior to the issuance of an OL, for example, through a construction permit (CP) amendment request. Possession of radioactive material by Kairos would be evaluated when an application is submitted to the NRC.

9.6.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of Kairos's possession and use of byproduct, source, and SNM are as follows:

- 10 CFR 50.34, "Contents of applications; technical information," paragraph (a), "Preliminary safety analysis report."
    - 50.34(a)(3)(ii) requires "The design bases and the relation of the design bases to the principal design criteria."
    - 50.34(a)(3)(iii) requires "Information relative to materials of construction, general arrangement, and approximate dimensions, sufficient to provide reasonable assurance that the final design will conform to the design bases with adequate margin for safety."
    - 50.34(a)(4) which requires "A preliminary analysis and evaluation of the design and performance of structures, systems, and components [SSCs] of the facility…"
    - 50.34(a)(5) requires "An identification and justification for the selection of those variables, conditions, or other items which are determined as the result of preliminary safety analysis and evaluation to be probable subjects of technical specifications for the facility."
- 10 CFR 50.35, "Issuance of construction permits."
- 10 CFR 50.40, "Common standards."

As described in subsection 9.1.1 above, the staff did not evaluate whether requirements in 10 CFR Part 20 would be met for the construction of the Hermes reactor. Instead, the staff assessed whether Kairos identified the relevant requirements for an operating facility and provided descriptions of the preliminary facility design. The staff assessed this to determine whether the PSAR provides an acceptable basis for the development of systems and whether there is reasonable assurance that Kairos will comply with the regulations in 10 CFR Part 20 during Hermes facility operation.

The applicable guidance for the evaluation of Kairos's possession and use of byproduct, source, and SNM is as follows:

- NUREG-1537, Parts 1 and 2, Section 9.5, “Possession and Use of Byproduct, Source, and Special Nuclear Material.”

9.6.3 Technical Evaluation

The Hermes core will contain two types of pebbles: pebbles that contain fuel particles and moderator pebbles. In PSAR Section 9.6.1, Kairos states that SNM at the Hermes facility during operation would consist of the fuel particles contained in fuel pebbles. Hermes SNM fuel pebbles will use uranium enriched to various levels less than 20 percent enrichment. PSAR Section 9.6.2 states Hermes will also utilize pebbles with unenriched uranium particles, and therefore source material will also be present at the Hermes facility during operation. Handling, use, and storage of SNM and source material will occur in fresh fuel handling areas, the reactor vessel, and the PHSS.

In PSAR Section 9.6.3, Kairos states that byproduct material will be used to support Hermes operation and byproduct material will also be generated by Hermes operation. Byproduct material at Hermes will include tritium, which is generated as a result of the nuclear reaction in the core, and which will be present in the irradiated fuel pebbles (in the reactor vessel and PHSS) and the primary cooling system.

PSAR Section 9.6.4 states that byproduct material, source material, and SNM may also be handled in laboratories at the Hermes facility for research and testing purposes. Further detail regarding the laboratory use of radioactive materials would be provided as part of an OL application and reviewed by the staff at the OL stage.

PSAR Sections 9.6.1 and 9.6.3 state that the designs of the fuel pebbles, reactor vessel, PHSS, and TMS prevent uncontrolled releases of radioactive material. Shielding is also used to reduce any direct doses from irradiated fuel pebbles, consistent with ALARA practices. PSAR Section 9.6.4 states that any material used in laboratories under the reactor license will be handled appropriately (e.g., using glove boxes and air exhaust systems, as applicable) to ensure any doses are ALARA and within 10 CFR Part 20 limits. In addition, as discussed in PSAR Section 9.6, spaces in which radioactive material is used and equipment used to handle radioactive material will be subject to administrative controls to minimize contamination, prevent radiological sabotage, theft, or diversion, and prevent uncontrolled release of the materials. Kairos states that byproduct material, source material, and SNM at the Hermes facility will be managed by compliance with the applicable provisions of 10 CFR Parts 30, 40, and 70, respectively.

The preliminary designs of the Hermes fuel, reactor vessel, PHSS, and TMS are discussed in further detail in PSAR Sections 4.2, 4.3, 9.3, and 9.1.3 respectively. The staff reviewed the information on the preliminary design of these items and found it acceptable for the issuance of a CP, as discussed in Sections 4.2.1, 4.3, 9.3, and 9.1.3 of this SE.

PSAR Section 11.2.2 describes the preliminary design of the Hermes radioactive waste handling systems, and states that the systems will be designed to control releases of radioactive materials to the environment such that 10 CFR Part 20 limits will not be exceeded. The staff reviewed the information on the preliminary design of the waste handling systems and found it acceptable for the issuance of a CP, as discussed in Section 11.2 of this SE.

PSAR Section 9.6 states that further information on administrative procedures related to the use of byproduct material, source material, and SNM during Hermes operation would be provided in an application for an OL. These administrative procedures would cover several technical and programmatic areas. PSAR Chapter 11 provides preliminary information on administrative controls for radioactive material at the Hermes facility and the Hermes ALARA program. The staff reviewed the preliminary information provided in PSAR Chapter 11 and found it acceptable for the issuance of a CP as discussed in Chapter 11 of this SE. PSAR Sections 11.2.1 and 12.8 state that a description of the radioactive waste management program for the Hermes facility, and a description of the security plan for Hermes, respectively, will also be provided in an OL application. PSAR Section 9.4 states that the Hermes fire protection system will be designed to prevent a continuing fire from resulting in an unacceptable release of radioactive material and that details of a Hermes fire hazards analysis and fire protection program plan will be provided in an OL application. PSAR Chapter 12, Appendix A, provides a preliminary plan for addressing emergencies (including emergencies involving a potential release of radioactive material) at the Hermes facility, which the staff reviewed and found acceptable for the issuance of a CP as discussed in Section 12.7 of this SE. PSAR Chapter 14 includes the potential items or variables that are expected topics of technical specifications for the Hermes facility. Administrative controls, including those for managing SNM, source, and byproduct material, will be provided in the application for an OL. The staff documented its review of Kairos's probable subjects of technical specifications for the Hermes facility in Chapter 14 of this SE.

The staff reviewed the information in PSAR Section 9.6 and other PSAR sections related to the Hermes facility preliminary design with respect to the byproduct material, source material, and SNM that will be used in the facility. PSAR Section 9.6 and other PSAR sections describe a preliminary design with appropriate systems and controls to help ensure that doses from radioactive material at Hermes are within 10 CFR Part 20 dose limits and ALARA. In combination with this and based on its reviews of information in other PSAR sections as summarized above, the staff finds that the information in the PSAR demonstrates an adequate design basis for a preliminary design and satisfies the applicable acceptance criteria of NUREG-1537, Part 2, Section 9.5. Based on this review, the staff finds that: (1) the auxiliary facilities and systems are designed for the possession and use of source material, SNM and byproduct material located at Hermes and produced by the reactor and (2) the Hermes design provides reasonable assurance that uncontrolled release of radioactive material to the unrestricted environment and public will not occur. Because the design bases include limits on potential personnel exposures, the staff has reasonable assurance that Kairos will comply with the regulations in 10 CFR Part 20 and the ALARA program during Hermes facility operation.

9.6.4 Conclusion

Based on the review and findings described above, the staff concludes that the information provided in the PSAR and the preliminary design of the Kairos program and auxiliary facilities for the possession and use of byproduct material, source material, and SNM at Hermes, as described in the PSAR, is sufficient and meets the applicable regulatory requirements and guidance identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Based on the staff review and findings above, the staff also concludes that the preliminary design and programs described in the PSAR provide reasonable assurance that Kairos will comply with 10 CFR Part 20 during operation. Further technical or design information required to approve operation of the test reactor will be evaluated in the review of the OL application.

9.7 <u>Plant Water Systems</u>

Section 9.7 of the Hermes PSAR describes four auxiliary water systems:

- Service Water
- Treated Water
- Component Cooling Water
- Chilled Water

The auxiliary water systems do not provide any safety related function or support any safety related SSCs, are not needed to mitigate any postulated event, and are not credited with performing safe shutdown functions. No technical specifications are proposed in the PSAR for these water systems. These water systems perform the following non-safety related functions:

- Supply, treat, and store water
- Distribute water for cooling and maintenance
- Remove heat from non-essential loads
- Remove heat from essential loads
- Discharge heat to the environment

The introduction to PSAR Section 9.7 states that water systems which directly interface with systems containing radioactive material will be designed to meet the requirements of 10 CFR 20.1406. As indicated by PSAR Figure 9.7-1, only the CCWS interfaces with systems containing radioactive material in the current design. Kairos confirmed in the General Audit that, in the final design, any auxiliary water systems which connect to a system containing radioactive material will be designed to meet the requirements of 10 CFR 20.1406.

9.7.1 Regulatory Evaluation for Auxiliary Water Systems

Common regulatory requirements and guidance for auxiliary water systems are identified here. Any additional requirements or guidance specific to a system are identified in the subsection for that system. The applicable regulatory requirements for the evaluation of the Hermes non-power test reactor auxiliary water systems are:

- 10 CFR 50.34, “Contents of applications; technical information,” paragraph (a), “Preliminary safety analysis report.”
    - 50.34(a)(3)(ii) requires “The design bases and the relation of the design bases to the principal design criteria.”
    - 50.34(a)(3)(iii) requires “Information relative to materials of construction, general arrangement, and approximate dimensions, sufficient to provide reasonable assurance that the final design will conform to the design bases with adequate margin for safety.”
    - 50.34(a)(4) which requires “A preliminary analysis and evaluation of the design and performance of structures, systems, and components [SSCs] of the facility…”
- 10 CFR 50.35, “Issuance of construction permits.”
- 10 CFR 50.40, “Common standards.”

Guidance for this review includes:

- NUREG-1537, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors, Parts 1 and 2.” Specifically, Section 9.7, “Other Auxiliary Systems” provides review criteria and procedures. The guidance notes that the design, functions, and potential malfunctions of the auxiliary systems should not result in reactor accidents or uncontrolled release of radioactivity and no function or malfunction of the auxiliary systems should interfere with or prevent safe shutdown of the reactor.

9.7.2 Service Water System

9.7.2.1 Introduction

The Hermes Service Water System draws water from municipal sources and provides the water to other water systems and supports general facility services (e.g., potable water). The Service Water System is not safety related and is not credited for the mitigation of postulated events. The Service Water System is designed in accordance with local building codes.

9.7.2.2 Technical Evaluation

Principal design criteria applicable to the Service Water System are:

- PDC 2, Design Bases for Protection Against Natural Phenomena
- PDC 4, Environmental and Dynamic Effects Design Bases

Section 9.7.1 of the PSAR describes the Service Water System as a supply to other water systems and for general facility use. PSAR Section 9.7.1 identifies traits of the system that will enable it to meet regulatory requirements. The detailed design of the Service Water System and its relation to safety evaluations will be reviewed as part of the OL application.

No portion of the Service Water System will be located in the proximity of safety related SSCs. Thus, staff finds that the preliminary design of the Service Water System is consistent with the objective of PDC 2 to withstand the effects of natural phenomena and is consistent with the guidance of NUREG-1537 Part 2, Section 9.7 for auxiliary systems to not cause accidents to the reactor, uncontrolled release of radioactivity, or interfere with safe shutdown of the reactor.

The Service Water System is a low-pressure system and will not create pipe whip or jet impingement threats to safety related SSCs. Thus, staff finds that the preliminary design is consistent with the objective of PDC 4 to accommodate the effects of environmental and dynamic effects during operation, maintenance, testing, and postulated accidents.

9.7.2.3 Conclusion

Kairos has identified traits of the Service Water System in PSAR Section 9.7.1. The staff finds that the traits described in the PSAR demonstrate that the preliminary design is consistent with PDC 2, PDC 4, and the guidance of NUREG-1537 Part 2, Section 9.7. Based on the staff’s review and the findings above, the staff concludes that the preliminary design of the Service Water System is sufficient and meets the applicable regulatory requirements and guidance identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40.

9.7.3 Treated Water System

9.7.3.1 Introduction

PSAR Section 9.7.2 states that the Treated Water System provides chemistry control for water supplied to the CCWS, the Chilled Water System, and the Decay Heat Removal System. Portions of the Treated Water System may be located in proximity to SSCs with safety related functions and portions of the system may cross the base-isolation moat that provides seismic protection for the reactor cell and PHSS cell. The Treated Water System is not safety related and is not credited for the mitigation of postulated events. The Treated Water System is designed in accordance with local building codes.

9.7.3.2 Technical Evaluation

Principal design criteria applicable to Treated Water System are:

- PDC 2, Design Bases for Protection Against Natural Phenomena
- PDC 4, Environmental and Dynamic Effects Design Bases

The PSAR identifies traits of the Treated Water System that will enable it to meet regulatory requirements. Implementation of these traits and associated specific design features are not needed for the preliminary design required by a CP. The detailed design of the Treated Water System and its relation to safety evaluations will be reviewed as part of the operating license application.

Since portions of the Treated Water System may be located in proximity to SSCs with safety related functions, the system will be designed through various means identified in the PSAR to protect those safety related SSCs. Thus, staff finds that the preliminary design of the Treated Water System is consistent with the objective of PDC 2 to withstand the effects of natural phenomena and is consistent with the guidance of NUREG-1537 Part 2, Section 9.7 for auxiliary systems to not cause accidents to the reactor, uncontrolled release of radioactivity, or interfere with safe shutdown of the reactor.

The Treated Water System is a low-pressure system. Since portions of the Treated Water System cross the base-isolation moat, design features are provided to protect safety related SSCs. The staff finds that the low-pressure design and protective features are consistent with the objective of PDC 4 to accommodate the effects of environmental and dynamic effects during operation, maintenance, testing, and postulated accidents.

9.7.3.3 Conclusion

Kairos has identified traits of the Treated Water System in PSAR Section 9.7.2. The staff finds that the traits of the system, as described in the PSAR, demonstrate that the preliminary design is consistent with PDC 2, PDC 4, and the guidance of NUREG-1537 Part 2, Section 9.7. Based on the staff’s review and the findings above, the staff concludes that the preliminary design of the Treated Water System is sufficient and meets the applicable regulatory requirements and guidance identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40.

9.7.4 Component Cooling Water System

9.7.4.1 Introduction

PSAR Section 9.7.3 states that the CCWS provides water cooling for the RBHVAC, the ESCS, the Spent Fuel Cooling System (SFCS), and the IGS. The CCWS is managed by the plant control system to maintain desired operational temperature limits. Heat from the CCWS is rejected to the environment.

The CCWS does not perform safety related functions and is not credited for the mitigation of postulated events. Portions of the CCWS may be located in proximity to SSCs with safety related functions and portions of the system may cross the base-isolation moat that provides seismic protection for the reactor cell and PHSS cell.

9.7.4.2 Regulatory Evaluation

As described in subsection 9.1.1 above, the staff did not evaluate whether requirements in 10 CFR Part 20 would be met for the construction of the Hermes reactor. Instead, the staff assessed whether Kairos identified the relevant requirements for an operating facility and provided descriptions of the preliminary facility design. The staff assessed this to determine whether the PSAR provides an acceptable basis for the development of systems and whether there is reasonable assurance that Kairos will comply with the regulations in 10 CFR Part 20 during Hermes facility operation.

9.7.4.3 Technical Evaluation

Principal design criteria applicable to the CCWS are:

- PDC 2, Design Bases for Protection Against Natural Phenomena
- PDC 4, Environmental and Dynamic Effects Design Bases
- PDC 44, Structural and Equipment Cooling
- PDC 45, Inspection of Structural and Equipment Cooling Systems
- PDC 46, Testing of Structural and Equipment Cooling Systems

Section 9.7.3 of the PSAR provides a summary description of the CCWS and identifies traits of the CCWS that will enable it to meet regulatory requirements. Implementation of these traits and specific design features of the system are not needed for the preliminary design required by a CP. The detailed design of the CCWS and its relation to safety evaluations will be reviewed as part of the OL application.

The CCWS will interface with water systems that may contain radioactive material. The CCWS will be designed to minimize the contamination of the facility and the environment and minimize the generation of radioactive waste. Based on these design traits, staff finds that the preliminary design of the CCWS provides reasonable assurance that the design will be consistent with the requirements of 10 CFR 20.1406.

Since portions of the CCWS may be located in proximity to SSCs with safety related functions, the system is designed, through various means identified in the PSAR, to protect those safety related SSCs. Because of these design features, staff finds that the preliminary design of the CCWS is consistent with the objective of PDC 2 to withstand the effects of natural phenomena and meets the guidance of NUREG-1537 Part 2, Section 9.7 for auxiliary systems to not cause accidents to the reactor, uncontrolled release of radioactivity, or interfere with safe shutdown of the reactor.

The CCWS is a low-pressure system. Since portions of the CCWS cross the base-isolation moat, design features are provided to protect safety related SSCs. Because of the low-pressure design and protective features, staff finds that the CCWS is consistent with the objective of PDC 4 to accommodate the effects of environmental and dynamic effects during operation, maintenance, testing and postulated accidents.

The CCWS is designed to permit periodic inspection and testing to ensure the integrity and capability of the system to cool SSCs and to adequately transfer heat to the ultimate heat sink. Based on this capability, the staff finds that the CCWS is consistent with PDC 44, PDC 45, and PDC 46.

9.7.4.4 Conclusion

Kairos has identified traits of the CCWS in PSAR Sections 9.7 and 9.7.3. The staff finds that the traits described in the PSAR demonstrate that the preliminary design is consistent with PDC 2, PDC 4, PDC 44, PDC 45, PDC 46, 10 CFR 20.1406, and the guidance of NUREG-1537 Part 2, Section 9.7. Based on the staff's review and the findings above, the staff concludes that the preliminary design of the CCWS is sufficient and meets the applicable regulatory requirements and guidance identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40.

9.7.5 Chilled Water System

9.7.5.1 Introduction

PSAR Section 9.7.4 states that the Chilled Water System provides cooling water to the RBHVAC system and other facility SSCs that are not safety related. The Chilled Water System is not safety related and is not credited for the mitigation of postulated events. The Chilled Water System is designed in accordance with local building codes.

9.7.5.2 Technical Evaluation

Principal design criteria applicable to Treated Water System are:

- PDC 2, Design Bases for Protection Against Natural Phenomena
- PDC 4, Environmental and Dynamic Effects Design Bases

The PSAR identifies traits of the Chilled Water System that will enable it to meet regulatory requirements. Implementation of these traits and associated design features specific to the system are not needed for the preliminary design required by a CP. The detailed design of the Chilled Water System and its relation to safety evaluations will be reviewed as part of the OL application.

No portion of the Chilled Water System will be located in the proximity of safety related SSCs. Thus, staff finds that the preliminary design of the Chilled Water System is consistent with the objective of PDC 2 to withstand the effects of natural phenomena and meets the guidance of

NUREG-1537 Part 2, Section 9.7 for auxiliary systems to not cause accidents to the reactor, uncontrolled release of radioactivity, or interfere with safe shutdown of the reactor.

The Chilled Water System is a low-pressure system, precluding pipe whip and jet impingement threats to safety related SSCs. Based on this, the staff finds that the preliminary design is consistent with the objective of PDC 4 to accommodate the effects of environmental and dynamic effects during operation, maintenance, testing, and postulated accidents.

9.7.5.3 Conclusion

Kairos has identified traits of the Chilled Water System in PSAR Section 9.7.4. The staff finds that the traits described in the PSAR demonstrate that the preliminary design is consistent with PDC 2, PDC 4, and the guidance of NUREG-1537 Part 2, Section 9.7. Based on the staff's review and the findings above, the staff concludes that the preliminary design of the Chilled Water System is sufficient and meets the applicable regulatory requirements and guidance identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40.

9.8 Other Auxiliary Systems

9.8.1 Remote Maintenance and Inspection System

9.8.1.1 Introduction

The Hermes test reactor will have a Remote Maintenance and Inspection System, as described in PSAR Section 9.8.1. The Remote Maintenance and Inspection System will provide the ability to remotely access, inspect, and handle components in the reactor system, the PHTS, and the PHSS. The Remote Maintenance and Inspection System is located in the reactor building and includes manipulators, tooling, cameras, monitors, cranes and rigging. The Remote Maintenance and Inspection System is not safety related and does not perform safety related functions. Portions of the system may cross the base-isolation moat that provides seismic protection for the reactor cell and PHSS cell.

9.8.1.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of the Hermes Remote Maintenance and Inspection System are as follows:

- 10 CFR 50.34, "Contents of applications; technical information," paragraph (a), "Preliminary safety analysis report."
  - 50.34(a)(3)(ii) requires "The design bases and the relation of the design bases to the principal design criteria."
  - 50.34(a)(3)(iii) requires "Information relative to materials of construction, general arrangement, and approximate dimensions, sufficient to provide reasonable assurance that the final design will conform to the design bases with adequate margin for safety."
  - 50.34(a)(4) which requires "A preliminary analysis and evaluation of the design and performance of structures, systems, and components [SSCs] of the facility…"
- 10 CFR 50.35, "Issuance of construction permits."
- 10 CFR 50.40, "Common standards."

As described in subsection 9.1.1 above, the staff did not evaluate whether requirements in 10 CFR Part 20 would be met for the construction of the Hermes reactor. Instead, the staff assessed whether Kairos identified the relevant requirements for an operating facility and provided descriptions of the preliminary facility design. The staff assessed this to determine whether the PSAR provides an acceptable basis for the development of systems and whether there is reasonable assurance that Kairos will comply with the regulations in 10 CFR Part 20 during Hermes facility operation.

Guidance for this review includes:

- NUREG-1537, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors, Parts 1 and 2," Section 9.7, "Other Auxiliary Systems."

9.8.1.3 Technical Evaluation

Principal design criteria applicable to the Remote Maintenance and Inspection System are:

- PDC 2, Design Bases for Protection Against Natural Phenomena
- PDC 4, Environmental and Dynamic Effects Design Bases

Section 9.8.1 of the PSAR provides a summary description of the Remote Maintenance and Inspection System and identifies traits of the system that will enable it to meet applicable regulatory requirements. Implementation of these traits and associated specific design features are not needed for the preliminary design required by a CP. The detailed design of the system and its relation to safety evaluations will be reviewed as part of the OL application.

The purpose of the Remote Maintenance and Inspection System is to reduce personnel radiation exposure by providing tools for remote work on components in the reactor system, the PHTS, and the PHSS. The staff finds that Kairos has shown that there is reasonable assurance that the Remote Maintenance and Inspection System will meet the requirements of 10 CFR 20.1101(b) during operation through the use of tooling to remotely handle potentially radioactive material.

The Remote Maintenance and Inspection System will interface with components that may contain radioactive material. PSAR Section 9.8.1 states that the system will be designed to minimize the contamination of the facility and facilitate decommissioning. Based on these design traits, the staff finds that the preliminary design of the system will be consistent with the requirements of 10 CFR 20.1406.

Since portions of the Remote Maintenance and Inspection System may be located in proximity to SSCs with safety related functions, the system will be designed so that it cannot interfere with a safety system's ability to perform a safety function. Because of these design features, staff finds that the preliminary design of the system is consistent with the objective of PDC 2 to withstand the effects of natural phenomena and will meet the guidance of NUREG-1537 Part 2, Section 9.7 for auxiliary systems to not cause accidents to the reactor, uncontrolled release of radioactivity, or interfere with safe shutdown of the reactor.

Since portions of the Remote Maintenance and Inspection System cross the base-isolation moat, design features are provided to protect safety related SSCs. The staff finds that the protective features are consistent with the objective of PDC 4 to accommodate the effects of environmental and dynamic effects during operation, maintenance, testing, and postulated accidents.

9.8.1.4 Conclusion

In PSAR Section 9.8.1, Kairos has identified design features for the Remote Maintenance and Inspection System. The staff finds that the traits described in the PSAR demonstrate that the preliminary design is consistent with PDC 2, PDC 4, and the guidance of NUREG-1537 Part 2, Section 9.7. Based on the staff's review and the findings above, the staff concludes that the preliminary design of the Remote Maintenance and Inspection System is sufficient and meets the applicable regulatory requirements and guidance identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. The staff also concludes that the design features described in the PSAR help provide reasonable assurance that Kairos will comply with 10 CFR 20.1101(b) and 10 CFR 20.1406.

9.8.2 Spent Fuel Cooling System

9.8.2.1 Introduction

PSAR Section 9.8.2, "Spent Fuel Cooling System," describes a preliminary design for the SFCS, which cools spent fuel canisters in the spent fuel storage pool and storage bay. PSAR Section 9.8.2 states that the system does not perform safety related functions.

9.8.2.2 Regulatory Evaluation

The applicable regulatory requirements are as follows:

- 10 CFR 50.34, "Contents of applications; technical information," paragraph (a), "Preliminary safety analysis report," including subparagraphs 50.34(a)(3)(ii), 50.34(a)(3)(iii), 50.34(a)(4), and 50.34(a)(5).
- 10 CFR 50.35, "Issuance of construction permits."
- 10 CFR 50.40, "Common standards."

As described in subsection 9.1.1 above, the staff did not evaluate whether requirements in 10 CFR Part 20 would be met for the construction of the Hermes reactor. Instead, the staff assessed whether Kairos identified the relevant requirements for an operating facility and provided descriptions of the preliminary facility design. The staff assessed this to determine whether the PSAR provides an acceptable basis for the development of systems and whether there is reasonable assurance that Kairos will comply with the regulations in 10 CFR Part 20 during Hermes facility operation.

The applicable guidance for the staff's evaluation is as follows:

- NUREG-1537, Parts 1 and 2, Section 9.2, "Handling and Storage of Reactor Fuel."

9.8.2.3 Technical Evaluation

Principal design criteria applicable to Treated Water System are:

- PDC 2, Design Bases for Protection Against Natural Phenomena
- PDC 4, Environmental and Dynamic Effects Design Bases

PSAR Section 9.8.2 states that the SFCS performs the following: (1) provides forced air cooling for the spent fuel storage canisters located in the storage bay of the PHSS and (2) recirculates water in the spent fuel storage pool to help cool spent fuel storage canisters in the pool. The SFCS transfers heat from the recirculating water to the CCWS. Temperatures in and around the storage canisters and other SSCs served by the SFCS will be monitored and controlled by the plant control system such that the SFCS fans and piping maintain the temperatures within desired limits. In addition, the SFCS will be capable of passively cooling the spent fuel storage canisters during postulated events, for example during a loss of power. PSAR Section 9.3.3 states that the storage part of PHSS will be designed with spacing between canisters in the spent fuel storage pool and the storage bay to ensure passive cooling (e.g., by natural convection) during postulated events.

PSAR Section 9.8.2 states that the SFCS's functions are not safety related. However, portions of the SFCS may be near safety related SSCs. Therefore, PSAR Section 9.8.2 states that SFCS components will be designed and positioned to preclude adverse interactions with safety related SSCs. PSAR Section 9.8.2 also states that because there will be no pressurized piping systems in or around the SFCS, the SFCS design is precluded from pipe whip hazards. Because failures of the SFCS will not adversely affect safety related SSCs, the staff finds that these design features are consistent with PDC 2 and PDC 4.

PSAR Section 9.8.2 also states that the SFCS has the potential to become contaminated based on its location and system interfaces, and therefore, the SFCS will be designed to minimize such contamination consistent with the requirements of 10 CFR 20.1406, "Minimization of contamination."

For the SFCS, the staff used the guidance and acceptance criteria in NUREG-1537, Parts 1 and 2, Section 9.2, "Handling and Storage of Reactor Fuel," to review the SFCS preliminary design description in PSAR Section 9.8.2, "Spent Fuel Cooling System." As part of its review, the staff assessed whether PSAR Section 9.8.2 identifies the appropriate PDC for the SFCS. The staff finds that Kairos has described the design bases for the SFCS and that the preliminary information on the design and functional description of the SFCS provides reasonable assurance that the SFCS will conform to the design bases. The staff finds that the SFCS is a non-safety related system that will be designed such that irradiated fuel can be cooled as necessary to avoid radionuclide release from the fuel during moving and storage within the facility. Therefore, based on its review, the staff determined that the level of detail provided on the SFCS, including the design base, and identification of relevant PDC is adequate for a preliminary design and is consistent with the applicable acceptance criteria of NUREG-1537, Part 2, Section 9.2.

9.8.2.4 Conclusion

On the basis of its review, the staff has determined that the level of detail provided regarding the SFCS demonstrates an adequate basis for a preliminary design and satisfies the applicable acceptance criteria of NUREG-1537 to support functions like preventing thermal failure and limiting radiation exposure. Based on the staff findings above, the staff concludes that the preliminary design of the SFCS, as described in the PSAR, is sufficient and meets the applicable regulatory requirements and guidance identified in this section for the issuance of a

CP in accordance with 10 CFR 50.35 and 50.40. Based on the review discussed above, the staff concludes that the preliminary design features intended to minimize contamination and support eventual decommissioning will help ensure compliance with the requirements of 10 CFR 20.1406. Further technical or design information required to approve operation of Hermes will be evaluated in the review of an OL application.

9.8.3 Compressed Air System

9.8.3.1 Introduction

Section 9.8.3 of the PSAR states that the Compressed Air System provides compressed air for general facility services and for use in valve operation. The Compressed Air System is not safety related and is not credited with performing safe shutdown functions.

9.8.3.2 Regulatory Evaluation

Regulatory requirements for the Compressed Air System are:

- 10 CFR 50.34, "Contents of applications; technical information," paragraph (a), "Preliminary safety analysis report."
    - 50.34(a)(3)(ii) requires "The design bases and the relation of the design bases to the principal design criteria."
    - 50.34(a)(3)(iii) requires "Information relative to materials of construction, general arrangement, and approximate dimensions, sufficient to provide reasonable assurance that the final design will conform to the design bases with adequate margin for safety."
    - 50.34(a)(4) which requires "A preliminary analysis and evaluation of the design and performance of structures, systems, and components [SSCs] of the facility…"
- 10 CFR 50.35, "Issuance of construction permits."
- 10 CFR 50.40, "Common standards."

Guidance for this review includes:

- NUREG-1537, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors, Parts 1 and 2," Section 9.7, "Other Auxiliary Systems."

9.8.3.3 Technical Evaluation

Principal design criteria applicable to the Compressed Air System are:

- PDC 2, Design Bases for Protection Against Natural Phenomena
- PDC 4, Environmental and Dynamic Effects Design Bases

PSAR Section 9.8.3 identifies traits of the Compressed Air System that will enable it to meet applicable regulatory requirements. Implementation of these traits and associated design features specific to the system are not needed for the preliminary design required by a CP. The detailed design of the Compressed Air System and its relation to safety evaluations will be reviewed as part of the OL application.

The Compressed Air System will be built so that failure of the system will not interfere with the ability of a safety related system to perform its safety function. Thus, staff finds that the preliminary design of the Compressed Air System is consistent with the objective of PDC 2 to withstand the effects of natural phenomena, achieve the objective of PDC 4 to accommodate the effects of environmental and dynamic effects, and meets the guidance of NUREG-1537 Part 2, Section 9.7 for auxiliary systems to not cause accidents to the reactor, uncontrolled release of radioactivity, or interfere with safe shutdown of the reactor.

9.8.3.4 Conclusion

Kairos has identified traits of the Compressed Air System in PSAR Section 9.8.3. The staff concludes that the traits described in the PSAR demonstrate that the preliminary design is consistent with PDC 2, PDC 4, and the guidance of NUREG-1537 Part 2, Section 9.7. Based on the staff's review and the findings above, the staff concludes that the preliminary design of the Compressed Air System is sufficient and meets the applicable regulatory requirements and guidance identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40.

9.8.4 Cranes and Rigging

9.8.4.1 Introduction

PSAR Section 9.8.4 describes a reactor building gantry crane that will be used to move equipment and support material receiving and shipping. Because of the heavy loads that would be lifted by the crane, failure or mis-operation of the crane could damage safety related SSCs if there were a load drop. The crane is not safety related and does not perform any safety related function.

9.8.4.2 Regulatory Evaluation

Regulatory requirements for installed cranes are:

- 10 CFR 50.34, "Contents of applications; technical information," paragraph (a), "Preliminary safety analysis report."
    - 50.34(a)(3)(ii) requires "The design bases and the relation of the design bases to the principal design criteria."
    - 50.34(a)(3)(iii) requires "Information relative to materials of construction, general arrangement, and approximate dimensions, sufficient to provide reasonable assurance that the final design will conform to the design bases with adequate margin for safety."
    - 50.34(a)(4) which requires "A preliminary analysis and evaluation of the design and performance of structures, systems, and components [SSCs] of the facility…"
- 10 CFR 50.35, "Issuance of construction permits."
- 10 CFR 50.40, "Common standards."

Guidance for this review includes:

- NUREG-1537, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors, Parts 1 and 2." Section 9.7, "Other Auxiliary Systems."

9.8.4.3 Technical Evaluation

Principal design criteria applicable to the crane are:

- PDC 2, Design Bases for Protection Against Natural Phenomena
- PDC 4, Environmental and Dynamic Effects Design Bases

Section 9.8.4 of the PSAR provides a summary description and evaluation of the reactor building crane and identifies traits of the crane that will enable it to meet regulatory requirements. Implementation of these traits and associated design features specific to the crane are not needed for the preliminary design required by a CP. The detailed design of the crane and its relation to safety evaluations will be reviewed as part of the OL application.

In PSAR Section 9.8.4.3, Kairos stated that it will implement the design standards in ASME B30.2-2016, “Overhead and Gantry Cranes (Top Running Bridge, Single or Multiple Girder, Top Running Trolley Hoist),” for the reactor building crane. As indicated in the General Audit, a description of the use of ASME B30.2-2016 for testing, inspection, operator training, operation, and maintenance of the crane and rigging will be provided in the OL application.

Since portions of the crane and its rigging may be located in proximity to SSCs with safety related functions, the crane is designed, through various means, to protect those safety related SSCs, including seismic mounting of certain components, physical separation, and barriers. Because of these design features, staff finds that the preliminary design of the crane is consistent with the objective of PDC 2 to withstand the effects of natural phenomena and meets the guidance of NUREG-1537 Part 2, Section 9.7 for auxiliary systems to not cause accidents to the reactor, uncontrolled release of radioactivity, or interfere with safe shutdown of the reactor.

The crane will be designed in accordance with ASME B30.2-2016, “Overhead and Gantry Cranes (Top Running Bridge, Single or Multiple Girder, Top Running Trolley Hoist).” Administrative controls will be provided to ensure that a dropped load does not interfere with the ability of safety related SSCs to perform their function during operation. The crane superstructure will be built to remain standing during and after a fire so that failure of the superstructure does not interfere with the ability of safety related SSCs to perform their safety function(s). Because of the design, protective features, and administrative controls, staff finds that the crane is consistent with the objective of PDC 4 to accommodate the effects of environmental and dynamic effects during operation, maintenance, testing, and postulated accidents.

9.8.4.4 Conclusion

Kairos has identified traits of the reactor building crane in PSAR Section 9.8.4. The staff concludes that the traits described in the PSAR demonstrate that the preliminary design is consistent with PDC 2, PDC 4, and the guidance of NUREG-1537 Part 2, Section 9.7. Based on the staff’s review and the findings above, the staff concludes that the preliminary design of the crane and rigging is sufficient and meets the applicable regulatory requirements and guidance identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40.

9.8.5 Auxiliary Site Services

9.8.5.1 Introduction

Section 9.8.5 of the PSAR states that the Hermes auxiliary site services include non-safety related systems and equipment that support operation of the plant, such as machine shops, chemistry laboratory, sewers, lighting, warehousing, and storage. The auxiliary services are not credited for the mitigation of postulated events and will be built so that they will not interfere with the ability of safety related SSCs to perform their safety function(s).

9.8.5.2 Regulatory Evaluation

Regulatory requirements for the site auxiliary services are:

- 10 CFR 50.34, "Contents of applications; technical information," paragraph (a), "Preliminary safety analysis report."
    - 50.34(a)(3)(ii) requires "The design bases and the relation of the design bases to the principal design criteria."
    - 50.34(a)(3)(iii) requires "Information relative to materials of construction, general arrangement, and approximate dimensions, sufficient to provide reasonable assurance that the final design will conform to the design bases with adequate margin for safety."
    - 50.34(a)(4) which requires "A preliminary analysis and evaluation of the design and performance of structures, systems, and components [SSCs] of the facility…"
- 10 CFR 50.35, "Issuance of construction permits."
- 10 CFR 50.40, "Common standards."

Guidance for this review includes:

- NUREG-1537, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors, Parts 1 and 2," Section 9.7, "Other Auxiliary Systems."

9.8.5.3 Technical Evaluation

The principal design criterion applicable to the Compressed Air System is:

- PDC 2, Design Bases for Protection Against Natural Phenomena

The PSAR identifies traits of the auxiliary site services that will enable the SSCs that make up these services to meet applicable regulatory requirements. Implementation of these traits and associated specific design features are not needed for the preliminary design required by a CP. The detailed designs of the site services will be reviewed as part of the OL application.

Kairos states in the PSAR that safety related SSCs located in proximity to auxiliary site service SSCs are protected from failure of the auxiliary site services during a design basis earthquake by either seismically mounting the applicable auxiliary site service components, physical separation, or barriers to preclude adverse interactions. The staff finds that this design requirement is consistent with PDC 2.

Kairos states that the services will be built so that failure of the SSCs making up these services will not interfere with the ability of safety related SSCs to perform their safety function(s). Because auxiliary systems will be designed to not cause accidents to the reactor, uncontrolled release of radioactivity, or interfere with safe shutdown of the reactor, the staff finds that the preliminary design of the auxiliary site services meet the guidance of NUREG-1537 Part 2, Section 9.7.

9.8.5.4 Conclusion

Kairos has identified traits of the auxiliary site services in PSAR Section 9.8.5. The staff concludes that the traits described in the PSAR demonstrate that the preliminary design is consistent with PDC 2 and the guidance of NUREG-1537 Part 2, Section 9.7. Based on the staff's review and the findings above, the staff concludes that the preliminary design of the auxiliary site services is sufficient and meets the applicable regulatory requirements and guidance identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40.

9.9 Summary and Conclusions for Auxiliary Systems

The staff evaluated the information on the Hermes auxiliary systems as described in PSAR Chapter 9, as supplemented, and finds that the preliminary information on, and design criteria of, the auxiliary systems, including the PDCs, design bases, and other design information: (1) provide reasonable assurance that the final design will conform to the design bases, (2) meet all applicable regulatory requirements, and (3) meet the applicable acceptance criteria in NUREG-1537, Part 2, allowing the staff to make findings that:

- Kairos's preliminary information and commitments to design the reactor coolant auxiliary systems, HVAC systems, pebble handling and storage systems, communication systems, water systems, and other auxiliary systems are sufficient and meet the applicable regulatory requirements and guidance for the issuance of a CP. Further information on these items can reasonably be left for later consideration in the OL application.

- The preliminary information on fire protection systems and programs is sufficient and meets the applicable regulatory requirements and guidance for the issuance of a CP. Further information can reasonably be left for later consideration in the final safety analysis report, fire protection program, and fire hazards analysis submitted with an OL application.

- The preliminary design of the Kairos program and auxiliary facilities for the possession and use of byproduct material, source material, and SNM at Hermes is sufficient and meets the applicable regulatory requirements and guidance for the issuance of a CP. Further information related to possession and use of byproduct material, source material, and SNM during operations and decommissioning can reasonably be left for later consideration during future reviews of a Hermes OL application and proposed decommissioning plan, respectively.

Based on these findings referenced above, the staff concludes the following regarding the issuance of a CP in accordance with 10 CFR 50.35 and 50.40:

- Kairos has described the proposed design of the auxiliary systems, including, but not limited to, the principal architectural and engineering criteria for the design, and has identified the major features or components incorporated therein for the protection of the health and safety of the public.

- Such further technical or design information as may be required to complete the safety analysis, and which can reasonably be left for later consideration, will be supplied in the FSAR.

- Safety features or components which require research and development have been described by Kairos and a research and development program (see SE Section 1.1.5) will be conducted that is reasonably designed to resolve any safety questions associated with such features or components.

- There is reasonable assurance that safety questions will be satisfactorily resolved at or before the latest date stated in the application for completion of construction of the proposed facility.

- There is reasonable assurance: (i) that the construction of the Hermes facility will not endanger the health and safety of the public, and (ii) that construction activities can be conducted in compliance with the Commission's regulations.

- The issuance of a permit for the construction of the Hermes facility would not be inimical to the common defense and security or to the health and safety of the public.

9.10 References for Auxiliary Systems

American Society of Mechanical Engineers (ASME) B30.2-2016. "Overhead and Gantry Cranes (Top Running Bridge, Single or Multiple Girder, Top Running Trolley Hoist). ASME: Two Park Avenue, New York, NY. May 2017.

Kairos Power LLC, "Reactor Coolant for the Kairos Power Fluoride Salt-Cooled High Temperature Reactor Topical Report," KP-TR-005-P-A, Revision 1, July 2020, ADAMS No. ML20219A591.

-----. "Principal Design Criteria for the Kairos Power Fluoride-Salt Cooled, High Temperature Reactor," KP-TR-003-NP-A, Revision 1, June 2020, ADAMS No. ML20167A174.

-----. "Transmittal of Kairos Power CPA Changes," February 2022, ADAMS No. ML22049B555.

-----. "Transmittal of Changes to Hermes Construction Permit Application," February 2022, ADAMS No. ML22042A095.

-----. "Transmittal of Changes to PSAR Sections 9.1.1 and 9.1.4," June 2022, ADAMS No. ML22160A689.

-----. "Transmittal of Responses to NRC Requests for Confirmation of Information Hermes Preliminary Safety Analysis Report, Section 9.1," August 2022, ADAMS No. ML22231B228.

-----. "Submittal of the Preliminary Safety Analysis Report for the Kairos Power Fluoride Salt-Cooled, High Temperature Non-Power Reactor (Hermes), Revision 3," May 31, 2023, Pkg. ML23151A743.

Nuclear Regulatory Commission (U.S.) (NRC). NUREG-1537 Part 2, "Guidelines for Preparing and Reviewing Application for the Licensing of Non-Power Reactors, Parts 1 and 2." NRC: Washington, D.C. February 1996, ADAMS Accession Nos. ML042430055 and ML042430048.

-----. Regulatory Guide 4.20, "Constraint on Releases of Airborne Radioactive Materials to the Environment for Licensees Other Than Power Reactors," Revision 1, April 2012.

-----. "Summary Report for the Regulatory Audit of Kairos Power LLC Hermes Construction Permit Preliminary Safety Analysis Report – General Audit," June 2023, ML23160A287.

10 EXPERIMENTAL FACILITIES AND UTILIZATION

Non-power reactors may have many experimental uses. Many non-power reactors have special experimental facilities, which may penetrate the core or reflector, be located near the core, or be an integral part of the reactor. Using these facilities, samples can be irradiated in the core or reflector, or neutron or other radiation beams can be extracted from the core region through the biological shield. In addition to these traditional experimental purposes, some non-power reactors may be operated primarily to gather information and data that could be useful for the purposes of licensing future prototype facilities and power reactors. Such non-power reactors may not include specific experimental facilities, but the reactor itself and/or specific structures, systems, and components (SSCs) could be considered experimental facilities to demonstrate technology for eventual prototype and commercial scale up.

Kairos Power LLC’s (Kairos’s) Hermes preliminary safety analysis report (PSAR), Revision 3, Chapter 10, “Experimental Facilities and Utilization,” Section 10.1, “Summary Description,” states that Hermes will not include special facilities dedicated to the conduct of reactor experiments or experimental programs. However, as discussed in PSAR Chapter 1, “The Facility,” Section 1.1, “Introduction,” Kairos’s purpose for Hermes is to test and demonstrate the key technologies, design features, and safety functions of Kairos’s fluoride salt-cooled, high temperature reactor (KP-FHR) technology and its associated SSCs. As part of its construction permit review, the U.S. Nuclear Regulatory Commission (NRC) staff (the staff) evaluated information on Hermes SSCs in the PSAR, paying special attention to design and operating characteristics, unusual or novel SSCs being demonstrated by Hermes, and principal safety considerations. The preliminary design of unusual or novel SSCs, including special safety features for these SSCs and any added instrumentation or other features to monitor the performance of these SSCs, was evaluated to ensure the sufficiency of principal design criteria; design bases; information relative to materials of construction, general arrangement, and approximate dimensions; and high-level functional descriptions, to provide reasonable assurance that the final design will conform to the design bases. The information provided by Kairos in the PSAR was also evaluated to determine whether it was adequate to provide reasonable assurance that a Title 10, *Code of Federal Regulations* (10 CFR) Part 50 construction permit for the Hermes facility could be issued in accordance with applicable regulatory requirements and guidance on the basis that the facility could be constructed without undue risk to the health and safety of the public. The staff evaluations of unusual or novel Hermes SSCs are found in other chapters of this safety evaluation (SE), particularly Chapter 3, “Design of Structures, Systems, and Components,” Chapter 4, “Reactor Description,” Chapter 5, “Heat Transport System,” Chapter 6, “Engineered Safety Features,” and Chapter 9, “Auxiliary Systems.”

In addition, the staff reviewed Kairos’s Quality Assurance Program Description (QAPD) for ensuring the quality and performance of Hermes SSCs during the design, construction, and operation of the facility. The staff documented its review of Kairos’s QAPD in Chapter 12, “Conduct of Operations,” Section 12.9, “Quality Assurance,” of this SE.

The staff also reviewed Kairos’s identification and justification for the selection of those variables, conditions, or other items which are determined to be probable subjects of technical specifications (TSs) for the facility, with special attention given to those items which may significantly influence the final design. The staff documented its review of Kairos’s probable subjects of TSs for the facility in Chapter 14, “Technical Specifications,” of this SE.

PSAR Sections 4.3.1.1.1, 4.3.3, and 10.1 describe a material surveillance system (MSS), which is supported by the reactor vessel top head and provides a means to insert and remove material specimens (e.g., coupons) to support testing and assessment of material performance. During the General Audit (ML23115A480), Kairos confirmed that, consistent with PSAR Section 10.1, the MSS is not an experimental facility because the purpose of the MSS is to monitor and evaluate the performance of SSCs over Hermes's operating life and Kairos does not plan to use the MSS to evaluate or irradiate other novel or experimental materials, i.e., which are not representative of Hermes SSCs. Kairos also confirmed that any use of the MSS would not affect analyses of Hermes operation or accidents in PSAR Chapters 4 and 13.

The staff evaluated the information on the Hermes facility in the PSAR and found that the preliminary design of the facility does not include any facilities penetrating or located near the reactor that are specifically designated as experimental facilities. The staff notes that the Hermes facility includes unusual and novel SSCs that are an integral part of the facility, including tristructural isotropic particle (TRISO) fuel, Flibe salt coolant, with others, and that the facility includes features to monitor the performance of these SSCs to demonstrate the key technologies, design features, and safety functions of Kairos's KP-FHR technology. However, these SSCs and features, as well as the QAPD and probable subjects of TSs that will help ensure the quality, performance, and safe operation of SSCs, are evaluated in other chapters of this SE, as discussed above. Therefore, the staff concludes that a separate evaluation using the guidelines of NUREG-1537, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors," Part 2, "Standard Review Plan and Acceptance Criteria," Chapter 10, "Experimental Facilities and Utilization," is not required. The staff will confirm that the final design conforms to the design basis, including that Hermes will not include special facilities dedicated to the conduct of reactor experiments or experimental programs, during its review of a Hermes operating license application.

10.1 References

Kairos Power LLC. "Submittal of the Preliminary Safety Analysis Report for the Kairos Power Fluoride Salt-Cooled, High Temperature Non-Power Reactor (Hermes), Revision 3," May 31, 2023, Pkg. ML23151A743.

Nuclear Regulatory Commission (U.S.) (NRC). NUREG-1537, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors," Part 1, "Format and Content," and Part 2, "Standard Review Plan and Acceptance Criteria." NRC: Washington, D.C. February 1996. ADAMS Accession Nos. ML042430055 and ML042430048.

-----. "Summary Report for the Regulatory Audit of Kairos Power LLC Hermes Construction Permit Preliminary Safety Analysis Report – General Audit," June 2023, ML23160A287.

11 RADIATION PROTECTION AND WASTE MANAGEMENT

The purposes of radiation protection and waste management programs and provisions are to ensure safety of a reactor facility and to provide protection to the facility staff, members of the public, and the environment.

This chapter of the Kairos Power LLC (Kairos) Hermes test reactor construction permit (CP) safety evaluation (SE) describes the U.S. Nuclear Regulatory Commission (NRC) staff's (the staff's) technical review and evaluation of the preliminary information on the radiation protection and waste management programs and design provisions at Hermes as presented in Chapter 11, "Radiation Protection and Waste Management," of the Hermes preliminary safety analysis report (PSAR), Revision 3. The staff reviewed PSAR Chapter 11 against applicable regulatory requirements using regulatory guidance and standards to assess the sufficiency of the preliminary information Kairos provided regarding facility radiation protection and waste management for the issuance of a CP in accordance with Title 10, *Code of Federal Regulations* (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities." As part of this review, the staff evaluated information on the radiation protection and waste management programs and provisions at Hermes, with special attention to design and operating characteristics, unusual or novel design features, and principal safety considerations. The staff evaluated the preliminary design of the Hermes facility radiation protection program and waste management provisions to ensure the design criteria, design bases, and information relative to construction are sufficient to provide reasonable assurance that the final design will conform to the design basis. In addition, the staff reviewed Kairos's identification and justification for the selection of those variables, conditions, or other items which are determined to be probable subjects of technical specifications for the facility, with special attention given to those items which may significantly influence the final design.

The staff's reviews and evaluations for areas relevant to PSAR Chapter 11, including regulations and guidance used, summaries of the application information reviewed, and evaluation findings and conclusions, are discussed in the SE sections below for each of the two major areas of review (radiation protection and waste management) covered in this SE chapter. A summary and overall conclusion on the staff's technical evaluation of radiation protection and waste management at Hermes are provided in SE Section 11.3, "Summary and Conclusions on Radiation Protection and Waste Management."

11.1 Radiation Protection

11.1.1 Introduction

Hermes PSAR Section 11.1, "Radiation Protection," identifies the sources of radiation at the Hermes facility and describes at a high level the programs and provisions for radiation protection and maintaining exposures to radiation as low as is reasonably achievable (ALARA), including preliminary facility design information relevant to radiation protection.

11.1.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of radiation protection at Hermes are as follows:

- 10 CFR 50.34, “Contents of applications; technical information,” paragraph (a), “Preliminary safety analysis report,” including:
    - 10 CFR 50.34(a)(1)(i), which requires "[a] description and safety assessment of the site on which the facility is to be located, with appropriate attention to features affecting facility design”;
    - 10 CFR 50.34(a)(4), which requires “[a] preliminary analysis and evaluation of the design and performance of structures, systems, and components [SSCs] of the facility…”; and
    - 10 CFR 50.34(a)(6), which requires “[a] preliminary plan for the applicant's organization, training of personnel, and conduct of operations.”
- 10 CFR 50.35, “Issuance of construction permits.”
- 10 CFR 50.40, “Common standards.”

As provided in § 20.1002, “Scope,” the regulations in 10 CFR Part 20, “Standards for Protection Against Radiation,” “apply to persons licensed by the Commission to receive, possess, use, transfer, or dispose of byproduct, source, or special nuclear material or to operate a production or utilization facility.” Kairos has applied for a CP and has not specifically requested approval of any design information. A CP does not provide a license to operate the facility. In its Hermes CP application, Kairos also has not applied for licenses to receive, possess, use, transfer, or dispose of byproduct, source, or special nuclear material at the facility. Therefore, the staff did not evaluate whether requirements in 10 CFR Part 20 would be met for the construction of the Hermes reactor. Instead, the staff assessed whether Kairos had identified the relevant requirements for an operating facility and provided descriptions of the preliminary facility design and provisions for protecting the health and safety of the public, workers, and the environment in sufficient detail to determine whether the PSAR provides an acceptable basis for the development of the radiation protection programs and radioactive waste management, and whether there is reasonable assurance that Kairos will comply with the regulations in 10 CFR Part 20 during operation of the Hermes facility. This is consistent with 10 CFR 50.40(a), which provides that in determining whether a CP may be issued, the Commission will be guided by consideration of reasonable assurance that Kairos will comply with the regulations, including the regulations in 10 CFR Part 20, and that the health and safety of the public will not be endangered.

The applicable guidance for the evaluation of Hermes radiation protection is as follows:

- NUREG-1537, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors, Parts 1, “Format and Content,” and Part 2, “Standard Review Plan and Acceptance Criteria,” Section 11.1, “Radiation Protection.”

11.1.3 Technical Evaluation

11.1.3.1 Radiation Sources

PSAR Section 11.1.1 identifies the radiation sources that present a potential hazard to workers and the public from operation of the Hermes reactor. The generation of the radiation sources is described in general terms. PSAR Table 11.1-1, “Radiation Sources,” lists the SSCs or facility locations which contain fission products or other sources of radiation, with the specific contents identified (e.g., tritium, circulating activity in systems with liquid or gas flow, activation products in structures and components). PSAR Section 11.1.1 states that additional details of radiation sources, including activity and external radiation fields in the facility, will be provided in an operating license (OL) application.

During the General Audit (ML23115A480), the staff confirmed that Kairos developed preliminary isotopic values for fuel and Flibe radiation sources for preliminary shielding design. In its preliminary analysis, Kairos considered radiation sources consistent with Hermes core design and analysis information and methodology discussed in PSAR Chapter 4.

As described in PSAR Section 11.1.5, Kairos performed a conservative screening analysis of gaseous tritium emissions from the Hermes reactor resulting in projected doses to the public from emissions of tritium which are well below the allowable limits in 10 CFR Part 20. During the General Audit, the staff reviewed the methodology, inputs, and assumptions for the screening analysis results for tritium reported in the PSAR. The staff noted during the audit that to perform the gaseous effluent screening analysis, Kairos used the XOQDOQ atmospheric dispersion model and GASPAR gaseous effluent pathway model in the NRCDose3 computer code, with site-specific input on the release point, dose receptor locations, and 5 years of site-specific, validated meteorological data. The staff notes that NRCDose3 was developed by the NRC to implement the NRC's requirements for ALARA for radioactive effluents from nuclear powerplants. The staff noted during the audit that analysis assumptions for the tritium effluent release were based on a conservative tritium release rate equal to the generation rate, which does not account for retention in the reactor or engineered systems, which would reduce the effective tritium effluent rate. During the General Audit, based on its audit of the screening calculation described in the PSAR, the staff confirmed that Kairos's analysis assumptions and methods were consistent with the description in the PSAR and are consistent with the regulatory guidance identified by Kairos in PSAR Section 11.1.5.

In its response to request for confirmation of information (RCI) 12 for the Hermes environmental review, submitted by letter dated April 22, 2022, Kairos stated that the assumed effluent release quantities for gaseous radionuclide effluents other than tritium (used in the Hermes Environmental Report) were taken from the Clinch River Early Site Permit (ESP) Environmental Report, and were based on light-water small modular reactor preliminary design information.

During the General Audit, Kairos confirmed that although its effluent screening analyses discussed in PSAR 11.1.5 do not model liquid effluents, based on the preliminary Hermes design, liquid effluent releases direct to the environment are not expected.

The staff evaluated the sufficiency of the preliminary information on Hermes radiation sources, as described in PSAR Sections 11.1.1 and 11.1.5, using the guidance and acceptance criteria from Section 11.1.1 of NUREG-1537, Parts 1 and 2. The staff's review included a comparison of the bases for identifying potential radiation safety hazards with the process and facility descriptions to verify that such hazards were accurately and comprehensively identified. Based on its review of the information in the PSAR, supported by the General Audit, the staff finds that the high level description of radiation sources and their bases, including the effluent screening analysis, is consistent with generation and transport and cleanup of radionuclides, activation of materials, and radioactive waste production that would occur at Hermes. The staff finds that the results of the effluent screening analysis provide reasonable assurance that 10 CFR Part 20 limits will be met during Hermes operation. The staff finds use of the Clinch River ESP effluent information for radionuclides other than tritium to be a reasonable assumption for a preliminary scoping analysis, considering the relative power levels and design differences. The staff will review the effluent analysis corresponding to the detailed design in the application for an OL. Based on its review, the staff finds the PSAR information on Hermes radiation sources is adequate because it identifies the potential radiation safety hazards associated with the Hermes reactor and provides an acceptable preliminary basis for the development of the radiation protection program, and that it meets the applicable acceptance criteria of NUREG-1537, Part 2, Section 11.1.1.

11.1.3.2 Radiation Protection Program and ALARA Program

PSAR Sections 11.1.2 and 11.1.3 describe the 10 CFR Part 20 regulatory requirements for a radiation protection program and an ALARA program, respectively. The PSAR sections also describe, at a high level, features of the programs (e.g., periodic program review, ALARA controls, and a constraint on air emissions of radioactive materials) that Kairos states it would implement to ensure regulatory requirements are met. Kairos also identifies in the PSAR relevant NRC regulatory guides that Kairos will use to design and implement the radiation protection program and the ALARA program. The PSAR states that Kairos will provide additional details for both programs in an OL application.

The staff evaluated the sufficiency of the preliminary information on Kairos's radiation protection and ALARA programs for Hermes, as described in PSAR Sections 11.1.2 and 11.1.3 and other relevant portions of the PSAR, using the guidance and acceptance criteria from Sections 11.1.2 and 11.1.3 of NUREG-1537, Parts 1 and 2. Based on its review, the staff determined that the level of detail provided on the radiation protection and ALARA programs is adequate because it identifies applicable requirements and appropriate guidance and general features for implementation of the Hermes radiation protection and ALARA programs, and that it meets the applicable acceptance criteria of NUREG-1537, Part 2, Sections 11.1.2 and 11.1.3.

11.1.3.3 Radiation Monitoring and Surveying

PSAR Section 11.1.4 describes the requirements for and purpose of radiation monitoring and surveying at the Hermes facility, and states that written procedures for radiation monitoring and surveying will be established to ensure compliance with 10 CFR Part 20, Subpart F, "Surveys and Monitoring." PSAR Section 11.1.4 identifies NRC regulatory guides that Kairos will consider in development of the Hermes radiation monitoring and surveying programs. In addition, PSAR Sections 9.1.2, 9.1.3, and 9.2 describe preliminary design information for radiation monitoring in the cover gas space, tritium management system, and reactor building, respectively. PSAR Section 11.1.4 states that additional details of radiation monitoring and surveying, including a description of the equipment, methods, and procedures, will be provided in an OL application.

The staff evaluated the sufficiency of the preliminary information on Hermes radiation monitoring and surveying, as described in PSAR Section 11.1.4 and other relevant portions of the PSAR, using the guidance and acceptance criteria from Section 11.1.4 of NUREG-1537, Parts 1 and 2. Based on its review, the staff determined that the level of detail provided on the radiation monitoring and surveying is adequate because it identifies applicable requirements for radiation monitoring and surveying, and includes appropriate preliminary information on guidance, practices, and design features to help ensure that Hermes radiation fields and effluents are monitored and sampled as necessary, and that it meets the applicable acceptance criteria of NUREG-1537, Part 2, Section 11.1.4.

11.1.3.4 Radiation Exposure Control and Dosimetry

PSAR Section 11.1.5 provides a preliminary discussion of radiation exposure controls, including access controls and shielding, and effluent monitoring and controls, for the Hermes facility.

Radiological control areas will be established (including consideration of shielding) and access to high and very high radiation areas will be controlled as required by 10 CFR Part 20, Subpart G, “Control of Exposure from External Sources in Restricted Areas.” Precautionary procedures (e.g., posting of radiation areas) will be employed in the facility consistent with the requirements in 10 CFR Part 20, Subpart J, “Precautionary Procedures.” Additional details on dosimetry, radiation exposure control and assess control, including locations of radiological control areas, access controls, shielding, remote handling equipment, and expected annual radiation exposures, will be provided in an OL application.

PSAR Section 4.4 provides preliminary design information on the biological shield, including its design bases. In addition, during the General Audit, the staff audited preliminary shielding design information (primarily for the Hermes bioshield) to confirm that Kairos developed preliminary shielding design analyses, including consideration of types of shielding materials and shielding dimensions.

PSAR Sections 9.2 and 11.1.5 describe at a high level the preliminary design features to monitor facility effluents during normal operation and postulated events. PSAR Section 11.1.5 also indicates that the design of SSCs will limit uncontrolled liquid or gaseous effluent releases to work areas or the environment, consistent with the goal of maintaining radiation exposures ALARA. As discussed in PSAR Sections 9.2 and 11.1.5, systems through which gaseous effluents are generally released to the atmosphere include provisions for gaseous effluent monitoring and filtration.

The staff evaluated the sufficiency of the preliminary information on Hermes radiation exposure control and dosimetry, as described in PSAR Section 11.1.5 and other relevant portions of the PSAR, using the guidance and acceptance criteria from Section 11.1.5 of NUREG-1537, Parts 1 and 2. Based on its review, the staff determined that the level of detail provided on the radiation exposure control and dosimetry is adequate because it identifies applicable requirements for radiation exposure control and includes appropriate preliminary information on access controls, shielding, and design features to help ensure that uncontrolled radiation releases and unauthorized entry into high radiation areas will be prevented and radiation doses will be maintained ALARA and within regulatory limits, and that it meets the applicable acceptance criteria of NUREG-1537, Part 2, Section 11.1.5.

11.1.3.5 Contamination Control

PSAR Section 11.1.6 states that design features for the control of radioactive contamination at the Hermes facility will be developed consistent with the requirements in 10 CFR 20.1406, “Minimization of contamination.” The design of such features will also consider the guidance in NRC RG 4.21, “Minimization of Contamination and Radioactive Waste Generation: Life-Cycle Planning.” PSAR Section 11.1.6 states that a description of these design features will be provided in an OL application.

The staff evaluated the sufficiency of the preliminary information on Hermes contamination control, as described in PSAR Section 11.1.6, using the guidance and acceptance criteria from Section 11.1.6 of NUREG-1537, Parts 1 and 2. Based on its review, the staff determined that the level of detail provided on the contamination control is adequate because it identifies applicable requirements for contamination control and includes appropriate preliminary information on guidance, practices, and design features that will help ensure that the spread of contamination at Hermes will be minimized, and that it meets the applicable acceptance criteria of NUREG-1537, Part 2, Section 11.1.6.

11.1.3.6 Environmental Monitoring

PSAR Section 11.1.7 states that an operational radiological environmental monitoring program (REMP) will be established to meet the requirements in 10 CFR 20.1302, "Compliance with dose limits for individual members of the public," and will be implemented coincident with the start of Hermes operational activities. PSAR Section 11.1.7 identifies regulatory guidance for effluent and environmental monitoring for nuclear power plants that Kairos will consider for developing the operational REMP for Hermes. PSAR Section 11.1.7 states that a description of the REMP will be provided in an OL application.

The staff evaluated the sufficiency of the preliminary information on Hermes environmental monitoring, as described in PSAR Section 11.1.7, using the guidance and acceptance criteria from Section 11.1.7 of NUREG-1537, Parts 1 and 2. Based on its review, the staff determined that the level of detail provided on the environmental monitoring is adequate because it identifies applicable requirements for environmental monitoring and includes preliminary information on guidance for the REMP that will help ensure any environmental impacts from Hermes operation will be appropriately assessed, and that it meets the applicable acceptance criteria of NUREG-1537, Part 2, Section 11.1.7. The staff also determined that the environmental monitoring guidance referenced by Kairos is reasonable for use at Hermes, with consideration of the Hermes technology and as appropriate for a non-power reactor.

11.1.4 Conclusion

Based on its findings above, the staff concludes the information in Hermes PSAR Section 11.1 is sufficient and meets the applicable guidance and regulatory requirements identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Further information as may be required to complete the review of Hermes radiation protection can reasonably be left for later consideration in the OL application since this information is not necessary for the review of a CP application.

11.2 Radioactive Waste Management

11.2.1 Introduction

Hermes PSAR Section 11.2, "Radioactive Waste Management," describes at a high level the Hermes radioactive waste management program and preliminary facility design information for radioactive waste handling.

11.2.2 Regulatory Evaluation

The discussion of regulatory requirements provided above for radiation protection in SE Section 11.1 is also applicable for the staff's evaluation of radioactive waste management in SE Section 11.2. In addition, specific applicable portions of 50.34(a) with respect to radioactive waste management include:

- 10 CFR 50.34(a)(3)(ii) which requires "The design bases and the relation of the design bases to the principal design criteria."
- 10 CFR 50.34(a)(3)(iii) which requires "Information relative to materials of construction, general arrangement, and approximate dimensions, sufficient to provide reasonable

assurance that the final design will conform to the design bases with adequate margin for safety."

The applicable guidance for the evaluation of Hermes radioactive waste management is as follows:

- NUREG-1537, Parts 1 and 2, Section 11.2, "Radioactive Waste Management."

11.2.3 Technical Evaluation

11.2.3.1 Radioactive Waste Management Program

PSAR Section 11.2.1 states that a description of the radioactive waste management program for the Hermes facility will be provided in an OL application. PSAR Section 12.1 describes the preliminary Hermes organizational structure, including the radiation protection organization and its responsibilities.

The staff evaluated the sufficiency of the preliminary information on the Hermes radioactive waste management program, as described in PSAR Section 11.2.1 and other relevant portions of the PSAR, using the guidance and acceptance criteria from Section 11.2.1 of NUREG-1537, Parts 1 and 2. The staff finds that Kairos appropriately identifies the need for a radioactive waste management program and finds that Kairos's plan to provide the detailed description of the radioactive waste program with an OL application is reasonable given the preliminary nature of the design and the Hermes organizational structure. Therefore, based on its review, the staff determined that the level of detail provided on the radioactive waste management program is adequate and meets the applicable acceptance criteria of NUREG-1537, Part 2, Section 11.2.1.

11.2.3.2 Radioactive Waste Handling Systems and Controls

PSAR Section 11.2.2 describes the radioactive waste handling systems and controls, including discussion of the relevant functions and design features for the collection, packaging, storage, and dispositioning of low-level radioactive wastes in solid and liquid forms. PSAR Section 11.2.2 describes the SSCs that handle liquid and solid wastes at a functional level and identifies the relevant design bases as principal design criteria 2, 60, and 63 (see SE Chapter 3 and KP-TR-003-NP-A, "Principal Design Criteria for the Kairos Power Fluoride-Salt Cooled, High Temperature Reactor"). PSAR Section 11.2.2 also states that radioactive waste handling systems are designed to meet the requirements of 10 CFR 20.1406 as it relates to design for the minimization of contamination and eventual decommissioning of the facility. PSAR Section 11.2.2 states that radioactive waste handling systems will be designed to meet these criteria. The radioactive waste handling systems are not safety related but will be periodically tested for functionality.

Related to radioactive waste, the Hermes Environmental Report (ER), Section 4.10.2.4, "Transportation of Nonradioactive Materials and Hazardous Waste," indicates that a total of 40 tons of Flibe would be shipped to the site for use in the reactor. The Flibe is radioactive at the end of its useful life. ER Section 4.10.2 states that there will be sufficient storage capacity onsite for the radioactive Flibe wastes, which would be allowed to cool and solidify, and would likely remain at the Hermes facility until decommissioning. Based on the description of the Inventory Management System in PSAR Section 9.1.4, if there is replacement of Flibe during Hermes operation, the used Flibe would be stored in transfer canisters in a solid state at ambient temperatures.

PSAR Section 11.2.2 states that gaseous radioactive wastes are not handled in a dedicated gaseous radioactive waste system, but are discharged to the reactor building heating, ventilation, and air conditioning system, where they are filtered and monitored prior to release to the atmosphere. PSAR Section 11.1.5 provides a screening analysis of gaseous tritium releases from Hermes, which the staff reviewed as discussed in SE Section 11.1.1.

The staff evaluated the sufficiency of the preliminary information on the Hermes radioactive waste handling system and controls, as described in PSAR Section 11.2.2 and other relevant portions of the PSAR, using the guidance and acceptance criteria from Section 11.2.2 of NUREG-1537, Parts 1 and 2. The staff finds that Kairos has described methods by which the waste products from procedures and processes will be monitored or otherwise assessed for radioactive material contents, and when appropriate, controls will be established on the waste streams and products designed to prevent uncontrolled exposures or escape of radioactive waste. Therefore, based on its review, the staff determined that the level of detail provided on the radioactive waste handling system and controls, including the design bases and identification of relevant principal design criteria, is adequate and meets the applicable acceptance criteria of NUREG-1537, Part 2, Section 11.2.2.

11.2.3.3 Release of Radioactive Waste

PSAR 11.2.3 describes at a high level the disposition of radioactive waste. Gaseous wastes are filtered and monitored before release to the atmosphere, as also described in PSAR Section 11.2.2. Liquid radioactive waste may be recycled or released to sanitary sewerage in accordance with applicable regulations. Some liquid and solid radioactive waste is expected to be packaged and disposed of using a licensed and qualified low-level radioactive waste disposal vendor.

The staff evaluated the sufficiency of the preliminary information on the release of radioactive waste at Hermes, as described in PSAR Section 11.2.3 and other relevant portions of the PSAR, using the guidance and acceptance criteria from Section 11.2.3 of NUREG-1537, Parts 1 and 2. Based on its review, the staff determined that the level of detail provided on the release of radioactive waste is adequate because it includes preliminary information on how radioactive waste from Hermes will be dispositioned appropriately and in accordance with applicable regulations, and that it meets the applicable acceptance criteria of NUREG-1537, Part 2, Section 11.2.3.

11.2.4 Conclusion

Based on its findings above, the staff concludes the information in Hermes PSAR Section 11.2 is sufficient and meets the applicable guidance and regulatory requirements identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Further information as may be required to complete the review of Hermes radioactive waste management can reasonably be left for later consideration in the OL application since this information is not necessary for the review of a CP application.

11.3 Summary and Conclusions on Radiation Protection and Waste Management

The staff evaluated the information on radiation protection and waste management at Hermes, as described in PSAR Chapter 11, and finds that the preliminary information on and design criteria of the radiation protection and waste management programs and provisions, including the principal design criteria, design bases, and information relating to materials of construction, general arrangement, and approximate dimensions: (1) provide reasonable assurance that the final design will confirm to the design bases, (2) meet all applicable regulatory requirements, and (3) meet the applicable acceptance criteria in NUREG-1537, Part 2. Based on these findings, the staff makes the following conclusions regarding issuance of a CP in accordance with 10 CFR 50.35 and 10 CFR 50.40:

- Kairos has described the proposed facility design for radiation protection and waste management, including, but not limited to, the principal architectural and engineering criteria for the design, and has identified the major features or components incorporated therein for the protection of the health and safety of the public.
- Such further technical or design information as may be required to complete the safety analysis of radiation protection and waste management, and which can reasonably be left for later consideration, will be provided in the OL application.
- There is reasonable assurance: (i) that the construction of the Hermes facility will not endanger the health and safety of the public, and (ii) that construction activities can be conducted in compliance with the Commission's regulations.
- The issuance of a permit for the construction of the Hermes facility would not be inimical to the common defense and security or to the health and safety of the public.

11.4 References

Kairos Power LLC. KP-TR-003-NP-A, "Principal Design Criteria for the Kairos Power Fluoride Salt-Cooled, High Temperature Reactor," Revision 1, June 2020, ML20167A174.

-----. "Submittal of the Environmental Report for the Kairos Power Fluoride Salt-Cooled, High Temperature Non-Power Reactor (Hermes)." October 31, 2021. ADAMS Pkg. Accession No. ML21306A131.

-----. "Transmittal of Responses to NRC Requests for Confirmation of Information for the Review of the Hermes Environmental Report." April 22, 2022. ADAMS Pkg. Accession No. ML22115A204.

-----. "Submittal of the Preliminary Safety Analysis Report for the Kairos Power Fluoride Salt-Cooled, High Temperature Non-Power Reactor (Hermes), Revision 3," May 31, 2023, Pkg. ML23151A743.

Nuclear Regulatory Commission (U.S.) (NRC). NUREG-1537, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors," Part 1, "Format and Content," and Part 2, "Standard Review Plan and Acceptance Criteria." NRC: Washington, D.C. February 1996. ADAMS Accession Nos. ML042430055 and ML042430048.

-----. Regulatory Guide 4.21, "Minimization of Contamination and Radioactive Waste Generation: Life-Cycle Planning," Revision 0. NRC: Washington, D.C. June 2008. ML080500187.

-----. "Summary Report for the Regulatory Audit of Kairos Power LLC Hermes Construction Permit Preliminary Safety Analysis Report – General Audit," June 2023, ML23160A287.

Tennessee Valley Authority. “Clinch River Nuclear Site Early Site Permit Application, Part 3, Environmental Report,” Revision 2. January 2019. ADAMS Pkg. Accession No. ML19030A478.

12 CONDUCT OF OPERATIONS

The conduct of operations involves the administrative aspects of facility operation (i.e., the facility organizational structure, review and audit activities, facility procedures, required actions for technical specification violations, reporting requirements, and recordkeeping), emergency planning, quality assurance, security, operator training and requalification, and startup and material control and accounting (MC&A) plans.

This chapter of the Kairos Power LLC (Kairos) Hermes construction permit (CP) safety evaluation (SE) describes the U.S. Nuclear Regulatory Commission (NRC) staff's (the staff's) technical review and evaluation of the preliminary information provided in Chapter 12, "Conduct of Operations," of the Hermes preliminary safety analysis report (PSAR), Revision 3. The staff reviewed Hermes PSAR Chapter 12 against applicable regulatory requirements using regulatory guidance and standards to assess the sufficiency of the preliminary information on the Hermes conduct of operations for the issuance of a CP in accordance with Title 10, *Code of Federal Regulations* (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities." The staff's reviews and evaluations for areas relevant to PSAR Chapter 12, including regulations and guidance used, a summary of the application information reviewed, and evaluation findings and conclusions, are discussed in the SE sections below for each specific area of review. A summary and overall conclusion on the staff's technical evaluation of the Hermes conduct of operations are provided in SE Section 12.14, "Summary and Conclusions on Conduct of Operations."

12.1 <u>Organization</u>

12.1.1 Introduction

Hermes PSAR Section 12.1, "Organization," describes the organizational structure, functional responsibilities, levels of authority, and interfaces for establishing, executing, and verifying the organizational structure concerning facility operation. The organizational structure includes internal and external functions including interface responsibilities for multiple organizations. PSAR Section 12.1 also discusses the organizational aspects of the radiation protection (RP) program, staffing, and selection and training of personnel.

12.1.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of Kairos's organization are as follows:

- 10 CFR 50.34, "Contents of applications; technical information," paragraph (a), "Preliminary safety analysis report," including 10 CFR 50.34(a)(6), which requires that the PSAR include "[a] preliminary plan for the applicant's organization, training of personnel, and conduct of operations."
- 10 CFR 50.35, "Issuance of construction permits."
- 10 CFR 50.40, "Common standards."

The applicable guidance for the evaluation of Kairos's organization is as follows:

- NUREG-1537, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors,” Part 1, “Format and Content,” and Part 2, “Standard Review Plan and Acceptance Criteria,” Section 12.1, “Organization.”

12.1.3 Technical Evaluation

In PSAR Sections 12.1.1 and 12.1.2, Kairos describes the organizational structure for Hermes operations and the responsibilities for key positions at Kairos, including the positions in the organizational structure. The organizational structure is shown in PSAR Figure 12.1-1. PSAR Section 12.1.2 indicates that the Site Executive will have overall responsibility for compliance with a Hermes operating license (OL). The Plant Manager, who reports to the Site Executive, has responsibility for facility operations, maintenance, and engineering. Operations personnel such as the shift supervisor and reactor operators report to the Plant Manager. The Technical Services Manager, who has responsibility for facility services, also reports to the Site Executive. Facility services that the Technical Services Manager has responsibility for include RP. RP staff who are responsible for establishing and implementing the RP program report to the Technical Services Manager. According to PSAR Section 12.1.2 and PSAR Figure 12.1-1, the Quality Manager, who also reports to the Site Executive, is responsible for auditing for compliance with regulatory requirements and procedures and has sufficient independence to bring forward issues affecting safety and quality. The Hermes Review and Audit Committee (see SE Section 12.2), which separately reports to the Site Executive as illustrated in PSAR Figure 12.1-1, also has independent audit responsibilities that are separate from those of the Quality Assurance group.

PSAR Section 12.1.3 states that sufficient personnel resources will be provided to safely conduct Hermes facility operations, and specific details related to Hermes staffing, including minimum staffing levels, will be provided in an OL application.

PSAR Section 12.1.4 states that an indoctrination and training program will be maintained for personnel performing, verifying, or managing Hermes activities during Hermes facility operation. Kairos states that it will use the guidance in American National Standards Institute/American Nuclear Society (ANSI/ANS)-15.4-2016, “Selection and Training of Personnel for Research Reactors,” as applicable, for selecting and training Hermes personnel. Kairos states that details of its training programs and required minimum qualifications for Hermes staff will be provided in an OL application.

PSAR Section 12.1.5 states that sufficient resources in terms of staffing and equipment will be provided to implement an effective RP program at Hermes. PSAR Section 12.1.2.8 states that RP has the authority to terminate unsafe activities at Hermes (facility management could subsequently overrule such a termination, based on appropriate analysis and consideration). PSAR Section 12.1.5 states that further details related to the authority of RP staff with respect to Hermes operations will be provided in an OL application.

PSAR Section 14.1 states that technical specifications (TSs), which will be provided in an OL application, will include administrative controls and the content of the TSs will be consistent with the guidance in ANSI/ANS-15.1-2007, “The Development of Technical Specifications for Research Reactors.” The staff notes that ANSI/ANS-15.1-2007, Section 6.1, provides guidance for TS requirements related to facility organization, including organizational structure, responsibilities, staffing, and selection and training of personnel.

The staff evaluated the sufficiency of the preliminary information on Hermes organization, as described in PSAR Section 12.1, using the guidance and acceptance criteria from Section 12.1 of NUREG-1537, Parts 1 and 2. In its evaluation, the staff also considered the preliminary information in PSAR Section 14.1 regarding the content of the TSs. The staff finds that ANSI/ANS-15.1-2007, referenced by Kairos, provides guidance for facility organization that is generally consistent with the guidance in NUREG-1537. Based on its review, the staff determined that the level of detail provided on Hermes organization is adequate and meets the applicable acceptance criteria of NUREG-1537, Part 2, Section 12.1.

12.1.4 Conclusion

Based on its findings above, the staff concludes the information in Hermes PSAR Section 12.1 is sufficient and meets the applicable guidance and regulatory requirements identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Further information as may be required to complete the review of the Hermes organization (e.g., detailed information on staffing and training) can reasonably be left for later consideration in the OL application since this information is not necessary to be provided as part of a CP application.

12.2 Review and Audit Activities

12.2.1 Introduction

Hermes PSAR Section 12.2, "Review and Audit Activities," describes review and audit activities during facility operation at Hermes.

12.2.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of Kairos's review and audit activities are as follows:

- 10 CFR 50.34, "Contents of applications; technical information," paragraph (a), "Preliminary safety analysis report," including 10 CFR 50.34(a)(6), which requires that the PSAR include "[a] preliminary plan for the applicant's organization, training of personnel, and conduct of operations."
- 10 CFR 50.35, "Issuance of construction permits."
- 10 CFR 50.40, "Common standards."

The applicable guidance for the evaluation of Kairos's review and audit activities is:

- NUREG-1537, Parts 1 and 2, Section 12.2, "Review and Audit Activities."

12.2.3 Technical Evaluation

PSAR Section 12.2 states that the Hermes Site Executive will establish a Review and Audit Committee and the Site Executive will ensure that appropriate technical expertise will be available for review and audit activities. The Review and Audit Committee's activities will be summarized and reported to the Site Executive. Kairos states that details of review and audit activities, details of the Review and Audit Committee's approval authorities, and details of how the Review and Audit Committee interacts with Hermes facility management and Kairos corporate management will be provided in an OL application.

PSAR Section 14.1 states that TSs, which will be provided in an OL application, will include administrative controls and the content of the TSs will be consistent with the guidance in ANSI/ANS-15.1-2007. The staff notes that ANSI/ANS-15.1-2007, Section 6.2, provides guidance for TS requirements related to review and audit activities, including review and audit committee composition, qualifications, charter, and rules; and review and audit committee functions (e.g., specific items to be reviewed or audited, and reporting functions).

The staff evaluated the sufficiency of the preliminary information on review and audit activities for Hermes, as described in PSAR Section 12.2, using the guidance and acceptance criteria from Section 12.2 of NUREG-1537, Parts 1 and 2. In its evaluation, the staff also considered the preliminary information in PSAR Section 14.1 regarding the content of TSs. The staff finds that ANSI/ANS-15.1-2007, referenced by Kairos, provides guidance for review and audit activities that is generally consistent with the guidance in NUREG-1537. Based on its review, the staff determined that the level of detail provided on review and audit activities at Hermes is adequate and meets the applicable acceptance criteria of NUREG-1537, Part 2, Section 12.2.

12.2.4 Conclusion

Based on its findings above, the staff concludes the information in Hermes PSAR Section 12.2 is sufficient and meets the applicable guidance and regulatory requirements identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Further information as may be required to complete the review of Hermes review and audit activities (e.g., detailed information on review and audit committee composition, qualifications, charter, and rules, and review and audit committee functions including review, approval, audit, and reporting functions) can reasonably be left for later consideration in the OL application since this information is not necessary for the review of a CP application.

12.3 Procedures

12.3.1 Introduction

Hermes PSAR Section 12.3, "Procedures," describes the use of operating procedures during Hermes facility operation.

12.3.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of Kairos's procedures are as follows:

- 10 CFR 50.34, "Contents of applications; technical information," paragraph (a), "Preliminary safety analysis report," including 10 CFR 50.34(a)(6), which requires that the PSAR include "[a] preliminary plan for the applicant's organization, training of personnel, and conduct of operations."
- 10 CFR 50.35, "Issuance of construction permits."
- 10 CFR 50.40, "Common standards."

The applicable guidance for the evaluation of Kairos's procedures is as follows:

- NUREG-1537, Parts 1 and 2, Section 12.3, "Procedures."

12.3.3 Technical Evaluation

PSAR Section 12.3 states that for activities involving safety, Hermes facility personnel will use operating procedures that are approved and that provide appropriate direction to ensure the facility is operated within the design basis and TSs. The level of detail in procedures will consider the experience, education, and training of users and the consequences of errors. Expectations for the use of procedures will be documented and communicated to facility personnel. The general topics of procedures will be consistent with the guidance in ANSI/ANS-15.1-2007, Section 6.4, "Procedures." Kairos states that more specific information on facility procedures, including the review, approval, and change processes for procedures, will be provided in an OL application.

PSAR Section 14.1 states that TSs, which will be provided in an OL application, will include administrative controls and the content of the TSs will be consistent with the guidance in ANSI/ANS-15.1-2007. The staff notes that, in addition to listing recommended topics for which procedures should be required by TSs, ANSI/ANS-15.1-2007, Section 6.4, also provides guidance for TS requirements related to review and approval of procedures and changes to procedures.

The staff evaluated the sufficiency of the preliminary information on Hermes procedures, as described in PSAR Section 12.3, using the guidance and acceptance criteria from Section 12.3 of NUREG-1537, Parts 1 and 2. The staff finds that ANSI/ANS-15.1-2007, referenced by Kairos, provides guidance for procedures that is generally consistent with the guidance in NUREG-1537. Based on its review, the staff determined that the level of detail provided on Hermes procedures is adequate and meets the applicable acceptance criteria of NUREG-1537, Part 2, Section 12.3.

12.3.4 Conclusion

Based on its findings above, the staff concludes the information in Hermes PSAR Section 12.3 is sufficient and meets the applicable guidance and regulatory requirements identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Further information as may be required to complete the review of Hermes procedures (e.g., detailed information on review, approval, and change processes for procedures) can reasonably be left for later consideration in the OL application since this information is not necessary for the review of a construction permit application.

12.4 Required Actions

12.4.1 Introduction

Hermes PSAR Section 12.4, "Required Actions," describes actions that will be taken when a safety limit is exceeded or a limiting condition for operation or surveillance requirement is not met.

12.4.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of Kairos's required actions are as follows:

- 10 CFR 50.34, “Contents of applications; technical information,” paragraph (a), “Preliminary safety analysis report,” including 10 CFR 50.34(a)(6), which requires that the PSAR include “[a] preliminary plan for the applicant’s organization, training of personnel, and conduct of operations.”
- 10 CFR 50.35, “Issuance of construction permits.”
- 10 CFR 50.40, “Common standards.”

The applicable guidance for the evaluation of Kairos’s required actions is as follows:

- NUREG-1537, Parts 1 and 2, Section 12.4, “Required Actions.”

12.4.3 Technical Evaluation

PSAR Section 12.4 states that Hermes TSs will specify the actions to be taken when a safety limit is exceeded or a limiting condition for operation or surveillance requirement is not met. PSAR Section 12.4 also states that TSs are described in PSAR Chapter 14 and will be provided in an OL application. PSAR Section 14.1 states that the TSs which will be provided in an OL application will include administrative controls and the content of the TSs will be consistent with the guidance in ANSI/ANS-15.1-2007.

The staff evaluated the sufficiency of the preliminary information on Hermes required actions, as described in PSAR Section 12.4, using the guidance and acceptance criteria from Section 12.4 of NUREG-1537, Parts 1 and 2. The staff finds that ANSI/ANS-15.1-2007, referenced by Kairos, provides guidance that is generally consistent with the guidance in NUREG-1537 for types of events that should be reportable, and required actions for reportable events. Based on its review, the staff determined that the level of detail provided on Hermes required actions is adequate and meets the applicable acceptance criteria of NUREG-1537, Part 2, Section 12.4.

12.4.4 Conclusion

Based on its findings above, the staff concludes the information in Hermes PSAR Section 12.4 is sufficient and meets the applicable guidance and regulatory requirements identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Further information as may be required to complete the review of Kairos’s required actions can reasonably be left for later consideration in the OL application since this information is not necessary for the review of a CP application.

12.5 Reports

12.5.1 Introduction

Hermes PSAR Section 12.5, “Reports,” describes required routine operating reports and reporting requirements for changes to the Hermes facility or facility organization to be provided to the NRC.

12.5.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of Kairos’s reports are as follows:

- 10 CFR 50.34, “Contents of applications; technical information,” paragraph (a), “Preliminary safety analysis report,” including 10 CFR 50.34(a)(6), which requires that the PSAR include “[a] preliminary plan for the applicant’s organization, training of personnel, and conduct of operations.”
- 10 CFR 50.35, “Issuance of construction permits.”
- 10 CFR 50.40, “Common standards.”

The applicable guidance for the evaluation of Kairos’s reports is as follows:

- NUREG-1537, Parts 1 and 2, Section 12.5, “Reports.”

12.5.3 Technical Evaluation

PSAR Section 12.5 states that the Hermes TSs will specify the required routine operating reports and reporting requirements for changes to the facility or facility organization to be provided to the NRC, and that TSs are described in PSAR Chapter 14 and will be provided in an OL application. PSAR Section 14.1 states that TSs will include administrative controls and that the content of the TSs will be consistent with the guidance in ANSI/ANS-15.1-2007.

PSAR Section 12.4 also states that the Hermes TSs will specify actions to be taken for a TS violation, which the staff expects would include reports to the NRC, consistent with NRC reporting requirements.

The staff evaluated the sufficiency of the preliminary information on Hermes reports, as described in PSAR Sections 12.4 and 12.5, using the guidance and acceptance criteria from Section 12.5 of NUREG-1537, Parts 1 and 2. The staff finds that ANSI/ANS-15.1-2007, referenced by Kairos, provides guidance for reports, including routine operating reports, and special reports (e.g., reports of TS violations or facility personnel changes), that is generally consistent with the guidance in NUREG-1537. Based on its review, the staff determined that the level of detail provided on Hermes reports is adequate and meets the applicable acceptance criteria of NUREG-1537, Part 2, Section 12.5.

12.5.4 Conclusion

Based on its findings above, the staff concludes the information in Hermes PSAR Section 12.5 (supported by information in PSAR Section 12.4) is sufficient and meets the applicable guidance and regulatory requirements identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Further information as may be required to complete the review of Hermes reports can reasonably be left for later consideration in the OL application since this information is not necessary for the review of a CP application.

12.6 <u>Records</u>

12.6.1 Introduction

Hermes PSAR Section 12.6, “Records,” describes the process for managing test reactor facility records.

12.6.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of Kairos's records are as follows:

- 10 CFR 50.34, "Contents of applications; technical information," paragraph (a), "Preliminary safety analysis report," including 10 CFR 50.34(a)(6), which requires that the PSAR include "[a] preliminary plan for the applicant's organization, training of personnel, and conduct of operations."
- 10 CFR 50.35, "Issuance of construction permits."
- 10 CFR 50.40, "Common standards."

The applicable guidance for the evaluation of Kairos's records is:

- NUREG-1537, Parts 1 and 2, Section 12.6, "Records."

12.6.3 Technical Evaluation

PSAR Section 12.6 states that the Hermes TSs will specify for facility operation the required records to be maintained, where and how they are maintained, and the length of retention. PSAR Section 12.6 also states that TSs are described in PSAR Chapter 14 and will be provided in an OL application. PSAR Section 14.1 states that TSs will include administrative controls and the content of the TSs will be consistent with the guidance in ANSI/ANS-15.1-2007.

PSAR Section 12.6 also states that a records management program is implemented as part of the Quality Assurance Program described in PSAR Section 12.9.

The staff evaluated the sufficiency of the preliminary information on Hermes operational records, as described in PSAR Section 12.6, using the guidance and acceptance criteria from Section 12.6 of NUREG-1537, Parts 1 and 2. The staff finds that ANSI/ANS-15.1-2007, referenced by Kairos, provides guidance for operational records that is consistent with the guidance in NUREG-1537. Based on its review, the staff determined that the level of detail provided regarding Hermes operational records is adequate and meets the applicable acceptance criteria of NUREG-1537, Part 2, Section 12.6. The records management program during construction, as described in Kairos's Quality Assurance Program Description, is discussed in SE Section 12.9.

12.6.4 Conclusion

Based on its findings above, the staff concludes the information in Hermes PSAR Section 12.6 is sufficient and meets the applicable guidance and regulatory requirements identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Further information as may be required to complete the review of Hermes records can reasonably be left for later consideration in the OL application since this information is not necessary for the review of a CP application.

12.7 Emergency Planning

12.7.1 Introduction

Hermes PSAR Section 12.7, "Emergency Planning," discusses emergency planning. The Hermes PSAR provides a description of the preliminary plans for addressing emergencies in PSAR Chapter 12, Appendix A, "Description of the Emergency Plan," which is referenced in PSAR Section 12.7.

12.7.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of Kairos's preliminary plans for coping with emergencies are as follows:

- 10 CFR 50.34, "Contents of applications; technical information," paragraph (a), "Preliminary safety analysis report," including 10 CFR 50.34(a)(10), which requires that the PSAR include "[a] discussion of the applicant's preliminary plans for coping with emergencies."
- 10 CFR 50.35, "Issuance of construction permits."
- 10 CFR 50.40, "Common standards."
- 10 CFR Part 50, Appendix E, "Emergency Planning and Preparedness for Production and Utilization Facilities," Section I, "Introduction," and Section II, "The Preliminary Safety Analysis Report."

The applicable guidance for the evaluation of Kairos's preliminary plans for coping with emergencies is as follows:

- NUREG-1537, Parts 1 and 2, Section 12.7, "Emergency Planning."
- NRC Regulatory Guide (RG) 2.6, "Emergency Planning for Research and Test Reactors and Other Non-Power Production and Utilization Facilities," Revision 2.
- American National Standards Institute/American Nuclear Society standard (ANSI/ANS) 15.16-2015, "Emergency Planning for Research Reactors."
- NUREG-0849, "Standard Review Plan for the Review and Evaluation of Emergency Plans for Research and Test Reactors."

The regulation 10 CFR Part 50, Appendix E, Section I.3, states, in part, that the potential radiological hazards to the public associated with the operation of test reactors licensed under 10 CFR Part 50 involve considerations different than those associated with nuclear power reactors and that, consequently, the size of emergency planning zones (EPZs) for test reactors, and the degree to which compliance with the requirements of Appendix E is necessary, will be determined on a case-by-case basis. Accordingly, the staff evaluated Kairos's preliminary emergency plan for compliance with 10 CFR Part 50, Appendix E, Section II, using the criteria in the research and test reactor-specific guidance listed above.

12.7.3 Technical Evaluation

The staff's technical evaluation of the preliminary emergency plan for Hermes is detailed in the following subsections. The technical evaluation is organized into subsections documenting the staff's review and evaluation for each 10 CFR Part 50, Appendix E, Section II, PSAR requirement.

12.7.3.1 Facility Design Features, Site Layout, and Site Location (10 CFR Part 50, Appendix E, Section II General)

PSAR Chapter 2, “Site Characteristics,” and Chapter 12, Appendix A, provide a description of the Hermes reactor site layout and location, consideration of access routes, surrounding population distribution, land use, and jurisdictional boundaries. This information is graphically shown on PSAR Figure 2.1-2, “Prominent Features in Site Area,” and Figure 2.1-3, “Project Site Area and Zones Associated with the Facility.”

The staff reviewed PSAR Chapter 2 and Chapter 12, Appendix A, including associated figures, site layout, and maps. The staff conducted its review to determine if sufficient information was provided to meet the PSAR emergency plan requirements of 10 CFR Part 50, Appendix E, Section II, as it pertains to the facility design features, site layout, and site location with consideration of access routes, surrounding population distributions, land use, and local jurisdictional boundaries for the EPZs. The staff used the guidance in ANSI/ANS-15.16-2015, Section 3.1, “Introduction,” and the guidance evaluation items contained in NUREG-0849, Section 1.0, “Introduction,” to perform the evaluation for compliance with the 10 CFR Part 50, Appendix E, Section II, PSAR regulations. Based on its review, the staff finds that the information in the PSAR concerning the site layout and location, consideration of access routes, surrounding population distribution, land use, and jurisdictional boundaries addresses the applicable guidance in ANSI/ANS-15.16-2015 and the applicable guidance evaluation items contained in NUREG-0849. Therefore, the staff finds that this emergency plan preliminary information is sufficient and meets the applicable PSAR regulatory requirements of 10 CFR Part 50, Appendix E, Section II.

The staff notes that for an OL application, consistent with the applicable guidance in ANSI/ANS-15.16-2015 and the emergency planning evaluation items contained in NUREG-0849, complete and detailed emergency plan descriptions, such as a description of the location of the reactor facility, including access routes, should be included within the emergency plan.

12.7.3.2 Emergency Response Organization, Notification, and Documented Arrangements (10 CFR Part 50, Appendix E, Sections II.A and II.B)

PSAR Chapter 12, Appendix A, Section A.1, “Facility Organization,” and Section A.2, “Authorities and Responsibilities of Facility Emergency Personnel,” state that upon declaration of an emergency, designated members of the Hermes facility emergency personnel will fulfill corresponding roles in responding to the emergency. In the event of an emergency, the senior individual on-shift will become the Emergency Director and will be responsible for assessing and declaring an emergency and assuming command and control responsibilities following an emergency declaration. Likewise, upon declaration of an emergency, designated health physics personnel will undertake RP activities and designated engineering personnel will focus on plant assessment and technical support for operations. The Emergency Director, who will be the senior individual on-shift, will fulfill this role until their emergency response duties are transitioned to the dedicated replacement.

During the General Audit (ML23115A480), Kairos confirmed that it will provide further information on its emergency organization in the updated Hermes emergency plan that will be submitted as part of a Hermes OL application to address the bulleted items below from the guidance in NUREG-0849, Section 3.0, “Organization and Responsibilities”:

- The reactor's emergency organization, including augmentation of the reactor staff to provide assistance for coping with the emergency situation, recovery from the emergency, and maintaining emergency preparedness.
- The capability of the emergency organization to function around the clock for a protracted period of time following the initiation of emergencies that have or could have radiological consequences requiring around the clock emergency response.
- A block diagram that illustrates the interrelationship of the facility emergency organization to the total emergency response effort. Interfaces between reactor and other onsite emergency organization groups and offsite local support organizations and agencies should be specified.

PSAR Chapter 12, Appendix A, Section A.3, “Means for Notifications,” states that the capability for 24-hour notification to onsite and offsite organizations, including a primary and backup means to accomplish the required notifications will be provided. In addition, PSAR Chapter 12, Appendix A, Section B.2, “State Agencies,” states that the methods used to notify the Tennessee Emergency Management Agency (TEMA) and the information to be provided to TEMA will be established in coordination with TEMA.

PSAR Chapter 12, Appendix A, Section B, “Authorities and Responsibilities of Governmental Agencies,” describes the authorities, responsibilities, support functions, and the available emergency assistance provided from Federal, State, county, and local governmental agencies in an emergency situation.

During the General Audit, Kairos confirmed that in the updated Hermes emergency plan that will be submitted as part of a Hermes OL application, it will provide further information to address the NUREG-0849, Section 3.0, guidance on arrangements and agreements, confirmed in writing, with local support organizations that would augment and extend the capability of the Hermes emergency organization.

The staff reviewed PSAR Chapter 12, Appendix A, Sections A and B to determine if sufficient information was provided to meet the PSAR emergency plan requirements of 10 CFR Part 50, Appendix E, Section II.A and Section II.B. The staff used the guidance in ANSI/ANS-15.16-2015, Section 3.3, “Organization and Responsibilities,” and the guidance evaluation items contained in NUREG-0849, Section 3.0, to perform the evaluation. Based on its review, staff finds that the information in the CP application concerning the Hermes emergency response organization and the means for notification, in the event of an emergency, of persons assigned to the emergency organizations, addresses the applicable guidance in ANSI/ANS-15.16-2015 and the applicable guidance evaluation items contained in NUREG-0849. Therefore, the staff finds that this emergency plan preliminary information is sufficient and meets the applicable PSAR regulatory requirements of 10 CFR Part 50, Appendix E, Section II.A and Section II.B.

As discussed above, Kairos stated that it will provide additional information on the Hermes emergency response organization and Kairos’s documented arrangements with local, State, and Federal governmental agencies that have responsibility for coping with emergencies in the updated emergency plan that will be submitted with a Hermes OL application. Following receipt of the updated Hermes emergency plan and final safety analysis report (FSAR) to be submitted with the OL application, the staff will confirm that the updated emergency plan information contains sufficient information to address the applicable guidance and meet the applicable regulations.

12.7.3.3 Protective Measures to be Taken within the Site Boundary and within Each EPZ (10 CFR Part 50, Appendix E, Section II.C)

PSAR Chapter 12, Appendix A, Section C, “Protective Measures,” states that the Hermes reactor EPZ is coincident with the site boundary, describes the steps for taking protective action within the EPZ during an emergency, and states that the public address system and action specific alarms (e.g., site evacuation) can be used to communicate appropriate protective actions.

During the General Audit, Kairos confirmed that in the updated Hermes emergency plan that will be provided as part of a Hermes OL application, it will provide further information on emergency classification to address NUREG-0849, Section 4.0, guidance, specifically, an emergency classification system that is consistent with the guidance.

The staff reviewed PSAR Chapter 12, Appendix A, Section C. The staff conducted its review to determine if sufficient information was provided to meet the PSAR emergency plan requirements of 10 CFR Part 50, Appendix E, Section II.C. The staff used the guidance in ANSI/ANS-15.16-2015, Section 3.4, “Emergency Classification System,” and the guidance evaluation items contained in NUREG-0849, Section 4.0, “Emergency Classification System,” to perform the evaluation. Based on its review, the staff concludes that the information in the CP application concerning the Hermes protective measures to be taken within the EPZ in the event of an accident addresses the applicable guidance in ANSI/ANS-15.16-2015 and the applicable guidance evaluation items contained in NUREG-0849. Therefore, the staff finds that this preliminary information on protective measures is sufficient and meets the applicable PSAR regulatory requirements of 10 CFR Part 50, Appendix E, Section II.C.

As discussed above, Kairos stated it will provide additional information on the Hermes emergency classification system in an updated emergency plan that will be submitted with a Hermes OL application. Following receipt of the updated Hermes emergency plan and FSAR to be submitted with the OL application, the staff will confirm that the updated emergency plan information contains sufficient information to address the applicable guidance and meet applicable regulations.

12.7.3.4 Emergency Treatment, Transportation, and Decontamination for Injured Individuals (10 CFR Part 50, Appendix E, Sections II.D and II.E)

PSAR Chapter 12, Appendix A, Section D, “First Aid, Decontamination, and Emergency Transportation,” states that contaminated personnel will be kept in an area isolated from other personnel activities to avoid the spread of contamination and that injured personnel will be decontaminated if possible and then dispatched to either the Oak Ridge Methodist Medical Center or the University of Tennessee Hospital. Injured persons are monitored and cared for first and then uninjured personnel will be checked for contamination and any necessary actions will be taken to remove whatever contamination is detected. Personnel with serious injuries and that are contaminated will be transported by ambulance directly to the emergency room at Oak Ridge Methodist Medical Center or the University of Tennessee Hospital. Showers are available onsite that can be used for personnel decontamination and there are personnel decontamination facilities located offsite at Oak Ridge Methodist Medical Center and the University of Tennessee Hospital. In addition, first aid and decontamination kits will be available throughout the Hermes facility. PSAR Chapter 12, Appendix A, Section E, “Offsite Treatment,” also states that the Oak Ridge Methodist Medical Center and the University of Tennessee Medical Center have standard operating procedures for dealing with radiological emergencies, including contaminated patients.

The staff reviewed PSAR Chapter 12, Appendix A, Sections D and E. The staff conducted its review to determine if sufficient information was provided to meet the PSAR emergency plan requirements of 10 CFR Part 50, Appendix E, Section II.D and Section II.E. The staff used the guidance in ANSI/ANS-15.16-2015, Section 3.8, “Emergency Facilities and Equipment,” and the applicable guidance evaluation items contained in NUREG-0849, Section 8.0, “Emergency Facilities and Equipment,” to perform the evaluation. Based on its review, the staff finds that the information in the CP application concerning Hermes facility onsite emergency first aid, decontamination, emergency transportation, and treatment at offsite facilities for individuals injured at the Hermes facility, addresses the applicable guidance in ANSI/ANS-15.16-2015 and the applicable guidance evaluation items contained in NUREG-0849. Therefore, the staff finds that the onsite emergency first aid, decontamination, emergency transportation, and treatment at offsite facilities for injured individuals are sufficient and meet the applicable PSAR regulatory requirements of 10 CFR Part 50, Appendix E, Sections II.D and II.E.

12.7.3.5 Provisions for a Training Program (10 CFR Part 50, Appendix E, Section II.F)

PSAR Chapter 12, Appendix A, Section F, “Training,” states that an initial training and periodic retraining program will be conducted at Hermes to maintain the ability of emergency response personnel to perform their assigned functions. Section F also states that the personnel involved in the training program would include facility personnel responsible for decisionmaking and transmitting emergency information. In addition, offsite personnel, and agencies whose assistance is needed in responding to an emergency, will be provided training, such as briefings or site orientation visits, as appropriate.

The staff reviewed PSAR Chapter 12, Appendix A, Section F. The staff conducted its review to determine if sufficient information was provided to meet the PSAR emergency plan requirements of 10 CFR Part 50, Appendix E, Section II.F. The staff used the guidance of ANSI/ANS-15.16-2015, Section 3.10, “Maintaining Emergency Preparedness,” and the guidance evaluation items contained in NUREG-0849, Section 10.0, “Maintaining Emergency Preparedness,” to perform the evaluation. Based on its review, the staff finds that the information in the CP application concerning Hermes facility training provisions addresses the applicable guidance of ANSI/ANS-15.16-2015 and the guidance evaluation items contained in NUREG-0849. Therefore, the staff finds that the provisions for training are sufficient and meet the applicable PSAR regulatory requirements of 10 CFR Part 50, Appendix E, Section II.F.

12.7.3.6 Preliminary Analysis of Radiological Consequences of Emergency Situations (10 CFR Part 50, Appendix E, Sections II.G and II.H)

PSAR Chapter 12, Appendix A, Section H, “Emergency Equipment and Facilities,” states that a preliminary analysis indicates the Hermes EPZ is coincident with the site boundary (PSAR Figure 2.1-3 shows the Hermes site boundary with respect to the proposed Hermes reactor building), and that there is no offsite release above the Environmental Protection Agency protective action guides (1 rem whole body or 5 rem thyroid). PSAR Chapter 12, Appendix A, Section H, concludes that there is no need for offsite monitoring teams, a technical support center (TSC), or an emergency operations facility (EOF). PSAR Chapter 12, Appendix A, Section A, also concludes that no offsite emergency organization or offsite emergency plan actions are required to cope with emergencies at the Hermes facility. However, PSAR Chapter 12, Appendix A, Section H, states that timely notification will be made to the public for a declared emergency. PSAR Chapter 12, Appendix A, Section G, also states that state and local governments will be notified as appropriate. PSAR Chapter 12, Appendix A, Sections A.3, B, and C provide preliminary information on the means and timing for notification to state and local government organizations. PSAR Chapter 12, Appendix A, Section H, provides a representative listing of radiation monitoring instruments, portable air samplers, and specific radionuclide identification and analysis instrumentation available for use during an emergency. PSAR Chapter 12, Appendix A, Section H, states that a listing of the current locations for emergency equipment cabinets and other emergency equipment storage areas, plus the representative equipment inventories for these storage locations that will also specify the actual equipment in the Hermes facility, will be provided in a Hermes OL application.

PSAR Chapter 12, Appendix A, Section G, states that 10 CFR Part 50, Appendix E, Section II.G, which contains the requirement that the PSAR include "discussion of preliminary analyses projecting the time and means to be employed in the notification of State and local governments and the public in the event of an emergency," is not applicable to Hermes because it is not a nuclear power reactor. However, the staff notes that 10 CFR Part 50, Appendix E, does not preclude applicability of this portion of Section II.G for non-power reactors, as appropriate, and therefore the degree to which compliance with this requirement is necessary for a non-power reactor is determined on a case-by-case basis as discussed above.

The staff reviewed PSAR Chapter 12, Appendix A, Section H, and relevant information in other sections of PSAR Chapter 12, Appendix A. The staff conducted its review to determine if sufficient information was provided to meet the PSAR emergency plan requirements of 10 CFR Part 50, Appendix E, Section II.G and Section II.H. The staff used the guidance contained in ANSI/ANS-15.16-2015, Section 3.5, "Emergency Action Levels (EAL)," Section 3.6, "Emergency Planning Zones," Section 3.7, "Emergency Response," and Section 3.8, "Emergency Facilities and Equipment," and the guidance evaluation items contained in NUREG-0849, Section 5, "Emergency Action Levels," Section 6, "Emergency Planning Zones," Section 7, "Emergency Response," and Section 8, "Emergency Facilities and Equipment," to perform the evaluation. Based on its review, the staff finds that the information in the CP application discussing Kairos's preliminary analysis reflecting the need to include facilities, systems, and methods for identifying the degree of seriousness and potential scope of radiological consequences of emergency situations, reflecting the role of an onsite TSC and an EOF in assessing information, recommending protective action, and disseminating information to the public, and projecting the time and means of offsite notifications, addresses the applicable guidance in ANSI/ANS-15.16-2015 and the applicable guidance evaluation items contained in NUREG-0849. Therefore, the staff finds that the information on preliminary analysis of radiological consequences of emergency situations is sufficient and meets the applicable PSAR regulatory requirements of 10 CFR Part 50, Appendix E, Sections II.G and II.H.

12.7.4 Conclusion

Based on its evaluation of the information in PSAR Section 12.7 and PSAR Chapter 12, Appendix A, and information in PSAR Chapter 2 as discussed above, the staff finds that the descriptions of Kairos's preliminary plans for coping with emergencies address the applicable guidance in ANSI/ANS-15.16-2015 and the applicable guidance evaluation items contained in NUREG-0849, and are also consistent with the guidance in NUREG-1537, Parts 1 and 2, and NRC RG 2.6, Revision 2, as applicable. Therefore, the staff concludes that Kairos's preliminary plans for coping with emergencies are sufficient and comply with the applicable requirements of

10 CFR Part 50, Appendix A, Section II, and 10 CFR 50.34(a)(10), which requires that an applicant for a CP provide preliminary emergency planning information. Accordingly, the staff concludes that the emergency planning information in the PSAR is sufficient and meets the applicable guidance and regulatory requirements identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Further information as may be required to complete the review of Hermes emergency planning can reasonably be left for later consideration in the OL application since this information is not necessary for the review of a CP application.

12.8 Security

12.8.1 Introduction

PSAR Section 12.8, "Security," provides preliminary information on security planning for the Hermes facility.

12.8.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of Kairos's security planning are as follows:

- 10 CFR 50.35, "Issuance of construction permits."
- 10 CFR 50.40, "Common standards."

The applicable guidance for the evaluation of Kairos's security planning is as follows:

- NUREG-1537, Parts 1 and 2, Section 12.8, "Security Planning."

12.8.3 Technical Evaluation

Kairos did not submit a security plan for its CP application. As stated in PSAR Section 12.8, "[a] description of the security plan will be provided with the application for an [o]perating [l]icense consistent with 10 CFR 50.34(c) and will consider the guidance provided in [Regulatory Guide] RG 5.59, 'Standard Format and Content for a Licensee Physical Security Plan for the Protection of Special Nuclear Material of Moderate or Low Strategic Significance,' Revision 1."

The staff evaluated the sufficiency of the preliminary information on security planning, as described in Kairos Power PSAR Section 12.8, using the guidance from Section 12.8, "Security Planning," of NUREG-1537, Parts 1 and 2. The staff notes that a security plan is not required by NRC regulations to be submitted for a CP application. The staff also notes that the regulation 10 CFR 50.34(c), referenced by Kairos, may not be applicable to require Kairos to submit a security plan with an OL application because Hermes would utilize low-enriched uranium fuel and would not be a nuclear power reactor, but that Kairos would be required to submit and implement a security plan for Hermes operation consistent with other applicable NRC regulations (e.g., 10 CFR 70.22(k) and 73.67(c)(1)) and OL conditions, as appropriate. Based on its review, the staff determined that the level of detail provided on Hermes security planning is adequate and meets the applicable guidance in NUREG-1537.

12.8.4 Conclusion

Based on its findings above, the staff concludes the information in Hermes PSAR Section 12.8 is sufficient and meets the applicable guidance and regulatory requirements identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Further information as may be required to complete the review of Hermes security planning can reasonably be left for later consideration in the OL application since this information is not necessary for the review of a CP application.

12.9 Quality Assurance

12.9.1 Introduction

Hermes PSAR Section 12.9, "Quality Assurance," describes quality assurance for the Hermes facility, and states that the description of Kairos's quality assurance (QA) program for the design, construction, and operation of Hermes is based on ANSI/ANS 15.8-1995 (R2005), "Quality Assurance Program Requirements for Research Reactors," and the guidance in RG 2.5, "Quality Assurance Program Requirements for Research and Test Reactors," Revision 1. Kairos provided its Quality Assurance Program Description (QAPD) as Appendix B to PSAR Section 12 (i.e., PSAR Appendix 12B).

12.9.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of Kairos's QA program are as follows:

- 10 CFR 50.34, "Contents of applications; technical information," paragraph (a), "Preliminary safety analysis report," including 10 CFR 50.34(a)(7), which requires that the PSAR include "[a] description of the quality assurance program to be applied to the design, fabrication, construction, and testing of the structures, systems, and components of the facility."
- 10 CFR 50.35, "Issuance of construction permits."
- 10 CFR 50.40, "Common standards."

The applicable guidance for the evaluation of Kairos's QA program is as follows:

- NUREG-1537, Parts 1 and 2, Section 12.9, "Quality Assurance."
- ANSI/ANS-15.8-1995, "Quality Assurance Program Requirements for Research Reactors."
- NRC RG 2.5, "Quality Assurance Program Requirements for Research and Test Reactors," Revision 1.

12.9.3 Technical Evaluation

PSAR Appendix 12B provides the Hermes QAPD. The staff reviewed the information in the QAPD using the guidance in ANSI/ANS-15.8-1995, which is endorsed by NRC RG 2.5, Revision 1. As discussed below, the staff evaluated QAPD Section 1, "Introduction," and Section 2, "Design, Construction, and Modifications," for the issuance of a CP because those sections apply to Hermes design, fabrication, construction, and testing. However, the staff did not evaluate QAPD Section 3, "Facility Operations," because it applies to Hermes operation and is therefore not required for the issuance of a CP. The staff's review and findings for each section of the QAPD are discussed under the headings below.

12.9.3.1 QAPD Section 1, "Introduction"

Based on its review of QAPD Section 1, "Introduction," the staff determined that the description of the scope, applicability, and definitions for the Hermes QAPD is consistent with the guidance provided in Section 1 of ANSI/ANS-15.8-1995, because it includes information specified in Section 1 of the ANSI/ANS standard regarding matters affecting quality of the structures, systems, and components (SSCs) in the Hermes plant, including the design, fabrication, construction, and testing and states that the terms used in the QAPD are as defined in the ANSI/ANS standard with the exception of the term "safety-related items" defined in the standard. QAPD Section 1.2, "Definitions," states that for the QAPD, "safety-related items" is replaced with "safety-related SSCs," with an alternate definition given in QAPD Section 1.2. The staff finds that the use of "safety-related SSCs" and its definition in the QAPD are consistent with the definition of "safety-related SSCs" in PSAR Sections 1.2.3 and 3.1.1. Based on the above, the staff finds the description in QAPD Section 1 acceptable.

12.9.3.2 QAPD Section 2, "Design, Construction, and Modifications"

Based on its review of QAPD Section 2.1, "Organization," the staff determined that organizational controls described in QAPD Section 2.1 are consistent with the guidance provided in Section 2.1 of ANSI/ANS-15.8-1995, because QAPD Section 2.1 provides an organizational structure and definitions of roles and responsibilities that help ensure the achievement and maintenance of quality by those assigned to perform work. Therefore, the staff finds the description in QAPD Section 2.1 acceptable.

Based on its review of QAPD Section 2.2, "Quality Assurance Program," the staff determined that the general QA program requirements in QAPD Section 2.2 are consistent with the guidance provided in Section 2.2 of ANSI/ANS-15.8-1995, because QAPD Section 2.2 states that the Hermes QA program will be established in accordance with the QAPD requirements and be established at the earliest time consistent with Kairos's schedule for accomplishing quality-affecting activities. This section also indicates that the QA program provides for the training necessary for Hermes staff to perform quality-affecting activities. The QAPD also applies a graded approach to all activities affecting quality, which the staff finds is consistent with the ANSI/ANS standard and will ensure that controls are applied commensurate with risks associated with controlled items. Therefore, the staff finds the description in QAPD Section 2.2 acceptable.

Based on its review of QAPD Section 2.3, "Design Control," the staff determined that Kairos's design controls in QAPD Section 2.3 are consistent with the guidance provided in Section 2.3 of ANSI/ANS-15.8-1995, because QAPD Section 2.3 adequately addresses the ANSI/ANS standard recommendations for design requirements, processes, verification, documents and records, verification of commercial grade items, and change controls necessary to maintain design control. The staff also determined that the QAPD Section 2.3 statement that design interfaces shall be identified and controlled, and the design efforts shall be coordinated among the participating organizations, is consistent with the ANSI/ANS standard and will help ensure appropriate coordination among all organizations participating in the design of the Hermes facility. Therefore, the staff finds the description in QAPD Section 2.3 acceptable.

Based on its review of QAPD Section 2.4, “Procurement Document Control,” the staff determined that Kairos’s procurement document controls in QAPD Section 2.4 are consistent with the guidance provided in Section 2.4 of ANSI/ANS-15.8-1995 because QAPD Section 2.4 reflects the controls recommended to maintain sufficient technical and quality requirements throughout the procurement process, and ensures that the items and services satisfy the facility’s needs as prescribed in its procurement processes or specifications. Therefore, the staff finds the description in QAPD Section 2.4 acceptable.

Based on its review of QAPD Section 2.5, “Procedures, Instructions, and Drawings,” the staff determined that Kairos’s controls for instructions, procedures, and drawings in QAPD Section 2.5 are consistent with the guidance provided in Section 2.5 of ANSI/ANS-15.8-1995, because QAPD Section 2.5 contains the measures recommended to ensure that activities affecting quality are performed in accordance with appropriate documented instructions, quality procedures, or drawings. Therefore, the staff finds the description in QAPD Section 2.5 acceptable.

Based on its review of QAPD Section 2.6, “Document Control,” the staff determined that Kairos’s document controls in QAPD Section 2.6 are consistent with the guidance provided in QAPD Section 2.6 of ANSI/ANS-15.8-1995 because they include, as recommended, processes to identify documents to be controlled and how they will be distributed; identification of responsibilities for preparing, reviewing, approving, and issuing documents; and requirements for review of documents for adequacy, completeness and correctness prior to issuance and approval. Therefore, the staff finds the description in QAPD Section 2.6 acceptable.

Based on its review of QAPD Section 2.7, “Control of Purchased Items and Services,” the staff determined that Kairos’s controls for purchased items and services in QAPD Section 2.7 are consistent with the guidance provided in Section 2.7 of ANSI/ANS-15.8-1995, because QAPD Section 2.7 includes the information recommended to ensure that suppliers are selected based on evaluation of their capabilities to provide the required items or services. Also, as recommended by ANSI/ANS-15.8-1995, Section 2.7 has measures to control the supplier’s performance, establishes the responsibility of the supplier for the quality of their products, requires documented evidence of that quality in accordance with established methods, and establishes a system to ensure that purchased items and services conform to procurement specifications. Therefore, the staff finds the description in QAPD Section 2.7 acceptable.

Based on its review of QAPD Section 2.8, “Identification and Control of Items,” the staff determined that Kairos’s controls for identification and control of items in QAPD Section 2.8 are consistent with the guidance provided in Section 2.8 of ANSI/ANS-15.8-1995, because QAPD Section 2.8 provides the recommended measures for item identification and traceability control; employment of physical separation, procedural control, or other appropriate means, when physical identification of items is either impractical or insufficient; and means to identify and control items that have limited calendar or operating life. Therefore, the staff finds the description in QAPD Section 2.8 acceptable.

Based on its review of QAPD Section 2.9, “Control of Special Processes,” the staff determined that Kairos’s controls for special processes in QAPD Section 2.9 are consistent with the guidance provided in Section 2.9 of ANSI/ANS-15.8-1995, because QAPD Section 2.9 includes the recommended means to control special processes by instructions, drawings, checklists, travelers, or other appropriate means.

As recommended, QAPD Section 2.9 also indicates that Kairos and its suppliers will be responsible for complying with approved procedures and processes when performing special processes for Hermes, indicates that the procedures or instructions for the special process will include the requirements of applicable codes and standards, and specifies appropriate record maintenance requirements. Therefore, the staff finds the description in QAPD Section 2.9 acceptable.

Based on its review of QAPD Section 2.10, “Inspections,” the staff determined that Kairos’s controls for inspections described in QAPD Section 2.10 are consistent with the guidance provided in Section 2.10 of ANSI/ANS-15.8-1995, because QAPD Section 2.10 describes the recommended requirements to plan, document, and perform inspections required to verify conformance of quality affecting items or activities, including items in-process or under construction, to specified requirements. QAPD Section 2.10 also requires the recommended examination of the associated quality records for adequacy and completeness, requires that measuring and test equipment used to perform inspections be identified in the inspection documentation, and describes the qualification and training requirements, including on-the-job training, for the plant personnel performing the inspection activities. Therefore, the staff finds the description in QAPD Section 2.10 acceptable.

Based on its review of QAPD Section 2.11, “Test Control,” the staff determined that Kairos’s controls for testing in QAPD Section 2.11 are consistent with the guidance provided in Section 2.11 of ANSI/ANS-15.8-1995 because QAPD Section 2.11 describes the recommended formal testing requirements to verify conformance of designated SSCs to specified requirements and demonstrate satisfactory performance for service or to collect data to support design or fabrication. QAPD Section 2.11 also requires, as recommended by ANSI/ANS-15.8-1995, the documentation and evaluation of test results by a Kairos responsible authority, and that verification and validation of computer programs be performed. Therefore, the staff finds the description in QAPD Section 2.11 acceptable.

Based on its review of QAPD Section 2.12, “Control of Measuring and Test Equipment,” the staff determined that Kairos’s controls for measuring and test equipment (M&TE) in QAPD Section 2.12 are consistent with the guidance provided in Section 2.12 of ANSI/ANS-15.8-1995, because QAPD Section 2.12 includes recommended requirements for control, calibration, and adjustment that need to be performed for tools, gauges, instruments, and other M&TE equipment used for activities affecting quality, as well as measures, consistent with ANSI/ANS recommendations, that will be taken for out-of-calibration devices, and requirements, consistent with ANSI/ANS recommendations, to maintain records of calibration data for each piece of M&TE. Therefore, the staff finds QAPD Section 2.12 acceptable.

Based on its review of QAPD Section 2.13, “Handling, Storage, and Shipping,” the staff determined that Kairos’s QAPD Section 2.13 is consistent with the guidance provided in Section 2.13 of ANSI/ANS-15.8-1995, because QAPD Section 2.13 includes the specific controls for handling, storage, and shipping recommended in the ANSI/ANS standard. Therefore, the staff finds QAPD Section 2.13 acceptable.

Based on its review of QAPD Section 2.14, “Inspection, Test, and Operating Status,” the staff determined that Kairos’s controls for inspection, test, and operating status in QAPD Section 2.14 are consistent with the guidance provided in ANSI/ANS-15.8-1995 because QAPD Section 2.14 includes ANSI/ANS standard recommended actions that allow the traceability of the status of inspection and test activities of items and avoid the installation or operation of items that have not passed the required inspections and tests. Therefore, the staff finds QAPD Section 2.14 acceptable.

Based on its review of QAPD Section 2.15, “Control of Non-Conforming Items and Services,” the staff determined that Kairos’s controls for non-conforming items and services in QAPD Section 2.15 are consistent with the guidance provided in Section 2.15 of ANSI/ANS-15.8-1995 because QAPD Section 2.15 includes the measures recommended to prevent inadvertent installation or use of non-conforming items and to allow identification, documentation, evaluation, and segregation of these items. In addition, as recommended by ANSI/ANS-15.8-1995, QAPD Section 2.15 includes requirements for documenting the technical justification for the acceptability of non-conforming items and for the reexamination of repaired or reworked items, in accordance with applicable Kairos procedures. Therefore, the staff finds QAPD Section 2.15 acceptable.

Based on its review of QAPD Section 2.16, “Corrective Actions,” the staff determined that Kairos’s controls for corrective actions in QAPD Section 2.16 are consistent with the guidance provided in Section 2.16 of ANSI/ANS-15.8-1995 because, as recommended, QAPD Section 2.16 requires the prompt identification and correction of conditions adverse to quality and requires that investigation and corrective actions be performed for conditions that are significantly adverse to quality to preclude recurrence. Therefore, the staff finds QAPD Section 2.16 acceptable.

Based on its review of QAPD Section 2.17, “Quality Records,” the staff determined that Kairos’s controls for quality records in QAPD Section 2.17 are consistent with the guidance provided in Section 2.17 of ANSI/ANS-15.8-1995 because, as recommended, QAPD Section 2.17 includes requirements to store records applicable to quality for specified periods and under appropriate conditions. Therefore, the staff finds QAPD Section 2.17 acceptable.

Based on its review of QAPD Section 2.18, “Assessments,” the staff determined that Kairos’s controls for assessments in QAPD Section 2.18 are consistent with the guidance provided in Section 2.18 of ANSI/ANS-15.8-1995. As recommended, QAPD Section 2.18 requires Kairos to conduct and document periodic assessments of quality-affecting activities during design, construction, or modification to evaluate the effectiveness of the as-implemented QA program and requires the review of such assessments by management. QAPD Section 2.18, as recommended by ANSI/ANS-15.8-1995, also requires Kairos management to investigate adverse findings, schedule corrective actions, and notify the appropriate assessing organization of any actions taken or planned. QAPD Section 2.18, as recommended ANSI/ANS-15.8-1995, further requires the maintenance of assessment records and requires that the personnel selected for assessment assignments have the requisite experience and training. Therefore, the staff finds QAPD Section 2.18 acceptable.

The staff determined that Kairos did not provide in its QAPD a description of controls for experimental equipment, as recommended by the guidance in ANSI/ANS-15.8-1995, Section 2.19, “Experimental Equipment.” PSAR Section 10.1 states that Hermes will not include special facilities dedicated to the conduct of reactor experiments or experimental programs. Therefore, the staff finds it acceptable that the QAPD does not include controls for experimental equipment.

12.9.3.3 Other QAPD Sections

The staff notes that Hermes QAPD Section 3, "Facility Operations," provides a description of elements of a QA program for the conduct of operations at Hermes. The staff also notes the QAPD did not include a description of the applicability of the QA program to existing facilities or decommissioning, as recommended by Section 4, "Applicability to Existing Facilities," and Section 5, "Decommissioning," of the ANSI/ANS-15.8-1995 standard. The regulation at 10 CFR 50.34(a)(7) only requires that an applicant provide a description of its QA program that will be implemented for design, fabrication, construction, and testing. Therefore, the staff did not evaluate Section 3 of the QAPD for its CP review because it covers operations and is not required by 10 CFR 50.34(a)(7) to be included in a CP application. Furthermore, the staff finds that ANSI/ANS-15.8-1995, Sections 4 and 5, are not applicable to the Hermes CP application and it is acceptable that the QAPD does not include this recommended information because Kairos did not indicate that the QAPD will apply to any existing facilities and because submission of decommissioning plans and associated QA provisions is not required until a licensee applies for license termination after permanent cessation of operations. As appropriate, the staff will review information related to QA during operations and decommissioning during future reviews of a Hermes OL application and proposed decommissioning plan, respectively.

12.9.4 Conclusion

Based on its evaluation of the Hermes QAPD, the staff finds that the QAPD discussed in PSAR Section 12.9 and provided in PSAR Appendix 12B meets the guidance relevant to design, fabrication, construction, and testing in Sections 1 and 2 of ANSI/ANS 15.8-1995, which the NRC endorsed in RG 2.5, Revision 1, and that the QAPD is also consistent with the guidance contained within Section 12.9 of NUREG-1537, Parts 1 and 2. Therefore, the staff finds that the Hermes QAPD is sufficient and complies with the requirements of 10 CFR 50.34(a)(7), which requires that an applicant for a CP provide a description of the QA program to be applied to the design, fabrication, construction, and testing of the SSCs of the facility. Accordingly, the staff concludes that the information in PSAR Section 12.9 and PSAR Appendix 12B is sufficient and meets the applicable guidance and regulatory requirements identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40, and, as such, the Hermes QAPD is acceptable for implementation during the design and construction of the Hermes facility. Further information as may be required to complete the review of Kairos's QA program for the conduct of operations and decommissioning can reasonably be left for later consideration in the OL application (or a proposed decommissioning plan, as appropriate) since this information is not necessary for the review of a CP application.

In order to provide reasonable assurance that regulatory requirements and license commitments for QA are adequately included in the design, procurement, and construction of the Hermes facility, the staff recommends that the CP include the following condition:

> Kairos shall implement the QA program described, pursuant to 10 CFR 50.34(a)(7), in Chapter 12, Appendix B, of Revision 3 of the Hermes PSAR, including revisions to the QA program in accordance with the provisions below.
>
> Kairos may make changes to its previously accepted QA program description without prior Commission approval, provided the changes do not reduce the commitments in the QA program description as accepted by the Commission. Changes to the QA program description that do not reduce the commitments must be submitted to the Commission within 90 days.

Changes to the QA program description that do reduce the commitments must be submitted to the Commission and receive Commission approval prior to implementation, as follows:

- Changes must be submitted as specified in 10 CFR 50.4.

- The submittal of changes to the QA program description must include all pages affected by the changes and must be accompanied by a forwarding letter identifying the changes, the reason for the changes, and the basis for concluding that the revised program incorporating the changes continues to satisfy the PSAR Revision 3 QA program description commitments previously accepted by the NRC (the letter need not provide the basis for changes that correct spelling, punctuation, or editorial items).

- A copy of the forwarding letter identifying the changes must be maintained as a record by Kairos for three years.

- Changes to the QA program description shall be regarded as accepted by the Commission upon Kairos's receipt of a letter to this effect from the appropriate reviewing office of the Commission or 60 days after Kairos's submittal to the Commission, whichever occurs first.

12.10 Operator Training and Requalification

12.10.1 Introduction

PSAR Section 12.10, "Reactor Operating Training and Requalification," provides preliminary information on Hermes operator training and requalification.

12.10.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of Kairos's operator training and requalification are as follows:

- 10 CFR 50.35, "Issuance of construction permits."
- 10 CFR 50.40, "Common standards."

The applicable guidance for the evaluation of Kairos's operator training and requalification is as follows:

- NUREG-1537, Parts 1 and 2, Section 12.10, "Operator Training and Requalification."

12.10.3 Technical Evaluation

Kairos did not submit an operator training and requalification plan for its CP application. As stated in Hermes PSAR Section 12.10, "[t]he operating training and requalification plan will be provided with the application for the [o]perating [l]icense, consistent with the requirements in 10 CFR 50.34(b)(8)," and the plan will be developed in accordance with 10 CFR Part 55, "Operators' Licenses."

The staff evaluated the sufficiency of the preliminary information on operator training and requalification that Kairos provided in PSAR Section 12.10, using the guidance and acceptance criteria from Section 12.10, “Operator Training and Requalification,” in NUREG-1537, Parts 1 and 2. The staff notes that an operator training and requalification plan is not required by NRC regulations to be submitted for a CP application. Accordingly, the staff determined that the level of detail provided on Hermes operator training and requalification is adequate for the CP application and meets the applicable acceptance criteria in NUREG-1537, Part 2, Section 12.10.

12.10.4 Conclusion

Based on its findings above, the staff concludes the information in Hermes PSAR Section 12.10 is sufficient and meets the applicable guidance and regulatory requirements identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Further information as may be required to complete the review of Hermes operator training and requalification can reasonably be left for later consideration in the OL application since this information is not necessary for the review of a CP application.

12.11 Startup Plan

12.11.1 Introduction

PSAR Section 12.11, “Startup Plan,” discusses the Hermes startup plan.

12.11.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of Kairos’s startup plan are as follows:

- 10 CFR 50.35, “Issuance of construction permits.”
- 10 CFR 50.40, “Common standards.”

The applicable guidance for the evaluation of Kairos’s startup plan is as follows:

- NUREG-1537, Parts 1 and 2, Section 12.11, “Startup Plan.”

12.11.3 Technical Evaluation

PSAR Section 12.11 states that the “startup plan will be provided with the application for the Operating License, consistent with the requirements in 10 CFR 50.34(b)(6)(iii).”

The staff evaluated the sufficiency of the preliminary information on the Hermes startup plan, as discussed in PSAR Section 12.11, using the guidance and acceptance criteria from Section 12.11, “Startup Plan,” in NUREG-1537, Parts 1 and 2. Using the guidance in NUREG-1537, the staff considered the statement in the PSAR and concluded that further information regarding a startup plan for operation of the Hermes facility is not necessary for the issuance of a CP given that a startup plan should be based on a final design.

12.11.4 Conclusion

Based on its findings above, the staff concludes the information in Hermes PSAR Section 12.11 is sufficient and meets the applicable guidance and regulatory requirements identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Further information as may be required to complete the review of a Hermes startup plan can reasonably be left for later consideration in the OL application since this information is not necessary for the review of a CP application.

12.12 Environmental Report

Kairos did not provide, and the staff did not review, environmental information in the PSAR as described in Section 12.12, “Environmental Reports,” of NUREG-1537, Parts 1 and 2. In lieu of providing environmental information in the PSAR, Kairos provided environmental information in the form of a separate Environmental Report submitted by letter dated October 31, 2021. The staff’s evaluation of Kairos’s environmental information is documented in a Draft Environmental Impact Statement.

12.13 Material Control and Accounting Plan

NUREG-1537, Parts 1 and 2, do not include guidance or acceptance criteria for MC&A plans. Furthermore, Kairos did not provide, and the staff did not review, a MC&A plan in the PSAR.

While MC&A is not discussed in the PSAR, PSAR Section 9.6 states that Kairos plans to request authorization to possess special nuclear material (SNM) pursuant to 10 CFR Part 70, “Domestic Licensing of Special Nuclear Material” in the future. The staff notes that licensees possessing SNM must comply with the applicable requirements of 10 CFR Part 74, “Material Control and Accounting of Special Nuclear Material.”

During the General Audit, Kairos confirmed that it will provide an MC&A plan with a Hermes OL application or other licensing submittal (e.g., a CP amendment) requesting authorization to possess SNM, as appropriate.

Because the CP application does not request authorization to possess SNM, and because information on MC&A is not required for an applicant that does not request authorization to possess SNM, the staff finds that it is acceptable that the PSAR does not include information on MC&A. Information on MC&A at the facility can reasonably be left for later consideration in a Hermes OL application or other licensing application requesting authorization to possess SNM, as appropriate.

12.14 Summary and Conclusions on the Conduct of Operations

The staff evaluated the information on the Hermes conduct of operations as described in PSAR Chapter 12 and finds that the preliminary plans and information on the Hermes conduct of operations: (1) meet all applicable regulatory requirements and (2) meet the applicable acceptance criteria in NUREG-1537, Part 2, allowing the staff to make findings that:

- Kairos’s preliminary information and commitments to develop the Hermes organization, review and audit programs, procedures, required actions, reporting and recordkeeping requirements, security plan, and operator training and requalification plans are sufficient and meet the applicable regulatory requirements and guidance for the issuance of a CP.

Further information on these items can reasonably be left for later consideration in the OL application.
- Information on the Hermes startup plan and MC&A plan can reasonably be left for later consideration in the OL application.
- The preliminary information on emergency planning is sufficient and meets the applicable regulatory requirements and guidance for the issuance of a CP. Further information can reasonably be left for later consideration in the FSAR and updated emergency plan submitted with an OL application.
- The Hermes QAPD is sufficient and meets the applicable regulatory requirements and guidance for the issuance of a CP. Further information related to quality assurance during operations and decommissioning can reasonably be left for later consideration during future reviews of a Hermes OL application and proposed decommissioning plan, respectively.

Based on these findings and subject to the condition referenced above, the staff concludes the following regarding the issuance of a CP in accordance with 10 CFR 50.35 and 50.40:

- Such further technical or design information as may be required to complete the safety analysis, and which can reasonably be left for later consideration, will be supplied in the FSAR.
- There is reasonable assurance: (i) that the construction of the Hermes facility will not endanger the health and safety of the public, and (ii) that construction activities can be conducted in compliance with the Commission's regulations.
- Kairos is technically qualified to engage in the construction of its proposed Hermes facility in accordance with the Commission's regulations.
- The issuance of a permit for the construction of the Hermes facility would not be inimical to the common defense and security or to the health and safety of the public.

12.15 References

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-----. ANSI/ANS-15.4-2016, "Selection and Training of Personnel for Research Reactors," American Nuclear Society, La Grange Park, Illinois.

Kairos Power LLC. "Submittal of the Environmental Report for the Kairos Power Fluoride Salt-Cooled, High Temperature Non-Power Reactor (Hermes)." October 31, 2021. ADAMS Pkg. ML21306A131.

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13 ACCIDENT ANALYSES

This section provides the U.S Nuclear Regulatory Commission (NRC) staff's evaluation of Kairos's deterministic safety analysis for the Hermes test reactor. Chapter 13, "Accident Analysis," of the Hermes preliminary safety analysis report (PSAR), Revision 3, as supplemented, provides information and analyses results for the potential radiological consequences of an accident at the Hermes facility. The evaluation of the safety of a test reactor requires analyses of the plant's responses to postulated equipment failures or malfunctions. Such analyses help to determine the limiting conditions for operation (LCOs), limiting safety system settings, and design specifications for safety related components and systems to protect public health and safety. Kairos's analyses are also performed to demonstrate that the reactor site criteria in 10 CFR Part 100 are met. Kairos is not requesting Commission approval of the safety of any design feature or specification in the construction permit (CP) application, as permitted by 10 CFR 50.35(b).

Kairos uses the functional containment approach where the tristructural isotropic (TRISO) fuel and a molten salt that is a mixture of lithium fluoride (LiF) and beryllium fluoride (BeF_2) (Flibe) coolant are the barriers credited to retain fission products. The use of the functional containment approach to protect public health and safety was approved by the Commission in the Staff Requirements Memoranda to SECY-18-0096, "Functional Containment Performance Criteria for Non-Light-Water-Reactors." A more detailed discussion on the functional containment approach can be found in Section 6.2 of this Safety Evaluation (SE). Kairos uses the dose consequences of a maximum hypothetical accident (MHA) to bound the potential postulated events (anticipated operational occurrences and design basis accidents).

In its review of areas relevant to PSAR Chapter 13, the staff considered the information in Revision 1, dated September 29, 2022, of the technical report KP-TR-017, "KP-FHR Core Design and Analysis Methodology," and Revision 2, dated February 24, 2023, of the technical report KP-TR-018, "Postulated Event Analysis Methodology," which are part of the Hermes CP application, as supplemented, and which are referenced in the PSAR, Revision 3.

13.1 Initiating Events and Scenarios

PSAR Section 13.1, "Initiating Events and Scenarios," defines the postulated events evaluated by Kairos for the Hermes facility. The event categories identified in PSAR Section 13.1 are consistent with those listed in NUREG-1537, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors," Section 13.1, "Accident-Initiating Events and Scenarios," except for the malfunction of an experiment. As discussed in Chapter 10 of this SE, Hermes will not include special facilities dedicated to the conduct of reactor experiments or experimental programs, so the experiment malfunction event is not applicable. Some events are precluded by design and are discussed in Section 13.1.10 of this SE.

13.1.1 Maximum Hypothetical Accident

13.1.1.1 Introduction

Section 13.1.1, "Maximum Hypothetical Accident," of the PSAR provides the MHA event description and assumptions. Section 13.2.1, "Maximum Hypothetical Accident," of the PSAR provides a conservative evaluation of the MHA in order to bound the radionuclide release of all credible accidents. This analysis is done to demonstrate that the 10 CFR 100.11 dose reference values are met at the exclusion area boundary (EAB) and outer boundary of the low population zone (LPZ) in support of the safety analysis requirements in 10 CFR 50.34(a)(1)(i) and the test reactor siting evaluation factors in 10 CFR 100, Subpart A for all credible accidents.

An important part of the analysis of the MHA and its consequences is the identification of the radionuclide material at risk for release (MAR) due to the accident scenario, which includes the release from in-service TRISO fuel, fuel manufacturing defects, Flibe coolant inventory, gas space inventory, and radionuclides which are deposited within steel or graphite structures within the reactor system and primary heat transport system (PHTS). Except for the transient fuel releases, the radionuclide retention and transport are determined following the methodology provided in the staff approved mechanistic source term topical report (MST TR) KP-TR-012-NP-A, "KP-FHR Mechanistic Source Term Methodology Topical Report," Revision 3. Bounding values for Flibe circulating activity, retained tritium, and activated argon are assumed. In PSAR Section 14.1, Kairos provided regulatory controls based on the bounding values assumed in the MHA analysis. PSAR Chapter 14, "Technical Specifications," Table 14.1-1, "Proposed Variables and Conditions for Technical Specifications," includes proposed technical specification (TS) LCO in Section 3.3, "Coolant Systems," which will include an upper bound radionuclide limit in the reactor coolant during steady state to ensure postulated events do not exceed limits. The proposed LCO will also include an upper bound limit on quantity of radioactive MAR in the cover gas to ensure a postulated event does not exceed limits. The specific values for the upper bound limits will be based upon the finalized event analyses, including the MHA, to be provided in the operating license (OL) application.

Retention and transport of radionuclides is predominately a function of the associated fuel, Flibe vapor space temperatures, and the available surface area and volumes for deposited nuclides. The MHA uses a bounding fuel, Flibe, and stainless steel (SS)-316 temperature versus time profile. These factors bound the other evaluated events.

13.1.1.2 Regulatory Evaluation

The staff reviewed PSAR Chapter 13 against applicable regulatory requirements, regulatory guidance, and standards, to assess the sufficiency of the preliminary accident analysis for the issuance of a CP.

- 10 CFR 50.34, "Contents of applications; technical information," paragraph (a), "Preliminary safety analysis report."
    - 10 CFR 50.34(a)(1)(i), which requires "[a] description and safety assessment of the site on which the facility is to be located, with appropriate attention to features affecting facility design"
    - 10 CFR 50.34(a)(4), which requires that each applicant for a CP include "[a] preliminary analysis and evaluation of the design and performance of [SSCs] of the facility with the objective of assessing the risk to public health and safety resulting from operation of the facility and including determination of the margins of safety during normal operations and transient conditions anticipated during the life of the facility, and the adequacy of [SSCs], provided for the prevention of accidents and the mitigation of the consequences of accidents…"
- 10 CFR 50.35, "Issuance of construction permits."
- 10 CFR 50.40, "Common standards."
- 10 CFR Part 100, "Reactor Site Criteria."

- 10 CFR 100.11, “Determination of exclusion area, low population zone, and population center distance,” which provides criteria for the EAB, LPZ, and population center distance for a test reactor for the purposes of site evaluation.

The applicable guidance and acceptance criteria for the evaluation of Hermes’s MHA postulated event is as follows:

- NUREG-1537, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors” Parts 1 and 2, Section 13, “Accident Analyses”

The staff’s evaluation of the preliminary accident analysis does not constitute approval of the safety of any design feature or specification. Such approval will be made following the evaluation of the final design of the Hermes facility as described in the final safety analysis report (FSAR) to be submitted as part of the Hermes OL application.

13.1.1.3 **Technical Evaluation**

Initial Conditions Assumptions

The expected normal or nominal operating conditions are given in PSAR Table 4.1-1, “Reactor Parameters.” Kairos’s modeling of the fission product transport is driven primarily by temperature and hence chose conservative bounding fuel and Flibe temperatures to provide bounding radionuclide releases to the environment and subsequent radiological consequences for the MHA. The conservative nature of the selected temperatures will be evaluated for the specific transients evaluated in the following sections of this SE.

Kairos assumes that the initial inventory of radionuclides from defective fuel remain with the fuel and have not been deposited elsewhere during normal operation in the system and hence is available for release during the MHA. The staff agrees that this assumption is conservative for the associated fuel releases as the Flibe circulating activity is already assumed to be at the maximum allowed value at the start of the MHA. The staff finds that this assumption, along with conservative gas space and structural fission product inventories available for release, will yield a conservative radionuclide inventory available for release.

As described in PSAR Section 13.2.1, the modeling of diffused tritium is simplified by assuming tritium fluoride is the only species for an oxidizing salt. This assumption results in a higher graphite inventory and higher total release of tritium than the alternative of assuming the only species is molecular tritium in a reducing salt. The tritium retained in the pebble and graphite structures is assumed to be released directly into the reactor building, bypassing the Flibe. Tritium in the Flibe and contained in the pebble graphite is released as a puff release at the beginning of the MHA transient while tritium diffuses out of the other structural graphite as a function of time using the MHA temperature curve.

Because argon gas has low solubility in Flibe, the argon cover gas diffuses through the Flibe and enters graphite closed pores and becomes activated during reactor operation. The result is that argon-41 (Ar-41) will be trapped in the pores of the graphite structural material as well as the carbonous fuel pebble overcoat. During a transient, a puff release of Ar-41 from the core (reactor) graphite is released directly into the cover gas. Because the treatment of Ar-41 generation, retention, and transport is not described in detail in the staff approved MST TR, the staff discussed this topic in the Accident Analysis Audit report (ML23160A287). The staff was able to audit documentation, including the Hermes MHA analysis calculation and a technical memorandum on methods to estimate Ar-41 inventories in pebbles and structural graphite, which supports the description of Ar-41 generation, retention, and transport in the PSAR. The staff noted that the MHA Ar-41 inventory assumption was based on trapping of the argon cover gas entrained in the Flibe within the closed pores in Flibe wetted graphite surfaces and subsequent neutron activation. The staff found in the Accident Analysis Audit that the treatment of Ar-41 in the MHA radiological consequence analysis is based on the Hermes preliminary design and conservative modeling assumptions and is therefore acceptable.

Structures, Systems, and Components Mitigation Assumptions

The reactor protection system (RPS) is credited with detecting and initiating a reactor trip, tripping the primary coolant pump, and tripping the process of pebble extraction and insertion. The RPS limits heat generation and maintains temperatures within prescribed limits, while the pump trip limits entrained cover gas. The staff's finding regarding the adequacy of the RPS design is found in Section 7.3 of this SE. The adequacy of assumed analytical setpoints are determined by the staff's evaluation of the PSAR Chapter 13 postulated event temperatures staying below those assumed in the MHA. The ability to insert a sufficient rate and amount of negative reactivity is addressed by the staff review of shutdown functions described in PSAR Chapter 13 and PSAR Section 4.2.2, "Reactivity Control and Shutdown System."

The decay heat removal system (DHRS) is designed to remove decay heat during a reactor shutdown. The staff's evaluation of the DHRS adequacy is discussed in Section 6.3 of this SE.

Transient Assumptions

Technical report KP-TR-018-NP, Section A.5, "Pebble Handling and Storage System Malfunction Event," states that the fuel MAR assumes an equilibrium core with an assumed pebble fuel cycle of six passes through the core, with an equal number of pebbles associated with each pass. For each of the six pebble subgroups, the outlet burnup, as determined by a Serpent 2 code calculation, is used to determine the fuel MAR. The steady state or pre-transient TRISO particles are assumed to have retained their full radionuclide inventory and hence the inventory is independent of the number of in-service failures or manufactured defects. Bounding in-service and manufactured failure fractions by cohort are applied as part of the transient MHA fuel release. The transient MHA fuel release is divided into a short- and long-term fuel kernel release phase, and short- and long-term coating release from the various cohorts (exposed kernels, kernel, buffer outer pyrolytic carbon, etc.).

The fuel release uses the MHA kernel temperature/316H temperature curve given in PSAR Figure 13.2-1 as inputs for temperature dependent diffusivities. The short term kernel fractional release, where the reduced diffusion coefficient is less than 0.155, is given by equation 1 in KP-TR-018-NP. The diffusion coefficients are from the staff approved MST TR and the equivalent sphere used with the reduced diffusion coefficient is the kernel radius. This formulation assumes no additional nuclide generation during the course of the event and is appropriate for long lived and stable isotopes where the radionuclide half-life is long, or the isotope is stable. The staff finds this formulation acceptable as it is consistent with accepted state-of-the-art kernel release models in computer codes and literature such as those used in MELCOR and documented in International Atomic Energy Agency (IAEA) TECDOC-1645, "High Temperature Gas Cooled Reactor Fuels and Materials." Though developed for use with fuel in a high temperature gas reactor (HTGR), the same methodology is applicable to the Hermes design due to the similarity of the Hermes fuel kernel and because the same temperature driven radionuclide diffusion mechanism applies.

The long-term kernel release, for a reduced diffusion coefficient greater than 0.155, is given by equation 2 in KP-TR-018. The staff reviewed the cited journal article and IAEA TECDOC-1645, which describes the formulation of equation 2 in KP-TR-018-NP and finds the use of the equation acceptable for the same reasons provided above for the kernel short term releases. Likewise, the staff agrees that the kernel fractional releases can reasonably be predicted based on the use of the approved diffusion coefficients and the expected kernel diameter described in PSAR Section 4.2.1, "Reactor Fuel."

The next barrier to radionuclide release for a TRISO particle are the coating layers. Modeling approximations are determined by the solution of the diffusion equation for a thin-walled spherical shell. The short- and long-term fractional release of the coating layers is described by KP-TR-018-NP equations 3 and 4, respectively. As with the kernel release models, the coating release model uses a reduced diffusion coefficient, the species diffusivities from the MST TR, and the coating layer thickness. The staff finds that the approximate short term release is in good agreement or conservative with respect to the exact solution out to a reduced coefficient of 0.2. For large diffusion times (larger reduced diffusion coefficients), mathematical simplifications lead to the long-term fractional release approximation found in KP-TR-018-NP equation 4. The staff finds that for longer diffusion times, the long-term approximation shows nearly identical results to the exact solution as shown by IAEA TECDOC-1645, Figure 67, "Fractional release calculations based upon the exact solution and the solution for long diffusion times." The staff reviewed the equations used by Kairos and compared them to the formulations in IAEA TECDOC-1645 and found that the equations are equivalent. The staff finds that using KP-TR-018-NP equations 3 and 4 (an established approximate solution of the diffusion equation for a spherical shell geometry), approved diffusion coefficients, and the expected coating thicknesses, yield reasonable coating fractional releases.

To yield a conservative species fractional fuel release, Kairos uses KP-TR-018-NP, equation 5, which assumes the total release of radionuclides from the fuel over the event time interval is released instantaneously. The staff finds this assumption is conservative as it neglects the depletion of radionuclide inventory that would occur due to radioactive decay over the event duration. This assumption effectively creates a constant species concentration challenging the various barrier combinations.

The MHA fuel radionuclide release to the Flibe uses the methodology and radionuclide grouping described in the MST TR. The non-gaseous radionuclides such as salt soluble fluoride species, oxides, and noble metals add to the existing assumed circulating activity available for evaporation from the Flibe surface while the gases and high volatility noble metals that enter the Flibe have near instantaneous release fractions of 100 percent. Fuel radionuclide release into the Flibe and cover gas space was predominantly driven by the IPyC induced SiC failures and the fraction of exposed kernels due to manufacturing defects. Since the MHA assumes no incremental failures, as discussed below, the normal operation IPyC induced SiC and manufactured exposed kernel failure fractions become the primary fuel radionuclide releases. The staff reviewed the value assumed by Kairos and determined the value is reasonable based on the Advanced Gas-Cooled Reactor (AGR) program manufacturing data but notes that the final value will depend on the Kairos final fuel specification.

Kairos stated that TRISO particles have sufficient margin to prevent incremental coating layer failures when subjected to the MHA temperature curve given in PSAR Figure 13.2-1. The assumption that incremental failures are not statistically significant assumes all failure mechanisms are only a function of absolute temperature and not the rate of temperature change. The staff's evaluation of rapid power changes on the potential for incremental failure is discussed in Section 4.2.1 of this SE. The AGR program safety case results, as summarized in topical report EPRI–AR-1(NP)-A, "Uranium Oxycarbide (UCO) Tristructural Isotropic (TRISO)-Coated Particle Fuel Performance," Figure 7-15, "SiC layer and full TRISO failure fractions (upper limit at 95 percent confidence) for combined AGR-1 and AGR-2 UCO results during irradiations and safety tests" show increasing temperatures up to 1600°C yields only small increases in TRISO and SiC failures. This temperature is significantly greater than the maximum 1150 °C used in the MHA for the first 10 minutes, and releases at lower temperatures were negligible based on the data in Reference 1. Therefore, the staff finds that incremental failures will not meaningfully affect the potential fuel radionuclide releases, provided temperatures remain below the MHA temperature values.

In addition to assuming no incremental coating failures are associated with the temperature curve assumed in the MHA, Kairos also assumes that no incremental failures occur due to shutdown element insertion into the pebble bed. This assumption is addressed by the staff's SE of the KP-TR-011-NP-A, "Fuel Qualification Methodology for the Kairos Power Fluoride Salt-Cooled High Temperature Reactor," Revision 2, topical report (fuel qualification TR). The staff's review of the fuel qualification TR found that the pebble testing program is adequate to determine if element insertion causes pebble and TRISO failures. Based on the SE for the fuel qualification TR, the staff finds that it is reasonable to assume no additional failures would be caused by shutdown element insertion but a final determination will be made in the OL review based on the testing results.

Release from the pebble and structural graphite is the other source of radionuclide release to the Flibe. The two radionuclides of interest are tritium and Ar-41. The tritium is generated primarily by neutron interactions with the Flibe coolant as described by Section 3.2.5, "Tritium," of the MST TR. The tritium generation rate is proportional to the assumed core thermal power with Kairos using a bounding 50 MW thermal power level. The staff notes that the bounding 50 MW thermal power will create a higher tritium concentration than the 35 MW thermal licensed power limit and hence is a conservative input.

The uptake of tritium in the pebble and structural graphite is based on the mass transfer rates from the Flibe to the pebble and structural graphite as described in Sections 3.5, "Retention of Tritium in the Graphite Pebble," for pebbles and 5.3.2, "Tritium Retention and Permeation," for structural graphite of the MST TR. Kairos performed graphite inventory calculations for tritium gas (T_2) and tritium fluoride (TF) and determined the highest tritium inventory occurred for an oxidizing salt Flibe chemistry which leads to TF formation.

The diffusion of tritium into the graphite grains assumes a constant concentration and the graphite is assumed to be a perfect absorber. The uptake of tritium in structural graphite is assumed to occur over 10 years with a 100 percent capacity factor which maximizes structural graphite inventory. Tritium inventory is removed from the system by removal of pebbles and radioactive decay. The staff reviewed graphite diffusivities, assumed grain size, the average pebble residence time and the chosen sorption temperatures and found these values were reasonable. The staff finds the methodology used to determine a conservative tritium uptake is reasonable based on the combination of an assumed higher thermal power, the use of approved tritium mass transport models, a perfect graphite adsorber assumption, and the use of reasonable graphite properties (diffusivity and grain size). Based on currently available design information, the calculated tritium inventory is reasonable for use in the release fractions used to determine the MHA tritium release. Final values are design dependent and final tritium inventories will be determined during the OL application review.

Kairos stated there are three intervals associated with the release of tritium from the pebble carbon matrix and structural graphite: (1) initial puff release of all retained tritium from the Flibe and pebble carbon matrix, (2) diffusion from the graphite reflector which is modeled as a function of time and (3) any remaining tritium in the system is transported out by a puff release after 24 hours. The initial tritium puff release from the Flibe is based on an assumed Flibe tritium inventory as discussed below. The pebble inventory puff release is based on the operating time in life corresponding to the maximum combined pebble and structural tritium inventory. The staff finds that selecting the pebble inventory puff released based on the time of maximum combined activities acceptable as it reflects the pebble tritium inventory assuming the worst-case combined tritium release (i.e., the bounding tritium release as a function of time). The conservatism associated with the pebble puff release methodology is based on the use of the MHA kernel temperature in PSAR Figure 13.2-1, and the pebble inventory based on the uptake methodology described above.

The structural graphite tritium inventory is selected using the same methodology as the pebble inventory but instead of a puff release, the structural tritium diffuses out as a function of the bounding MHA Flibe free surface and reflector time/temperature curve (PSAR Figure 13.2-1) assuming the concentration of tritium in the Flibe is reduced to zero once the transient begins. The reduction of the Flibe tritium concentration to zero increases the concentration gradient which maximizes the structural graphite release. The resulting tritium release to the reactor building is a product of the release fractions as a function of time and the initial stored inventory as determined by tritium uptake analysis described above. At 24 hours any remaining structural tritium inventory is puff released to the reactor building. The staff finds the structural release methodology acceptable based on setting the Flibe tritium concentration to zero, a reasonable structural tritium inventory using the uptake methodology, and using a bounding Flibe free surface and reflector temperature versus time curve to determine the release fraction.

The tritium is also contained in the circulating Flibe during normal operation. The Flibe tritium circulating activity chosen is an order of magnitude above that determined by experimental data. In addition, Kairos is proposing a TS LCO on coolant system radionuclide inventory in PSAR Chapter 14, Table 14.1-1, Section 3.3. While the details of the LCO are not provided as part of the CP application, the staff notes a Flibe tritium activity limit will be part of the TSs related to the coolant system that are submitted with the OL application. For the circulating Flibe tritium release the staff finds that a conservative calculational value is assumed based on experimental data and a Flibe tritium TS LCO would ensure the assumed calculated value would not be violated during normal operation. The staff also finds the assumption of a puff release of all tritium (T_2 and TF) in the Flibe is conservative.

As discussed above in the *Initial Conditions Assumptions* subsection, argon-40 in the cover gas entrained in the Flibe will become trapped in graphite pores and become Ar-41 by neutron capture. During the MHA transient, all the predicted Ar-41 within the graphite structures at the initiation of the transient is assumed to be puff released into the building space. The staff notes that this is a conservative release model as all the Ar-41 retained in the graphite is assumed to be released.

Radionuclide release from the Flibe to the gas space occurs by bubble burst and evaporation from the Flibe cover gas interface. The bubble burst is assumed to happen before transient diffusion from the fuel can occur, but the time dependent evaporation releases include the radionuclides from the MHA transient fuel releases to the Flibe. The bubble burst releases all the circulating noble gases and high volatility noble metals into the reactor building at the beginning of the MHA. The aerosol release fraction from the bubble burst is given by KP-TR-018, equation 9, and is a function of E_a, the ratio of the volume of particles generated by a single bubble bursting to the volume of the bubble, and the void fraction. The value of E_a was previously evaluated in the staff's evaluation of the MST TR and the void fraction is assumed based on an estimate of the entrained gas during forced circulation. The normal operation coolant void fraction caused by entrainment is controlled by a proposed TS LCO in Section 3.3 of PSAR Table 14.1-1. Therefore, the staff finds the assumed void fraction acceptable as it will be controlled by a TS LCO. The Flibe evaporative releases use the staff's approved methodology described in the Kairos MST TR and the time/temperature curve for the Flibe free surface and reflector in PSAR Figure 13.2-1.

Kairos stated that the amount of radioactive material released in the MHA transient is maximized by modeling bounding radionuclide evaporation characteristics. The conditions assumed to be conservative evaporation characteristics are the use of relatively high vapor pressure species to model transport, ideal solution behavior, a dilute solution which prevents positive deviations from ideality, and testing to ensure the proposed model is conservative.

The building and reactor vessel headspace are not credited as part of the confinement barriers and are modeled with increased leakage rates. The dispersion model evaluation assumes no radionuclides are filtered by the building. The staff finds a complete turnover of the building air volume in 2 hours is conservative as is not crediting any potential building filtering of radionuclides. This is consistent with assumptions used in regulatory guide (RG) 1.183, "Alternative Radiological Source Terms for Evaluating Design Basis Accidents at Nuclear Power Reactors," Revision 0, for passive release from an open containment or other building for a light water reactor (LWR) fuel handling accident, which also is not a high-pressure release.

The methods used to evaluate radionuclide inventory and transport are consistent with the methodology in the approved MST TR.

PSAR Section 13.2.1 provides a description of the radiological consequence analysis for the MHA and the results that demonstrate that the consequences of the MHA meet the dose reference values in 10 CFR 100.11. The staff's evaluation of Kairos's analysis of the radiological consequences of the MHA and whether the MHA dose results are bounding for other postulated events is discussed in more detail below in Section 13.2 of this SE.

13.1.1.4 **Conclusion**

On the basis of its review, the staff has determined that the level of detail provided on the Hermes MHA demonstrates an adequate design basis for a preliminary design and satisfies the applicable guidance and acceptance criteria of NUREG-1537, Part 2, Section 13, "Accident Analyses," allowing the staff to make the following relevant findings:

- Kairos developed and analyzed an MHA, which is an accident that would release fission products and would have consequences greater than any credible accident. The MHA scenario is not credible, and the combination of bounding conditions analyzed is beyond what is assumed for design basis accidents. The MHA serves as a bounding accident analysis for the Hermes facility.
- Because the assumptions of the scenario are bounding, the doses calculated for the MHA will likely not be exceeded by any accident considered credible.

Based on the above, the staff finds that the preliminary analysis of the MHA, as described in Hermes PSAR Section 13 is sufficient and meets the applicable regulatory requirements and guidance identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Further technical or design information required to complete the safety analysis may reasonably be left for later consideration. The staff will confirm that the final design conforms to the design basis during the evaluation of the FSAR as part of the OL application review.

13.1.2 Insertion of Excess Reactivity

13.1.2.1 Introduction

PSAR Section 13.1.2, “Insertion of Excess Reactivity,” and KP-TR-018-NP discuss the insertion of excess reactivity postulated event. KP-TR-018-NP Section A.1, “Insertion of Excess Reactivity,” provides an example analysis of the insertion of excess reactivity postulated event. The reactivity insertion transient involves a change in core reactivity that adds heat to the primary system. The narrative for the assumed limiting event is given in KP-TR-018-NP Section 3.2.2.2, “Insertion of Excess Reactivity,” and in PSAR Section 13.1.2. The PSAR states that this assumed limiting event bounds other insertion of reactivity events, including events listed in PSAR Section 13.1.2. Kairos also identified this event as one of the bounding fuel performance cases, as stated in KP-TR-018-NP Section 4.5.2.2, “Transient Analysis Methods.”

PSAR Section 13.1.10.7, “Insertion of Excess Reactivity Beyond Rate Assumed in Postulated Events,” describes why rapid reactivity insertions beyond that assumed in PSAR Section 13.1.2 are not considered. The staff evaluated this in Section 13.1.10.7 of this SE.

13.1.2.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of Kairos’s insertion of excess reactivity postulated event are as follows:

- 10 CFR 50.34, “Contents of applications; technical information.” paragraph (a), “Preliminary safety analysis report,”
    - 10 CFR 50.34(a)(4), which requires that each applicant for a construction permit include “[a] preliminary analysis and evaluation of the design and performance of [SSCs] of the facility with the objective of assessing the risk to public health and safety resulting from operation of the facility and including determination of the margins of safety during normal operations and transient conditions anticipated during the life of the facility, and the adequacy of [SSCs], provided for the prevention of accidents and the mitigation of the consequences of accidents…”
- 10 CFR 50.35, “Issuance of construction permits.”
- 10 CFR 50.40, “Common standards.”
- 10 CFR Part 100, “Reactor Site Criteria.”
    - 10 CFR 100.11, “Determination of exclusion area, low population zone, and population center distance,” which provides criteria for the EAB, LPZ, and population center distance for a test reactor for the purposes of site evaluation.

The applicable guidance and acceptance criteria for the evaluation of Hermes’s insertion of excess reactivity postulated event is as follows:

- NUREG-1537, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors” Parts 1 and 2, Section 13, “Accident Analyses”

13.1.2.3 **Technical Evaluation**

PSAR Section 13.1.2.2 states that the RPS is credited with detecting the reactivity insertion and initiating a reactor trip after sensing a high neutron flux or a high coolant temperature. The staff evaluation of the RPS design bases are in Section 7.3 of this SE. PSAR Section 13.1.2.2 states that the reactivity control and shutdown system (RCSS) is credited with shutting down the reactor upon receiving the reactor trip signal. The staff’s evaluation of the RCSS design bases is in Section 4.2.2 of this SE. PSAR Section 13.1.2.2 states that the DHRS and natural circulation within the reactor vessel are credited with removing an adequate amount of decay heat from the reactor to ensure that material design temperatures are not exceeded and that no incremental fuel failures occur due to elevated temperatures. The staff’s evaluations of the design bases of natural circulation in the vessel and the DHRS heat removal function are in SE Sections 4.3, “Reactor Vessel System,” and 6.3, “Decay Heat Removal System,” respectively. The TRISO fuel layers and the Flibe are credited with the radionuclide retention properties described in the staff’s approved MST TR. PSAR Section 13.1.2.2 states that the portion of the reactor vessel that ensures the pebbles in the core remain covered by Flibe is credited with maintaining integrity under the postulated event conditions. The reactor trip for the insertion of excess reactivity postulated event is initiated by a high flux protection signal.

The staff reviewed the transient analysis methodology in PSAR Sections 13.1.2 and 13.1.4 and in KP-TR-018-NP. Kairos Power Systems Analysis Module (KP-SAM) is a code that evaluates the event progression using neutronics parameters from the core design methodology, and KP-BISON is a code that evaluates the fuel performance using the output from KP-SAM. The core design methodology is evaluated in Section 4.5 of this SE. The reactivity coefficients from the core design methodology are conservatively inputted into KP-SAM as their least negative or most positive values, as discussed in KP-TR-018-NP Section 4.5.2.2. KP-TR-018-NP Section 4.1, “Systems Analysis,” states that KP-SAM calculates average power and average temperature distributions throughout the system during the transient. A hot channel factor method is used in KP-SAM to calculate maximum core hot channel outlet temperatures. KP-TR-018-NP Section 4.1.3, “Plant KP-SAM Model,” states that the hot channel factor methodology uses a hot channel factor to account for both radial peaking and neutronic uncertainties and a second hot channel factor to account for bulk flow maldistribution. Staff notes that KP-BISON receives the average power and average temperature distributions of the system during the transient from KP-SAM and the maximum core hot channel outlet temperatures from the hot channel factor methodology as inputs. KP-BISON calculates the peak kernel temperature, fuel failure probabilities, and fission product releases. Technical report KP-TR-017-NP, “KP-FHR Core Design and Analysis Methodology,” Revision 1, Section 5.3.1, “Porous Media Modeling,” states that the Kerntechnischer Ausschuss (KTA) correlation is used to account for pebble bed pressure drop in KP-SAM.

The staff finds that the use of KP-SAM to support the Hermes transient analysis methodology is appropriate for this CP because:

- KP-SAM is capable of modeling a two-dimensional (2D) geometry of Hermes, using a point kinetics model, calculating average power and average temperature distributions throughout the system, calculating temperature profiles within pebbles, and using a decay heat model.

- KP-SAM is based on a modification of the SAM code. The SAM code has been used for transient analyses of pebble bed fluoride salt cooled high temperature reactors as shown in Argonne National Laboratory's report "Development of a Reference Model for Molten-Salt-Cooled Pebble-Bed Reactor Using SAM," dated September 2020, which also showed relevant agreement between STAR–CCM+ and SAM for simulated flow.
- The staff's scoping analyses showed relative agreement with Kairos's preliminary transient analyses provided in the PSAR.

The staff notes that it will review KP-SAM further during its review of a Hermes OL application, as appropriate.

The staff finds that the use of KP-BISON to support the Hermes transient analysis methodology is appropriate for this CP because:

- KP-BISON is capable of calculating the peak kernel temperature, fuel failure probabilities, and fission product releases,
- The staff's scoping analyses showed relative agreement with Kairos's preliminary transient analyses provided in the PSAR.

The staff notes that it will review KP-BISON further during its review of a Hermes OL application, as appropriate.

The staff finds that this transient analysis methodology is acceptable for the preliminary design of Hermes because:

a. Reactivity coefficients are conservatively applied
b. Hot channel factors account for radial peaking, neutronic uncertainties, and bulk flow maldistribution
c. KP-BISON uses conservative inputs to calculate conservative peak kernel temperatures
d. Kairos will perform scoping testing for the pebble bed pressure drop
e. Staff scoping calculations for the insertion of excess reactivity postulated event showed general agreement with Kairos's preliminary example analysis

The staff will review a detailed mapping of all parameters and their uncertainties during its review of a Hermes OL application, as appropriate.

The figures of merit for the Hermes insertion of excess reactivity postulated event are discussed in KP-TR-018-NP, "Postulated Event Methodology," Section 3.4.2, "Postulated Event Figures of Merit," and the figure of merit acceptance criteria are listed in KP-TR-018-NP, Table 3-2, "Derived Figures of Merit and Acceptance Criteria for Postulated Events."

Kairos provided an example analysis of this postulated event in KP-TR-018-NP, Section A.1. KP-TR-018-NP, Table 4-4, "Input Parameters Considered for Postulated Events," discusses Kairos's assumptions for input parameters for the postulated events, including the example analysis in KP-TR-018-NP, Section A.1. Some numerical values for the assumptions are given in KP-TR-018-NP, Section A.1.

PSAR Section 13.1.2 states that the event is initiated by the continuous withdrawal of a control element, which is assumed to initially be fully inserted. PSAR Section 13.1.2.3, "Transient

Assumptions," states that the analysis assumes the highest worth shutdown element remains stuck out during the transient. The analysis assumes conservative trip and actuation delays to account for uncertainty in the signal time associated with the RPS, as discussed in KP-TR-018-NP, Section 4.5.2.1, "Initial Conditions," and Section A.1. As discussed in PSAR Section 13.1.2.3 and KP-TR-018-NP Section 4.5.2.2, Kairos states that a bounding control element maximum withdrawal speed is assumed. Kairos states in KP-TR-018-NP Section 4.5.2.2 that an analysis of the range of reactivity insertion rates will be provided in the FSAR. Bounding conditions are assumed for heat additions and heat removal. Power is assumed to be 102 percent of the rated thermal power to account for power measurement uncertainty, as shown in KP-TR-018-NP Table A1-1, "Initial conditions for Insertion of Excess Reactivity Assumed Bounding Event." Kairos states in KP-TR-018-NP Section 4.5.2.1 that a range of power levels will be analyzed for the FSAR to ensure that reactivity insertions from lower power levels do not unexpectedly challenge a figure of merit. The least negative and most positive reactivity coefficients are assumed in the input to limit feedback that reduces the severity of the reactivity insertion, as discussed in KP-TR-018-NP Section 4.5.2.2. The staff considers this to be conservative at this stage of the design. Normal heat rejection is conservatively assumed to not be available during the event. Heat removal assumes one of the four DHRS trains is unavailable, as discussed in PSAR Section 13.1.2.3.

The staff finds that these assumptions are acceptable at this stage of the design because the analyses; (1) assume that the transient starts at a high power level, which is biased to include uncertainties: (2) assume only three of four DHRS trains are available, which reduces heat removal capabilities and is a conservative, single failure assumption; (3) assume conservative reactivity coefficients, which minimizes negative reactivity feedback; (4) assume trip signal delays, which delays the trip; (5) assume a control element to be fully withdrawn at max speed, which is conservative; (6) assume the highest worth element is stuck out during the transient; (7) assume a concurrent pump trip; and (8) account for appropriate uncertainties.

KP-TR-018-NP, Section 3.2.2.2, lists the evaluated key figures of merit and the analysis results for the figures of merit are shown in KP-TR-018-NP, Figure A1-2, "Figures of Merit During and After Reactivity Insertion." The fuel failure probability and release fractions from the fuel performance analysis are given in KP-TR-018-NP, Table A1-2, "95% Confidence Level Upper Limit on In-Service Failure Fractions for Normal Operation and Reactivity Insertion Postulated Event," and in Table A1-3, "Compromised Fractions for Normal Operation and Reactivity Insertion Postulated Event," respectively. KP-TR-018-NP, Figure A1-2, shows that the maximum reflector temperature slightly exceeds the MHA free surface and graphite temperature limits for a short period of time (i.e., on the order of minutes). The other figures of merit shown on the figure do not exceed the other MHA temperature limits, and no significant probability of TRISO fuel failure was predicted. KP-TR-018-NP, Table 3-2 states that the peak structural graphite temperature-time figure of merit is only generally bounded by the MHA structural graphite temperature-time curve. The staff finds that the short exceedance above the MHA temperature limit for the maximum reflector temperature during the preliminary analysis of the insertion of excess reactivity postulated event is acceptable at this stage of the design because:

- the exceedance is on the order of minutes while the MHA graphite release is considered over a period of 24 hours, as discussed in PSAR Section 13.2.1.1, "Methodology and Inputs," and the exceedance is within the corresponding first X/Q window, as discussed in KP-TR-018-NP Section A.4, "Loss of Forced Circulation," and shown in KP-TR-018-NP Figure A1-2,

- the tritium release from the reflector is limited to diffusion, which is a time-at-temperature release mechanism, and is non-instantaneous, as discussed in PSAR Section 13.2.1.1, “Methodology and Inputs,” and in KP-TR-018-NP Section A.4,
- the TRISO temperature profile and Flibe temperature profiles remain bounded by the MHA limits, as shown in KP-TR-018-NP, Figure A1-2, and the fission product barriers remain intact, and
- no additional TRISO fuel failure was predicted, as shown in KP-TR-018-NP Tables A1-2 and A1-3.

The figures of merit for the insertion of excess reactivity postulated event and the acceptability of their exceedance, the bounding of the insertion of excess reactivity postulated event by the MHA, and the overall radiological consequences of the MHA will be verified at the OL stage.

The staff performed scoping calculations for the supposed bounding insertion of excess reactivity postulated event to compare with Kairos’s preliminary example calculations in KP-TR-018-NP, Section A.1. The staff’s scoping calculations showed reasonable agreement with Kairos’s preliminary calculations. The scoping calculations predicted a lower peak TRISO temperature for both the early and later peaks, predicted a lower final TRISO temperature, and predicted an earlier cooling time.

The staff finds that, based on the preliminary information, the MHA bounds the insertion of excess reactivity because:

- the transient analysis methodology is capable of calculating the necessary figures of merit,
- the assumptions are conservative and uncertainties are accounted for,
- Kairos’s preliminary example analysis predicted sufficiently low fuel failure probability and release fractions and predicted that only the reflector temperature makes an acceptably short deviation above the MHA limit while all other figures of merit remained below the MHA limits, and
- staff scoping calculations for the insertion of excess reactivity postulated event showed general agreement with Kairos’s preliminary example analysis.

As stated in KP-TR-018-NP Section 4.5.2.2, Kairos will provide analyses for a range of insertion rates for insertion of excess reactivity scenarios as part of the OL application. Staff will evaluate the analyses submitted with the OL application to confirm that they cover the events listed in PSAR Section 13.1.2 and remain bounded by the MHA.

13.1.2.4 **Conclusion**

On the basis of its review, the staff has determined that the level of detail provided on the preliminary analysis of the insertion of excess reactivity postulated event is acceptable at this stage of the design and satisfies the applicable guidance and acceptance criteria of NUREG-1537, Part 2, Section 13, “Accident Analysis,” allowing the staff to make the following findings:

- Kairos’s transient methodology is acceptable at this stage of the design.
- The MHA bounds the insertion of excess reactivity postulated event based on the preliminary information.

Based on the above, the staff finds that the preliminary analysis of the insertion of excess reactivity postulated event, as described in PSAR Section 13.1.2, is sufficient and meets the applicable guidance and regulatory requirements identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Further technical or design information required to complete the safety analysis may reasonably be left for later consideration. The staff will confirm that the final design conforms to the design basis during the evaluation of the FSAR as part of the OL application review.

13.1.3 Salt Spills

13.1.3.1 Introduction

A salt spill is a loss of coolant event in which a pipe break or other leak causes Flibe and associated radionuclides to be released into the reactor building. PSAR Section 13.1.3, "Salt Spills," describes the postulated limiting salt spill event. The PSAR states that the loss of salt inventory is detected by the RPS based on low reactor coolant inventory and the reactor is shut down by inserting the shutdown elements. The decay heat removal safety function is accomplished by parasitic losses or the operation of the DHRS and parasitic heat losses. Design features such as the safety related trip function for the primary salt pump (PSP) and anti-siphon features limit the salt inventory loss. Radionuclides are mobilized by aerosol generation from the break, pool splash, evaporation from the Flibe free surface, and air ingress oxidizing the non-wetted graphite surfaces.

13.1.3.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of Hermes salt spill postulated event are as follows:

- 10 CFR 50.34, "Contents of applications; technical information," paragraph (a), "Preliminary safety analysis report."
    - 10 CFR 50.34(a)(4) which requires that each applicant for a CP include "[a] preliminary analysis and evaluation of the design and performance of [SSCs] of the facility with the objective of assessing the risk to public health and safety resulting from operation of the facility and including determination of the margins of safety during normal operations and transient conditions anticipated during the life of the facility, and the adequacy of [SSCs], provided for the prevention of accidents and the mitigation of the consequences of accidents…"
- 10 CFR 50.35, "Issuance of construction permits."
- 10 CFR 50.40, "Common standards."
- 10 CFR Part 100, "Reactor Site Criteria."
    - 10 CFR 100.11, "Determination of exclusion area, low population zone, and population center distance," which provides criteria for the EAB, LPZ, and population center distance for a test reactor for the purposes of site evaluation.

The applicable guidance and acceptance criteria for the evaluation of Hermes's salt spill postulated event is as follows:

- NUREG-1537, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors" Parts 1 and 2, Section 13, "Accident Analyses"

13.1.3.3 **Technical Evaluation**

In PSAR Section 13.1.3, Kairos stated the bounding loss of coolant (spill) event is caused by a hypothetical double-ended guillotine break in the PHTS hot leg piping. The spill is detected by the RPS low-level signal, and the reactor and PSP are tripped. Three trains of the DHRS are assumed to remove the decay heat. Passive anti-siphon design features on the hot and cold legs minimize the amount of salt spilled to ensure sufficient inventory for in-vessel natural circulation, ensure the fuel remains covered, and limit the heat up and radionuclide release. The release to the reactor building is largely driven by the mass discharged, the resulting spill surface area, in-vessel Flibe free surface area, and oxidation of any exposed graphite. The mass of spilled Flibe will depend on a variety of factors including the break-size, the differential pressure between the vessel and building, fluid velocity out of the break, and time delays associated with the PSP trip and coast down. The staff agrees with Kairos's determination of the important factors which contribute to determining a conservative spill as shown in KP-TR-018-NP, Table A3-1, "Key Input Parameters."

Because both the primary side heat up and radionuclide release to the reactor building are a function of the spilled salt mass, the staff requested an estimate of the spilled mass and its effect on the heat up of structures for comparison to the MHA time/temperature curve in PSAR Figure 13.2-1, during the staff's audit of information supporting PSAR Chapter 13 and KP-TR-018-NP. In response to the staff's request, Kairos provided a response in Enclosure 1 to a letter dated August 31, 2022, which included an estimated maximum mass of salt loss and the associated loss of thermal capacity relative to the other radionuclide retaining structures (e.g., graphite reflector, pebbles, and steel). The staff notes that all the information provided in Enclosure 1 is proprietary and not available to the public. Based on the staff's review of the provided information on the salt spill and comparison to the assumptions for the MHA, the staff finds that the MHA time/temperature curve will bound the salt spill event-specific fuel, structural, and Flibe temperatures because the estimated Flibe mass spilled in the Kairos response is consistent with what is shown in KP-TR-018-NP Table A3-3, "Calculated Values for the Salt Spill Event" and will not cause a significant transient heat up.

Kairos assumes the break-discharged liquid jet breaks up independent of the falling height. The staff notes that this assumption maximizes aerosol generation particles below a specific cutoff diameter are considered aerosols that are small enough to be suspended in the air and are available for transport through the reactor building. Particles above the cutoff diameter form the liquid pool used in the evaporation evaluation. The average particle diameter is determined by a correlation which is a function of the break loss coefficient and the differential pressure between the vessel and the reactor building. From the average particle diameter, a distribution of particle sizes is assumed and the fraction of particles below the cutoff diameter is determined. The mass of the jet-induced aerosol particles is the product of the total break mass and the aerosol fraction. The staff notes that assuming the liquid jet breaks up is conservative as it maximizes aerosol generation, and because the methodology is consistent with the methodology documented in the staff approved MST TR.

Kairos assumes that the other source of aerosol generation is through pool splashing, when the jet or droplets fall into an accumulated Flibe pool which entrains air into the pool. The entrained air forms bubbles which can burst creating fine aerosol particles. The flow rate of entrained air is an empirical correlation which is a function of the break flow rate, the Froude number for the Flibe flow, droplet falling height, and droplet diameter. The amount of aerosol generated by pool bubble bursting is determined by the product of the calculated entrained air flow rate and a conservative entrainment coefficient. The staff notes that the methodology documented in

KP-TR-018-NP for pool splash aerosol generation is consistent with that provided in the staff approved MST TR and hence acceptable. As provided in KP-TR-018-NP, Table A3-3, the fraction of aerosolization through splashing is significantly less than the jet breakup aerosolization which is expected based on the break jet velocity.

Kairos assumes another radionuclide release mechanism to be through evaporation from the Flibe pool after the discharge is complete. The evaporative release from the liquid Flibe is the same method as described in the staff approved MST TR. The evaporation release terminates when the Flibe surface freezes due to heat transfer to the surrounding environment. The Flibe chemical form for the release from the pool is assumed to remain the same as that discharged to the pool since the reactor building compartment where the spill occurs is designed to prevent water or concrete interactions. The heat transfer between the liquid and the frozen Flibe is determined by the Globe-Dropkin correlation while the air side heat transfer is based on the McAdams correlation. The time to freeze is dependent on the spill surface-to-volume ratio which is a function of the final reactor building compartment designs or development of a generic bounding surface-to-geometry study. The staff finds that using the Globe-Dropkin correlation is reasonable to determine the heat transferred by natural convention in a non-heated pool at this state of the evaluation. This correlation is applicable to heat transfer for a low Prandtl number fluid of molten metal with the rapid formation of a solidified layer and has been used in the COUPLE code which models the heat transfer associated with a molten metal layer following an LWR severe accident. Likewise, the McAdams correlation is widely used to determine the heat transfer by convection from a horizontal pool (W. H. McAdams, Heat Transmission, Third Edition, New York, McGraw-Hill, 1954). The staff does note that the time to pool freeze and, hence, the evaporation releases, are dependent on the spill geometry which is based on the final reactor building design.

Kairos assumes that the final release radionuclide mechanism for the salt spill is through the oxidation of graphite and the associated release of tritium from the exposed graphite due to the Flibe inventory loss. In the MHA analysis, the entire tritium inventory in the pebbles is puff released at the beginning of the event and the tritium inventory in the structural graphite is released over a 24-hour period. For the salt spill analysis, the pebbles remain covered and hence do not release tritium due to oxidization; the graphite structural area which remains Flibe wetted is expected to have temperatures below that assumed in the MHA. If structural graphite is exposed to air due to the spill, graphite oxidation will occur which adds a release not explicitly evaluated in the MHA. The staff notes that if any surface area of the structural graphite is exposed, this will be a function of the final design and will therefore be evaluated in the OL application.

KP-TR-018-NP, Table A3-3, provides an example of the break Flibe mass and volume, fraction of jet breakup, and spilling aerosolization fraction for a double-ended guillotine hot leg break. The staff notes that no dose calculations are provided in the PSAR or KP-TR-018-NP and are not necessary for the CP review. Detailed comparisons of doses for postulated events are expected to be provided as part of the OL application.

PSAR Table 13.1-1, “Acceptance Criteria for Figures of Merit,” provides the acceptance criteria for each applicable event. The intent is that if the event analysis provided in the OL application meets the acceptance criteria, then the MHA is expected to remain bounding for the event. The staff evaluated each figure of merit and associated acceptance criteria and concluded that the acceptance criteria are reasonable and, if met, the MHA will bound the other credible events.

As discussed above, the staff notes that the salt spill event is expected to have a mild heat up and figures of merit which are temperature driven, such as peak TRISO temperature-time, TRISO failure probability, peak Flibe cover gas interfacial temperature, peak structural graphite temperature-time, and peak carbon matrix temperature-time, will all be bounded by the MHA temperature-time curve. Other design features, such as the PSP trip and anti-siphon design feature, limit the spilled salt amount thereby ensuring the fuel remains covered, limiting aerosol generation, spilled pool evaporation, and structural graphite oxidation. Finally, volatile product formation from Flibe chemical reactions with water and construction materials is limited by the reactor building design.

While the MHA does not include all the same release mechanisms as the salt spill (e.g., break aerosol generation and pool evaporation release), the staff finds that the MHA releases remain bounding because: (1) the MHA assumes a bounding temperature transient and a maximized fuel release term, while the salt spill transient fuel release is expected to be negligible based on a mild transient heat up and more realistic modeling of the pre-transient fuel radionuclide diffusion; (2) the tritium released due to the higher MHA temperatures is expected to be larger than the tritium release using salt spill event-specific temperatures and the additional tritium release due to oxidation of any exposed structural graphite; and, 3) while the MHA and salt spill event both use the same assumption for the initial Flibe circulating activity (upper bound), the MHA Flibe in-vessel free surface area temperature assumption is higher, leading to a higher overall Flibe evaporation release.

13.1.3.4 **Conclusion**

Based on the above, the staff finds that the preliminary analysis of the postulated salt spill event, as described in PSAR Chapter 13, is sufficient and meets the applicable guidance and regulatory requirements identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Based on the staff's review of the methodologies used to calculate break aerosol generation and spilled pool evaporation, the lower tritium releases due to graphite oxidation as compared to the MHA, and the sample transient results for the salt spill event in KP-TR-018-NP, Section A.3, "Salt Spill," the staff finds that, based on the preliminary information, the results of the MHA analysis bound the releases associated with the salt spill event.

Additionally, the staff finds that the information in PSAR Table 13.1-1, if met in the FSAR analysis, will ensure that the MHA analysis results remain bounding for the salt spill event. Further technical or design information required to complete the safety analysis may reasonably be left for later consideration. The staff will confirm that the final design conforms to the design basis during the evaluation of the FSAR as part of the OL application review.

13.1.4 Loss of Forced Circulation

13.1.4.1 **Introduction**

PSAR Section 13.1.4, "Loss of Forced Circulation," and KP-TR-018-NP, Sections 3.2.2.4 "Loss of Forced Circulation," and 4.5.3, "Loss of Forced Circulation," discuss the loss of forced circulation postulated event. KP-TR-018-NP Section A.4 provides example analyses of the loss of forced circulation postulated event. Two bounding, transient events, overheating and overcooling, are analyzed for the loss of forced circulation postulated event to evaluate long-term passive cooling performance. The postulated overheating event bounds the consequence from overheating due to a loss of forced circulation, and the postulated overcooling event bounds the consequence from freezing in the downcomer due to a loss of forced circulation. Kairos states in PSAR Section 13.1.4 that an assumed limiting loss of forced circulation event bounds other loss of forced circulation events, including events listed in PSAR Section 13.1.4.

13.1.4.2 **Regulatory Evaluation**

The applicable regulatory requirements for the evaluation of the Hermes loss of forced circulation postulated event are as follows:

- 10 CFR 50.34, “Contents of applications; technical information,” paragraph (a), “Preliminary safety analysis report.”
    - 10 CFR 50.34(a)(4), which requires that each applicant for a CP include “[a] preliminary analysis and evaluation of the design and performance of [SSCs] of the facility with the objective of assessing the risk to public health and safety resulting from operation of the facility and including determination of the margins of safety during normal operations and transient conditions anticipated during the life of the facility, and the adequacy of [SSCs], provided for the prevention of accidents and the mitigation of the consequences of accidents…”
- 10 CFR 50.35, “Issuance of construction permits.”
- 10 CFR 50.40, “Common standards.”
- 10 CFR Part 100, “Reactor Site Criteria.”
    - 10 CFR 100.11, “Determination of exclusion area, low population zone, and population center distance,” which provides criteria for the EAB, LPZ, and population center distance for a test reactor for the purposes of site evaluation

The applicable guidance and acceptance criteria for the evaluation of the Hermes loss of forced circulation postulated event is as follows:

- NUREG-1537, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors” Parts 1 and 2, Section 13, “Accident Analyses.”

13.1.4.3 **Technical Evaluation**

PSAR Section 13.1.4.2 states that the RPS is credited with initiating a reactor trip. The staff evaluation of the RPS design bases are in Section 7.3 of this SE. PSAR Section 13.1.4.2 states that the RCSS is credited with shutting down the reactor upon receiving the trip signal. The staff evaluation of the RCSS design bases is in Section 4.2.2 of this SE. PSAR Section 13.1.4.2 states that the DHRS and natural circulation within the reactor vessel are credited with removing an adequate amount of decay heat from the reactor to ensure that material design temperatures are not exceeded and that no incremental fuel failures occur due to elevated temperatures. The staff evaluation of the design bases of natural circulation in the reactor vessel and the DHRS heat removal function are in Sections 4.3 and 6.3 of this SE, respectively. PSAR Section 13.1.4.2 states that the TRISO fuel layers and the Flibe are credited with the radionuclide retention properties described in the MST TR. PSAR Section 13.1.4.2 states that the reactor vessel integrity is maintained by keeping the vessel temperatures below the design limit which ensures the pebbles in the core remain covered by Flibe under the postulated event conditions.

The evaluation of the transient analysis methodology used to analyze the loss of forced circulation events is in Section 13.1.2 of this SE. The figures of merit for the Hermes loss of forced circulation event postulated event are discussed in KP-TR-018-NP, Section 3.4.2, and the figure of merit acceptance criteria are listed in KP-TR-018-NP, Table 3-2. In KP-TR-018-NP Section 3.2.2.4, Kairos states that the overheating event considers the limiting case to analyze the peak vessel and core barrel temperatures to prevent vessel failure and maintain coolable geometry, and the overcooling event analyzes coolant freeze prevention in the downcomer.

Kairos provided an example analysis of these postulated events in KP-TR-018-NP Section A.4. KP-TR-018-NP Table 4-4 discusses Kairos's assumptions for input parameters for the postulated events, including the example analyses in KP-TR-018-NP Section A.4. The staff notes that some numerical values for the assumptions are given in KP-TR-018-NP Section A.4.

The staff notes that Kairos's analyses assume conservative trip and actuation delays to account for uncertainty in the signal time associated with the RPS. PSAR Section 13.1.4.3 states that the analysis assumes the highest worth element is stuck out during the transient. Both the fresh core and the equilibrium core were considered as limiting conditions for the overheating event, as shown in KP-TR-018-NP Table A4-1, "Initial Conditions for Loss of Forced Circulation Overheating Bounding Event." Flibe heat capacity is assumed to be 95 percent of its value to account for uncertainty in the heat capacity of Flibe, as shown in KP-TR-018-NP Table A4-1.

The staff notes that, for the overheating event, the PSP is conservatively assumed to stop instantly upon initiation of the event, as discussed in KP-TR-018-NP Section 4.5.3.2. Overheating is conservatively assumed to initiate from 102 percent reactor power, as shown in KP-TR-018-NP Table A4-1 and discussed in KP-TR-018-NP Section 4.5.3.1. The reactivity coefficients from the neutronics core design methodology are conservatively input into KP-SAM as 75 percent of their magnitude, as discussed in KP-TR-018-NP Section 4.5.3.2 and shown in KP-TR-018-NP Table A4-1. Normal heat rejection is conservatively assumed to not be available during the event. Heat removal assumes one of the four DHRS trains is unavailable, as discussed in PSAR Section 13.1.4.3 and KP-TR-018-NP Section A.4 and shown in KP-TR-018-NP Table A4-1. The staff finds that the assumptions for the overheating event are acceptable at this stage of the design because the analyses: (1) assume that the event starts at a high power level, which is biased to include uncertainties; (2) assume only three of four DHRS trains are available, which reduces heat removal capabilities; (3) assume conservative reactivity coefficients, which minimizes negative reactivity feedback; (4) assume trip signal delays, which delays the trip; (5) assume the PSP stops immediately; and (6) assume the highest worth element is stuck out during the transient.

KP-TR-018-NP Section A.4 states that the overcooling event is initiated by a control element insertion. KP-TR-018-NP Section A.4 states that the PSP is assumed to coast down normally. The reactivity coefficients from the core design methodology are input into KP-SAM as their nominal values, as shown in KP-TR-018-NP Table A4-2, "Initial Conditions for Loss of Forced Circulation Overcooling Assumed Bounding Event." Overcooling is assumed to initiate from 98 percent power, as shown in KP-TR-018-NP Table A4-2. Staff notes that DHRS capacity is conservatively modeled at 100 percent capacity, as shown in KP-TR-018-NP Table A4-2. The staff finds the above assumptions for the overcooling event are acceptable at this stage of the design because the analyses: (1) assume that it starts at a lower power level, which is biased to include uncertainties; (2) assume all four DHRS trains are available, which conservatively models heat removal capabilities; and (3) assume the PSP coasts down instead of stopping immediately.

KP-TR-018-NP, Section 3.2.2.4, lists the evaluated key figures of merit for both events. The analysis results for the figures of merit for the overheating event are shown in KP-TR-018-NP, Figure A4-1, “Figures of Merit – Overheating,” and the analysis results for the figures of merit for the overcooling event are shown in KP-TR-018-NP, Figure A4-2, “Figures of Merit – Overcooling.” The fuel failure probability and release fractions from the fuel performance analysis are given in KP-TR-018-NP, Table A4-5, “95 percent Confidence Level Upper Limit on In-Service Failure Fractions for Normal Operation and Loss of Forced Circulation Postulated Events,” and in Table A4-6, “Compromised Fractions for Normal Operation and Loss of Forced Circulation Postulated Event,” respectively. KP-TR-018-NP Figure A4-1 shows that the maximum reflector temperature and upper plenum temperature slightly exceed the MHA free surface and graphite temperature limits for a short period of time during the postulated overheating event. The other figures of merit shown on the figure do not exceed the other MHA temperature limits, and no significant probability of TRISO fuel failure was predicted. KP-TR-018-NP Table 3-2 states that the peak structural graphite temperature-time figure of merit is only generally bounded by the MHA structural graphite temperature-time curve. The staff finds that the short exceedances above the MHA temperature limits for the maximum reflector temperature and upper plenum temperature during the preliminary analysis of the overheating postulated event are acceptable at this stage of the designfor the following reasons.

- The exceedances of the maximum reflector temperature and upper plenum temperature are on the order of minutes while the release from graphite is considered over a period of 24 hours and the release from Flibe is considered over a period of more than 30 days, as discussed in PSAR Section 13.2.1.1, “Methodology and Inputs,” and the exceedances are within the first X/Q window of the reflector, as discussed in KP-TR-018-NP Section A.4 and shown in KP-TR-018-NP Figure A4-1.
- The tritium release from the reflector is limited to diffusion, which is a time-at-temperature release mechanism, and is non-instantaneous, as discussed in PSAR Section 13.2.1.1, “Methodology and Inputs,” and in KP-TR-018-NP Section A.4.
- The release from Flibe is limited to diffusion and evaporation, which are both time-at-temperature release mechanisms, and is non-instantaneous, as discussed in PSAR Section 13.2.1.1, “Methodology and Inputs,” and in KP-TR-018-NP Section A.4.
- The TRISO temperature profile remains bounded by the MHA maximum TRISO temperature limit, as shown in KP-TR-018-NP Figure A4-1, and the fission product barriers remain intact.
- No additional TRISO fuel failure was predicted, as shown in KP-TR-018-NP Tables A4-5 and A4-6.

Figure A4-2 shows that the minimum reactor vessel inner surface temperature is above the Flibe freezing temperature, which shows that Flibe does not freeze in the downcomer during the overcooling postulated event. The other figures of merit shown on the figure do not deviate from the MHA limits, and no significant probability of TRISO fuel failure was predicted. The figures of merit for the postulated loss of forced circulation event and the acceptability of their exceedance, the bounding of the loss of forced circulation postulated event by the MHA, and the overall radiological consequences of the MHA will be verified at the OL stage.

The staff performed scoping calculations for the assumed bounding loss of forced circulation postulated events to compare with Kairos’s preliminary example calculations in KP-TR-018-NP, Section A.4. The staff scoping calculations showed reasonable agreement with Kairos’s preliminary calculation. The staff scoping calculations for the overheating event predicted a lower peak TRISO temperature for both the early and later peaks, predicted a lower final TRISO temperature, and predicted an earlier cooling time. The staff scoping calculations for the overcooling event predicted a similar trend for the minimum reactor vessel inner surface temperature, which remained above the Flibe freezing temperature.

The staff finds that, based on the preliminary information, the MHA bounds the loss of forced circulation postulated event because:.

- The transient analysis methodology is capable of calculating the necessary figures of merit.
- The assumptions are conservative and uncertainties are accounted for.
- The staff evaluated Kairos's fuel performance methodology in Section 4.2 of this SE, and noted that Kairos's preliminary example analyses predicted fuel failure probabilities and release fractions for both events, which will be evaluated later for the OL application.
- Kairos's preliminary example analyses predicted that, for the overheating event, only the reflector temperature and upper plenum temperature make an acceptably short deviation above the MHA limit while all other figures of merit remained below the MHA limits, which will be evaluated later for the OL.
- Kairos's preliminary example analyses predicted that, for the overcooling event, Flibe does not freeze, which also will be evaluated later for the OL application.
- The staff scoping calculations for the loss of forced circulation postulated event showed general agreement with Kairos's preliminary example analysis.

Kairos stated in KP-TR-018-NP, Section 4.5.3.1, that sensitivity studies must be performed to ensure that loss of forced circulation events from lower power levels do not unexpectedly challenge figures of merit. As stated in KP-TR-018-NP, Section 3.2.2.4, Kairos will provide analyses for a spectrum of reactor decay heat levels and operating power levels for which staff has found will all be bounded by the MHA. Based on the staff's review , the staff expects that the analyses for a spectrum of reactor decay heat levels and operating power levels that will be submitted for the OL application will cover the events listed PSAR Section 13.1.4 and will remain bounded by the MHA.

13.1.4.4 **Conclusion**

On the basis of its review, the staff has determined that the level of detail provided on the preliminary analyses of the loss of forced circulation postulated events is acceptable at this stage of the design and satisfies the applicable acceptance criteria of NUREG-1537, Part 2, Section 13, "Accident Analysis." Thus, the staff finds that, based on the preliminary information, the MHA bounds the loss of forced circulation postulated events.

Based on the above, the staff finds that the preliminary analyses of the loss of forced circulation postulated events, as described in PSAR Section 13.1.4, are sufficient and meet the applicable regulatory requirements and guidance identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Further technical or design information required to complete the safety analysis may reasonably be left for later consideration. The staff will confirm that the final design conforms to the design basis during the evaluation of the FSAR as part of the OL application review.

13.1.5 Mishandling or Malfunction of Pebble Handling and Storage System

13.1.5.1 Introduction

Section 13.1.5 of the PSAR describes the preliminary evaluation of the category of postulated events involving a mishandling or malfunction of the Pebble Handling and Storage System (PHSS). As assumed by Kairos, the limiting postulated event for this category of events is a break in a fuel transfer line during extraction, resulting in a spill of pebbles to the floor of the room.

13.1.5.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of the Hermes's PHSS postulated event are as follows:

- 10 CFR 50.34, "Contents of applications; technical information," paragraph (a), "Preliminary safety analysis report."
  - 10 CFR 50.34(a)(4), which requires that each applicant for a CP include "[a] preliminary analysis and evaluation of the design and performance of [SSCs] of the facility with the objective of assessing the risk to public health and safety resulting from operation of the facility and including determination of the margins of safety during normal operations and transient conditions anticipated during the life of the facility, and the adequacy of [SSCs], provided for the prevention of accidents and the mitigation of the consequences of accidents…"
- 10 CFR 50.35, "Issuance of construction permits."
- 10 CFR 50.40, "Common standards."
- 10 CFR Part 100, "Reactor Site Criteria."
  - 10 CFR 100.11, "Determination of exclusion area, low population zone, and population center distance," which provides criteria for the EAB, LPZ, and population center distance for a test reactor for the purposes of site evaluation.

The applicable guidance for the evaluation of the PHSS postulated event is as follows:

- NUREG-1537, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors" Parts 1 and 2, Section 13, "Accident Analyses."

13.1.5.3 Technical Evaluation

Kairos stated that the design objective is to limit the total airborne release from the PHSS to below that assumed in the MHA when accounting for the unique PHSS event MAR contributions. The unique PHSS event contributors to airborne release include ex-vessel pebble oxidation and graphite dust.

Kairos stated that the limiting PHSS malfunction event is the PHSS transfer line break when pebbles are being removed form the core. Other types of PHSS malfunction events such as the loss of PHSS cooling and grinding of a pebble within the pebble handling machine are limited by specific design specifications, as noted in Section 3.2.2.5, "Pebble Handling and Storage System Malfunction," of KP-TR-018-NP. Kairos stated that for a PHSS transfer line break, criticality safety concerns are precluded by the low fissile inventory of the spilled pebbles due to the safety related PHSS trip Ih stops pebble movement into the PHSS. The heat removal function for both the spilled pebbles in the room and the pebbles that remain in the PHSS is satisfied by passive heat transfer to the surrounding room. The spilled pebbles are assumed to remain intact based on the pebble impact criteria established in the fuel qualification TR and the PHSS design which maintains impact forces below these limits. Heat up of the pebbles remaining in the PHSS mobilizes any Flibe accumulated in the PHSS piping. In addition to the spilled pebbles, any exposed pebbles remaining in the PHSS undergo oxidation and the air ingress oxidizes any exposed structural graphite due to the loss of vessel Flibe inventory.

Section 4.5.4.1, "Initial Conditions," of KP-TR-018-NP describes the biasing of the assumptions for the initial conditions of the event to maximize the amount of MAR released, such as assuming the break occurs in the longest pebble transfer line and a delay time before trip of the pebble handing machine to involve more pebbles in the event. The limiting PHSS line break assumes pebbles exposed to air, those spilled and those remaining in the PHSS, have the highest burnup and hence have the largest MAR and highest pebble surface temperature. The TRISO particle fission product inventory is determined by calculation with the Serpent 2 computer code and the fission product retention in the pebble matrix used to determine the pebble MAR for the oxidation and graphite dust activity release is calculated using KP-BISON.

Section 4.5.4.2, "Transient Analysis Methods," of KP-TR-018-NP states that pebbles exposed to air will oxidize and release radionuclides from the pebble matrix proportional to oxidation mass loss based on the expected surface temperature remaining within the kinetics-controlled regime (regime I). The oxidation rate correlation used is given by Equation 23 in KP-TR-018-NP and was chosen by Kairos based on the similarity of the graphite to that of the Hermes pebbles. Equation 23 of KP-TR-018-NP cites Reference 28 (X. Zhou, et. al., "Oxidation Behavior of Matrix Graphite and Its Effect on Compressive Strength," Science and Technology of Nuclear Installations, August 2017) where the authors develop an air oxidation correlation for newly developed A3-3 pebble matrix graphite for temperatures between 500 to 950 ^{o}C. Based on this reference, the staff finds this correlation reasonable for estimating the oxidation mass loss but notes that testing on the Kairos specific pebble matrix, in the expected temperature regime, will be performed as described in Section 3.6.4, "Material Compatibility," of the fuel qualification TR. As stated in the fuel qualification TR Section 3.6.4, "[t]he experiment data will be used to either validate an existing correlation for carbon matrix oxidation or develop a new correlation as appropriate." The staff finds the use of Reference 28 reasonable based on the correlation that was developed for new A3-3 matrix graphite for a range of temperatures (500-950 ^{o}C) which bound the expected conditions. However, the acceptability of the final pebble oxidation correlation will be determined as part of the OL application review based on the Kairos testing described in the fuel qualification TR.

The activity released due to the oxidation of the pebble matrix is a function of the radionuclides which are released from the TRISO particles (pebble activity by isotope) and the number of pebbles exposed to air. The pebble activity is a function of the manufacturing defects, in-service failures, and dispersed uranium. Kairos assumes the pebble activity is based on the fraction of exposed kernels (manufactured and complete TRISO failures), SiC coating failures, and dispersed uranium. The staff finds the assumed fraction of exposed kernels, SiC coating failures, and dispersed uranium is reasonable based on the AGR program values and specification.

Because of the methodology assumptions associated with: (1) the number of pebbles exposed to air; (2) all the pebbles having the maximum burnup (highest MAR); (3) a reasonable pebble matrix oxidation rate; and (4) the failure of the most important TRISO fission product barriers; the staff finds the pebble oxidation release activity to be conservatively estimated.

Graphite dust is generated by pebble interactions within the core and with the pebble handling system. Kairos's PHSS analysis assumes that graphite dust released during a PHSS line break is from the cover gas space and only generated due to pebble handling. During a PHSS line break, the depressurization will cause graphite dust accumulated in the PHSS to be expelled from the system, thereby dispersing radioactive graphite dust into the reactor building. The activity associated with graphite dust release is a function of the activity per unit mass and mass released into the room. The activity per unit mass is assumed to equal the concentration in the graphite matrix and corresponds to the highest pebble MAR loading as described above for the oxidation methodology. Since the dust in the PHSS line accumulates over the PHSS operating lifetime, credit is taken for radioactive decay of the various isotopes contained within graphite. The staff finds this methodology acceptable as it conservatively assumes the pebbles transiting the system have the highest MAR loading, whereas the actual dust will be from a range of pebble histories which will lead to a lower overall dust MAR.

The activity of graphite dust as function of the operating time is given by Equation 28 in KP-TR-018-NP. To solve KP-TR-018-NP, Equation 28, the dust mass generation rate must be determined utilizing KP-TR-018-NP, Equation 27, which is a function of the specific wear rate and operating time. The staff notes that the formulation of Equation 27 assumes the wear is only caused by the force related to the pebble mass and does not include any wear generated by the PHSS (e.g., removal screw, inspection handling). The specific wear rate per unit distance is estimated for the illustrative analysis in KP-TR-018-NP, Section A.5, but the staff notes that pebble wear rate tests will be performed as described in the fuel qualification TR, Section 3.6.2, "Tribology." As stated in the fuel qualification TR, Section 3.6.2, the wear rate for pebble-pebble, pebble graphite (structural) and pebble-metallic-structural (316H) interactions over a range of contact forces, in Flibe and argon, from room temperature to 700 ^{o}C depending on the test environment will be determined. The staff finds the dust generation rate method is reasonably based on the current state of the PHSS design but notes that forces other than the mass of the pebble on the wear surface may need to be considered once the final PHSS design is completed.

The amount of graphite dust resuspended is based on the MELCOR model discussed in the staff approved MST TR, which uses a critical aerosol diameter of 1 micron, above which particles will resuspend, and the upper diameter limit of 50 microns above which aerosols will deposit near the break. The staff finds these upper limit and cutoff diameters reasonable based on the staff's review of the MST TR (see Section 7.3.3.2.2, "Flibe Dust," of the MST TR).

Based on the discussion above, the staff finds the PHSS event methodology to determine (1) the pebble matrix radionuclide concentrations, (2) pebble matrix oxidation mass loss, (3) the generation of graphite dust in the PHSS, and (4) the mobilization of the dust based on aerosol size, is reasonably able to predict the releases associated with a PHSS line break.

Any Flibe potentially spilled as a result of a PHSS event may interact with the surrounding structures. To preclude Flibe chemical interactions with water and construction materials, Kairos assumes the use of appropriate design features to limit creation of more volatile chemical species. Likewise, Kairos assumes pebble-water oxidation is precluded by the use of appropriate design features so only pebble-air oxidation is evaluated. While these interactions are assumed to be precluded by the design, final confirmation of this assumption is dependent on final design as described in the FSAR for the OL application.

The staff notes that there are three release mechanisms in the PHSS event which are not accounted for in the MHA analysis: the oxidation of pebbles exposed to air, graphite dust mobilized to the reactor building, and evaporation of any Flibe discharge. Based on information provided in KP-TR-018-NP, Section A.5, two of three of these event contributors have relatively low activities compared to those released in the MHA (e.g., released tritium activity). The third release not accounted for in the MHA is the spilled Flibe mass which the staff expects to be low based on the low driving force (pressure differential) and available PHSS Flibe inventory as large amounts of frozen Flibe would likely impede pebble movement. The staff notes that lower Flibe mass loss associated with the PHSS event is also expected to lead to less, if any, oxidation of structural graphite when compared to the salt spill event and this release is therefore considered low. The staff notes that the assumption of little to no structural graphite oxidation is reasonable at this stage of the design, but the final design of the PHSS and its interface with the graphite internals will need to be considered during the OL application review. KP-TR-018-NP, Section 3.4.2.11, “Amount of materials at risk released,” states that the PHSS malfunction event includes two MAR release pathways that are not included in the MHA: graphite dust and Flibe mobilized from the PHSS. However, the event figures of merit for the PHSS malfunction event are developed based on limiting the dose from these pathways to below a derived limit to ensure that these release pathways do not cause the radiological consequences of the postulated PHSS malfunction event to exceed those of the MHA.

While the MHA does not include all the same release mechanisms as the PHSS, the staff finds the MHA releases remain bounding because: (1) the MHA assumes a bounding temperature and no pre-transient fuel radionuclide diffusion to maximize the fuel release term, while the PHSS event transient in-vessel fuel release is assumed to be negligible as no discernible transient heat up is expected from the Flibe loss; (2) the tritium released from both pebbles and structural graphite is expected to be higher in the MHA due to the higher assumed MHA temperatures than the tritium release using event specific temperatures and the additional tritium release due to oxidation of any exposed pebbles; (3) while the MHA and PHSS event both use the same assumption for the initial Flibe circulating activity (upper bound), the MHA Flibe in-vessel free surface area temperature assumption is higher, leading to a higher evaporation release which is expected to bound the spilled Flibe aerosol and evaporation release caused by the break. Other PHSS event assumptions such as Ar-41 release, the puff release of high volatility noble metals and gases in the Flibe, and aerosol generation caused by the in-vessel bubble burst are the same as the MHA.

13.1.5.4 **Conclusion**

The staff finds that the level of detail provided on the postulated PHSS event is consistent with the applicable guidance and acceptance criteria in NUREG-1537, Parts 1 and 2, Section 13, “Accident Analysis,” and demonstrates an adequate design basis for a preliminary design. The staff finds that the preliminary analysis of the postulated PHSS event, as described in Hermes PSAR Chapter 13, is sufficient and meets the applicable regulatory requirements and guidance identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. The staff finds, based on its review of the methodologies used to calculate oxidation and graphite dust releases, and the sample PHSS event analysis in KP-TR-018-NP, Section A.5, that the MHA analysis bounds the PHSS event releases. The staff finds that the figures of merit for the PHSS malfunction event will ensure that the MHA analysis results remain bounding for the PHSS event. Further technical or design information required to complete the safety analysis may reasonably be left for later consideration during the OL application. The staff will confirm that the final design conforms to the design basis during the evaluation of the FSAR as part of the OL application review.

13.1.6 Radioactive Release from a Subsystem or Component

13.1.6.1 Introduction

Section 13.1.6 of the PSAR describes the preliminary evaluation of the category of postulated events with radioactive release from a subsystem or component due to the failure of a system or component that contains radioactive material. As assumed by Kairos, the limiting event for this category of events is a seismic event that results in the failure of all systems containing radioactive material that are not qualified to maintain structural integrity in a design basis earthquake.

13.1.6.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of Hermes postulated seismic event leading to radioactive release from a subsystem or component are as follows:

- 10 CFR 50.34, “Contents of applications; technical information,” paragraph (a), “Preliminary safety analysis report.”
    - 10 CFR 50.34(a)(4), which requires that each applicant for a CP include “[a] preliminary analysis and evaluation of the design and performance of [SSCs] of the facility with the objective of assessing the risk to public health and safety resulting from operation of the facility and including determination of the margins of safety during normal operations and transient conditions anticipated during the life of the facility, and the adequacy of [SSCs], provided for the prevention of accidents and the mitigation of the consequences of accidents…”
- 10 CFR 50.35, “Issuance of construction permits.”
- 10 CFR 50.40, “Common standards.”
- 10 CFR Part 100, “Reactor Site Criteria”
    - 10 CFR 100.11, “Determination of exclusion area, low population zone, and population center distance,” which provides criteria for the EAB, LPZ, and population center distance for a test reactor for the purposes of site evaluation.

The applicable guidance for the evaluation of Hermes Radioactive Release from a Subsystem or Component postulated event is as follows:

- NUREG-1537, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors” Parts 1 and 2, Section 13, “Accident Analyses.”

13.1.6.3 Technical Evaluation

As shown in PSAR Table 13.1-1, the only figure of merit to ensure that the radioactive release from a subsystem or component category of events is bounded by the MHA radiological consequence analysis is the amount of radioactive material contained in the subsystems and components. As stated in Section 13.1.6 of the PSAR, Kairos is applying a design requirement on the amount of MAR in the systems expected to accumulate radionuclides during operation. Kairos identifies systems where the accumulation of radionuclides is expected to occur during the plant operating lifetime and could be released by a single initiating event such as a design basis earthquake. The systems identified by Kairos in PSAR Chapter 9, “Auxiliary Systems” which contain radionuclides are the tritium management system, inert gas system, chemistry control system (including filters), and inventory management system. The staff finds that subsystem or component MAR design limits can be set such that the MHA release remains bounding but the combined release from all subsystems and components not designed to withstand the limiting external or internal event will need to be evaluated as part of the OL application when specific MAR values are available.

13.1.6.4 **Conclusion**

The staff finds that the level of detail provided on radioactive release from a subsystem or component is consistent with the applicable guidance and acceptance criteria in NUREG-1537, Parts 1 and 2, Section 13, "Accident Analysis." Specifically, NUREG-1537, Part 2, Section 13, "External Events," states that "[f]or events that cause facility damage […], the damage is within the bounds discussed for other accidents in this chapter. Therefore, exposure to the workers and the public is within acceptable limits and external events do not pose an unacceptable risk to the health and safety of the public." Limiting the stored MAR in subsystems or components below an amount which ensures the MHA remains bounding satisfies the NUREG-1537 guidance. The staff finds that subsystem or component limits can be set such that the MHA release remains bounding. Based on the above, the staff finds that the preliminary analyses of the radioactive releases from a subsystem or component are sufficient and meet the applicable regulatory requirements and guidance identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. The staff notes the combined release from all subsystems and components not designed to withstand the limiting external or internal event will need to be evaluated as part of the OL application when specific MAR subsystem or component values are available.

13.1.7 General Challenges to Normal Operation

13.1.7.1 **Introduction**

Section 13.1.8, "General Challenges to Normal Operation," of the PSAR states that this category of events includes challenges to normal operation that require or cause an automatic or manual shutdown of the plant but are not covered by another event category. These events could be caused by control system anomalies, operator actions, or malfunctions of equipment or instrumentation.

13.1.7.2 **Regulatory Evaluation**

The applicable regulatory requirements for the evaluation of Hermes General Challenges to Normal Operation are as follows:

- 10 CFR 50.34, "Contents of applications; technical information," paragraph (a), "Preliminary safety analysis report."
    - 10 CFR 50.34(a)(4), which requires that each applicant for a CP include "[a] preliminary analysis and evaluation of the design and performance of [SSCs] of the facility with the objective of assessing the risk to public health and safety resulting from operation of the facility and including determination of the margins of safety during normal operations and transient conditions anticipated during the life of the facility, and the adequacy of [SSCs], provided for the prevention of accidents and the mitigation of the consequences of accidents…"
- 10 CFR 50.35, "Issuance of construction permits."
- 10 CFR 50.40, "Common standards."

- 10 CFR Part 100, “Reactor Site Criteria.”
    - 10 CFR 100.11, “Determination of exclusion area, low population zone, and population center distance,” which provides criteria for the EAB, LPZ, and population center distance for a test reactor for the purposes of site evaluation.

The applicable guidance for the evaluation of Hermes internal and external hazard events is as follows:

- NUREG-1537, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors” Part 1, and Part 2, Chapter 13, “Accident Analyses.”

13.1.7.3 **Technical Evaluation**

This section addresses initiating events caused by inadvertent operator action and control system equipment or instrument failure. Section 13.1.8 of the PSAR states that inadvertent operator actions are sensed by the RPS which initiates a reactor trip and the DHRS and/or parasitic heat losses provide the heat removal safety function. Inadvertent operator action or the loss of a control system due to equipment or instrumentation failure usually leads to deviation in plant parameters that either stabilizes at a new equilibrium condition or causes a reactor trip and an event similar to or less limiting than those evaluated in PSAR Chapter 13. The staff notes that a heat up event caused by an inadvertent operator action, control equipment or instrument failure, such as a decrease in heat rejection capability (e.g., closure of a heat rejection subsystem valve, loss of the heat rejection blower, loss of an operating DHRS train) is expected to result in lower temperature increases than the loss of forced circulation event described in PSAR Chapter 13.1.4.

Similarly, reactivity events caused by an inadvertent operator action or control equipment failure, such as incorrect pebble insertions or a cooldown caused by an increase in heat removal (e.g., heat rejection blower speed increase, cover gas flow rate increase), are expected to be less limiting than the insertion of excess reactivity event described in PSAR Chapter 13.1.2 for which the methodology evaluates a range of control element withdrawal reactivity worths and rates. Therefore, the staff finds that potential conditions created by an inadvertent operator action, control system equipment or instrument failure are less limiting than the conservative PSAR Chapter 13 postulated events analyzed and evaluated by the staff.

Likewise, the staff expects the conservative dose release events of PSAR Chapter 13 (e.g., salt spill analysis and PHSS line break) to bound a release caused by an inadvertent operator action, the failure of control system equipment or instrument inadvertent operator action, control equipment or instrument failure such as valve mis-operation, and leaks or failures in the PHTS due to the lower radionuclide mass release. For individual, non-safety systems which contain radionuclides, inadvertent operator action or control equipment or instrument failure in those systems that cause the release of radionuclides will be bounded by the release described in PSAR Section 13.1.6, “Radioactive Release from a Subsystem or Component” because that postulated event assumes all non-safety subsystems or components release their available radionuclide inventory (MAR). Therefore, the staff finds that an inadvertent operator action and the failure of control system equipment or instrument that releases radionuclides are bounded by limiting release events in the PSAR Chapter 13 analyses.

The staff expects that inadvertent operator actions or equipment or instrumentation malfunctions which cause the DHRS to be placed in-service potentially before sufficient residual heat exists to prevent freezing within 72 hours will be addressed as part of the startup or restart process to be described in the OL application. Likewise, the lack of potential operator action which fails to place the DHRS in-service during the transition between only parasitic and combined parasitic and DHRS heat removal will also be addressed as part of the OL application.

13.1.7.4 **Conclusion**

Based on the PSAR information regarding control system equipment and instrumentation, the staff finds that events caused by inadvertent operator action and failure of control equipment or instrumentation are not expected to cause reactor conditions or radionuclide releases which are more adverse than those associated with the events analyzed in SE Chapter 13. Therefore, the staff finds that the level of detail provided on general challenges to normal operation is consistent with the applicable guidance and acceptance criteria in NUREG-1537, Parts 1 and 2, Section 13, "Accident Analysis," and demonstrates an adequate design basis for a preliminary design. Based on the above, the staff finds that the preliminary analyses of general challenges to normal operation are sufficient and meet the applicable regulatory requirements identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Final determination that the consequences of Chapter 13 postulated events bound those of control and instrument malfunctions will be evaluated when detailed design is provided as part of the OL application.

13.1.8 Internal and External Hazard Events

13.1.8.1 **Introduction**

Section 13.1.9 of the PSAR describes the types of internal and external hazard events considered in the Hermes design bases and the design's ability to cope with these events.

13.1.8.2 **Regulatory Evaluation**

The applicable regulatory requirements for the evaluation of internal and external hazard events are as follows:

- 10 CFR 50.34, "Contents of applications; technical information," paragraph (a), "Preliminary safety analysis report."
    - 10 CFR 50.34(a)(4), which requires that each applicant for a CP include "[a] preliminary analysis and evaluation of the design and performance of [SSCs] of the facility with the objective of assessing the risk to public health and safety resulting from operation of the facility and including determination of the margins of safety during normal operations and transient conditions anticipated during the life of the facility, and the adequacy of [SSCs], provided for the prevention of accidents and the mitigation of the consequences of accidents…"
- 10 CFR 50.35, "Issuance of construction permits."
- 10 CFR 50.40, "Common standards."
- 10 CFR Part 100, "Reactor Site Criteria."
    - 10 CFR 100.11, "Determination of exclusion area, low population zone, and population center distance," which provides criteria for the EAB, LPZ, and population center distance for a test reactor for the purposes of site evaluation.

The applicable guidance for the evaluation of Hermes internal and external hazard events is as follows:

- NUREG-1537, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors” Part 1, and Part 2, Chapter 13, “Accident Analyses.”

13.1.8.3 **Technical Evaluation**

In this section of the SE, the staff evaluated the potential positive reactivity insertion caused by an increase in the pebble packing fraction caused by a seismic event. Other internal events are addressed in Chapter 13 “Accident Analysis” and Section 9.4 “Fire Protection Systems and Programs” of this SE. External events are addressed in Sections 3.4, “Seismic Damage,” 3.5, “Plant Structures,” Section 4.3, “Reactor Vessel System,” 4.7, “Reactor Vessel Support System,” and 6.3, “Decay Heat Removal System,” of this SE. The staff’s evaluation of the Hermes design’s capability to withstand high winds and water damage is addressed in Sections 3.2, “Meteorological Damage” and 3.3, “Water Damage,” of this SE respectively.

The staff notes that events evaluated by Kairos are separated into internal and external events. For internal events, PSAR Section 13.1.9 lists an internal fire and internal water flood. For internal fire, the staff evaluation of the fire protection system is described Section 9.4, Fire Protection Systems and Programs,” of this SE. By designing to the standards listed in PSAR Section 9.4.2, “Fire Protection Systems,” the fire protection systems, in combination with reactor building materials, are expected to preclude damage to the safety related SSCs needed to perform safe shutdown and mitigate any event caused by the fire (e.g., events caused by damage to non-safety related systems or non-protected control system instrumentation). The resulting loss of non-protected equipment will likely create events which are similar to those discussed in the staff’s evaluation of PSAR Section 13.1.8 relative to general challenges to normal operation above which includes the potential loss of control systems and instrumentation used for those control functions.

For events in which the fire can mobilize radioactive material, the amount of material at risk is assumed to be limited such that the MHA release remains limiting. The staff finds that non-protected SSCs can be designed to limit the materials at risk such that fire mobilized radionuclide releases are maintained less than the MHA. The staff notes that the amount of MAR becomes either a design constraint or the MAR containing areas are designed with fire protection systems such that the MHA remains the limiting release. The final means to limit the potential of fire mobilized MAR will be evaluated as part of the OL application.

The other internal event considered in the Hermes design bases is water flooding. As with the fire hazard, the SSCs needed to shut down the reactor and mitigate a postulated event are protected by design from internal flooding as evaluated in SE Section 3.3, “Water Damage.” For those areas not protected from internal floods, the loss of the non-protected equipment is expected to create events similar to those discussed in PSAR Section 13.1.8 and evaluated above. For flooding events, a potential criticality event becomes a concern as does overcooling of the reactor vessel leading to potential freezing of the Flibe coolant. The staff notes in PSAR Sections 9.3.1.8.1, “Spent Fuel Storage,” and 9.3.1.9, “New Fuel Pebble Introduction,” that subcritical conditions exist in a flooded storage canister and the new fuel pebble storage area is sized and arranged such that a subcritical geometry is maintained under all conditions. Likewise, PSAR Section 13.1.10.6, “DHRS Reactor Cavity Flooding,” states that significant leaks from the DHRS which could wet the reactor vessel are precluded by design.

The staff notes that external events for the Hermes facility include seismic, high wind, toxic release, mechanical impact or collision with SSCs, and external flooding. The ability of the safety related SSCs to perform their design function under a design basis seismic event is discussed in a number of sections in this SE including Sections 3.4, 3.5, 4.3, 4.7, and 6.3. The capability of the SSCs needed to perform the critical safety functions (reactor shutdown and decay heat removal) to withstand high winds is discussed in SE Section 3.2. The ability of the SSCs to address hazards associated with external floods is addressed in SE Section 3.3.

The staff notes that in a pebble bed reactor, a seismic event creates a potential reactivity insertion not evaluated in a reactor with fixed fuel. During a seismic event the pebbles and reflector geometry may change causing a positive reactivity insertion, which Kairos stated is bounded by the control element withdrawal event of PSAR 13.1.2. As discussed in the technical report KP-TR-018-NP, an increase in pebble packing fraction effectively removes Flibe, which is a negative reactivity insertion, but this negative reactivity insertion is somewhat compensated for by a positive reactivity addition near the reflector due to the higher carbon-to-heavy-metal atom ratio. Kairos stated that various packing fractions are used to demonstrate the reactivity impacts are small. The staff performed a literature search to identify relevant analyses associated with the reactivity inserted with an increase in packing fraction caused by a seismic event. The staff found literature regarding a similar evaluation for the HTR-10, a 10 MWt experimental HTGR located in China which has a similar thermal neutron spectrum but uses helium as the coolant instead of Flibe. For the similar sized HTR-10, 40 cents (standard unit of reactivity) of positive reactivity was inserted over a 4 minute seismic event as noted in the International Conference on Advances in Mathematics, Computation Methods, and Reactor Physics, “Analysis of an Earthquake-Initiated-Transient in a PBR,” from 2009.

The HTR-10 reactivity analysis also included the reactivity inserted by the lowering (densification) of the pebble bed (i.e., slumping) relative to the fixed control element locations. The reactivity addition caused by pebble bed slumping is not expected in the liquid cooled Hermes design, which uses buoyant fuel pebbles. Based on the reactivity inserted due to pebble bed slumping, combined with the lack of any significant negative reactivity insertion caused by a decrease in moderation in a HTGR, the staff expects the reactivity insertion of the HTR-10 analysis to bound those expected in Hermes. Therefore, based on the review of the Kairos evaluation and a literature review by the staff, the staff finds that a seismic induced positive reactivity insertion will likely be bounded by the evaluation presented in PSAR 13.1.2 as the analyzed reactivity insertions are larger than the HTR-10 reported values, but a detailed analysis for the final design should be provided in the OL application.

13.1.8.4 **Conclusion**

Hermes is designed to withstand internal and external hazards that are evaluated in Chapter 2 of this SE. The staff’s evaluations of the capabilities of SSCs to perform their intended safety functions under the conditions associated with these hazards are evaluated in other SE sections corresponding to particular SSCs {e.g., the evaluation of principal design criteria (PDCs) 2, 3 and 4 in SE Section 6.3}. Relative to internal fires, the staff finds it reasonable that either fire protection systems can be designed, or MAR amounts limited, such that the MHA remains bounding and the criteria of 10 CFR 100.11 are met, but a final determination will be based on the final design details provided as part of the OL application.

The staff finds the positive reactivity addition caused by a seismic event is bounded by the PSAR 13.1.2, “Insertion of Excess Reactivity,” event based on Kairos’s preliminary analysis discussed in KP-TR-018-NP and the staff's review of similar seismic induced reactivity insertion analyses in high temperature gas-cooled reactors, specifically the similar sized HTR-10. Therefore, the staff finds that the level of detail provided in PSAR Section 13.1.9 regarding the potential positive reactivity insertion caused by an increase in the pebble packing fraction as a result of a seismic event is consistent with the applicable guidance and acceptance criteria in NUREG-1537, Parts 1 and 2, Chapter 13, "Accident Analyses," which states that applicants should evaluate bounding insertions of excess reactivity.

Based on the above, the staff finds that the preliminary analyses of the internal and external hazard events are sufficient and meet the applicable regulatory requirements and guidance identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Further technical or design information required to complete the safety analysis may reasonably be left for later consideration during the OL application.

13.1.9 Prevented Events

13.1.9.1 Introduction

PSAR Section 13.1.10 describes events that were not analyzed in the PSAR as they are precluded by design.

13.1.9.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of Hermes prevented events are as follows:

- 10 CFR 50.34, "Contents of applications; technical information," paragraph (a), "Preliminary safety analysis report."
    - 10 CFR 50.34(a)(4), which requires that each applicant for a CP include "[a] preliminary analysis and evaluation of the design and performance of [SSCs] of the facility with the objective of assessing the risk to public health and safety resulting from operation of the facility and including determination of the margins of safety during normal operations and transient conditions anticipated during the life of the facility, and the adequacy of [SSCs], provided for the prevention of accidents and the mitigation of the consequences of accidents…"
- 10 CFR 50.35, "Issuance of construction permits."
- 10 CFR 50.40, "Common standards."

The applicable guidance for the evaluation of Hermes prevented events is as follows:

- NUREG-1537, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors" Parts 1 and 2.

13.1.9.3 Technical Evaluation

Recriticality or Reactor Shutdown System Failure

Recriticality refers to the situation where the reactor achieves subcriticality but returns to criticality due to the insertion of positive reactivity caused by conditions such as a reactor cooldown (assuming a negative total reactivity coefficient) and/or the decay of Xenon. To prevent a return to criticality, the reactor shutdown system must insert an amount of negative reactivity greater than the positive reactivity additions, accounting for malfunctions, for the duration of the postulated event, which is 72 hours as described in PSAR Section 13.1.8.

As discussed in PSAR Section 4.5, "Nuclear Design," shutdown margin calculations assume that two safety related shutdown elements insert into the pebble bed to provide negative reactivity (the third, highest worth shutdown element is assumed to remain stuck out). The assumption in PSAR Table 4.5-5, "Shutdown Margin for Equilibrium," is that the shutdown elements can insert sufficiently into the pebble bed such that the minimum shutdown element worth in PSAR Table 4.5-5 is satisfied. Because of questions regarding uncertainty associated with insertion of the shutdown elements into a relatively packed bed pebble, the staff issued RAI 348 via email on August 8, 2022, asking Kairos what testing will be performed to ensure sufficient insertion of the shutdown elements. By letter dated August 31, 2022, Kairos responded that testing of concurrent insertion of all shutdown elements will be performed to ensure the insertion amount and time bound those assumed in the PSAR Chapter 13 postulated event analyses. The results of Kairos's qualification test, which seeks to confirm that the design basis can be met with high degree of certainty, will be evaluated as part of the OL application.

The staff notes that a reactor shutdown system (RSS) failure event is a failure to achieve shutdown when shutdown is demanded by either manual action or the automatic action of the RPS. The probability of an RSS failure event is a function of the individual failure probabilities of the nuclear instrumentation to detect, the instrumentation and controls to process and transmit a signal to the shutdown element clutches, the clutch to disengage, and the shutdown elements to sufficiently insert. As discussed in Sections 4.2, "Reactor Core," and 7.3, "Reactor Protection System," of this SE, the ability to detect and send a signal to open the shutdown element clutches has been found to be consistent with PDC 29. PDC 29 states the protective reactivity safety function should be achieved with an extremely high probability which includes the ability to sufficiently insert the shutdown elements into the pebble bed. To that end, the staff issued RAI 348 asking Kairos what testing would be performed to ensure there is high probability of the shutdown elements inserting a sufficient amount of negative reactivity to preclude considering an RSS failure event. As discussed above for recriticality, test results that confirm the shutdown design basis is met with high degree of certainty will be evaluated as part of the OL application based on review of the testing results to ensure the probability of an RSS failure event is sufficiently low. Based on Kairos's response and testing plans for insertion of shutdown elements, the staff finds that the proposed shutdown element testing will ensure a high probability of achieving shutdown thereby precluding an RSS failure event.

Degraded Heat Removal or Uncooled Events

Degraded heat removal or uncooled events are defined as those beyond the loss of a single DHRS train already assumed in PSAR Chapter 13. Kairos notes in PSAR Section 13.1.10.2 that the DHRS is always running above a specific threshold power and hence failure of a DHRS train should be detected. Since the DHRS is typically in-service, a relatively continuous flow of makeup water is needed to maintain a DHRS tank water level within its expected operating band. An unexpected change in DHRS tank level or makeup flow rate would be a potential indication of a failure in that DHRS train.

There are four passive in-vessel natural circulation flow paths as described in PSAR Section 4.3.1.2.1, "Reflector Blocks," and hence redundancy exists should one natural flow decay heat removal pathway become degraded or fail. These passive natural circulation pathways are also always in-service as some amount of flow is expected through these pathways. The Hermes design has the ability to inspect the fluidic diode and monitor temperature in the natural circulation pathways as described in PSAR Section 4.3.3, "System Evaluation." The PSAR states that periodic inspection of the fluidic diode and temperature monitoring would provide an indication of a degraded or failed condition in a natural circulation flow pathway. Detailed staff evaluation the of the DHRS system is provided in Section 6.3, "Decay Heat Removal System," of this SE while the natural circulation flow path evaluation is documented in Sections 4.3, "Reactor Vessel System," and 4.6, "Thermal-Hydraulic Design," of this SE. Based on the passive design, the normally in-service configuration, redundancies in the heat removal pathways, and the ability to inspect and monitor the safety related heat removal systems, the staff finds that degraded heat removal or uncooled events beyond those analyzed are precluded by design.

Flibe Spill Beyond Maximum Volume Assumed in Postulated Salt Spills

Kairos has also excluded a Flibe spill beyond the maximum amount assumed in the postulated salt spill event described in PSAR Section 13.1.3 and evaluated above. Kairos stated that there are several design features which makes the salt spill analysis bounding, including the use of vessel anti-siphon devices. The staff has reviewed the anti-siphon features on the hot and cold legs, as described in PSAR Sections 5.1.1.2, "Primary Salt Pump" and 4.3.3, "System Evaluation." The staff found in Chapter 5 of the SE that the anti-siphon design features will limit salt loss. Likewise, the staff finds, as documented in Chapter 5 of this SE, that the safety related PSP trip will limit the amount of spilled salt. Finally, the staff finds that vessel integrity will be maintained for design basis events as documented in the staff's evaluation in Section 4.3 of this SE. Therefore, the staff finds that Flibe salt spilled beyond that assumed in the analysis described in PSAR Section 13.1.3 is not expected to occur.

In-Service TRISO Failure Rates and Burnups Above Assumptions in Postulated Events

Kairos stated that in-service failure rates and pebble burnup beyond those assumed in the postulated events are precluded by the fuel specification and measurement of pebble burnup. The TRISO particle manufacturing specifications limit the number of failed particles by coating layer type and the amount of dispersed uranium. The staff finds that manufactured defects will be limited by the fuel specification as the fuel quality assurance program is expected to statistically sample the manufactured fuel ensuring the specification by cohort will be met. During normal operation, in-service coating failures will be limited by monitoring the Flibe and cover gas activity per TSs and taking the necessary actions per the LCO.

As stated in PSAR 13.1.1.4, "Transient Assumptions," Kairos further assumes there are no additional in-service, incremental particle failures caused by the postulated events. The staff expects that incremental failures due to the postulated event conditions will be negligible but notes the Chapter 13 postulated event methodology evaluates this assumption using KP-BISON. Kairos stated that to prevent reinsertion of damaged pebbles the PHSS is designed to inspect the discharged pebbles, including by measuring pebble burnup, to preclude reinserting a damaged pebble or a pebble with too high of a burnup. The capabilities of the pebble inspection are further discussed in the fuel qualification TR. The staff notes that an inspection capability can be developed which inspects the pebble surface for damage. The staff finds that the pebble burnup is sufficiently conservative to infer that TRISO particle burnup will likely not be exceeded.

Significant Air Ingress Into the PHTS

During normal operation, the potential accumulation of significant air in the PHTS is monitored and limited by a TS LCO, as shown in PSAR Table 14.1-1, Section 3.3. During postulated events such as a heat rejection radiator tube break, the forced air entering the PHTS is limited by tripping the PSP pump and heat rejection blower. The effects of non-forced air entering the PHTS on safety related systems is bounded out to seven days by the materials qualification program, as described in PSAR Section 4.3. Beyond seven days, Kairos stated that mitigation strategies such as repairing the damaged SSC and reestablishing an inert system or defueling are possible strategies to place the plant in a final (post postulated event) safe state. The staff finds that air ingress during normal operation is precluded by meeting the proposed TS LCO. Likewise, the staff finds that forced air ingress will be limited by tripping the PSP and heat rejection blower and that, out to seven days, the material testing program will demonstrate the safety related SSCs are capable of performing their safety function. Beyond seven days, the proposed actions to place the plant in a final state which protects the public health and safety will likely to be successful.

DHRS Reactor Cavity Flooding

The design of the Hermes facility precludes DHRS cavity flooding through the use of leak detection and the design of the DHRS thimble wells, which includes a double wall construction, lowering the probability of significant water leakage into the vessel cavity. Kairos states in PSAR Section 6.3.1.4, “Leak Barrier,” that “continuous leak detection of the internal water pressure is possible by monitoring for a relative rise in humidity in the gas space and a drop in external surface temperature which would indicate a formation of a leak.” The staff finds based on the leakage detection and system and the double wall construction of the DHRS thimbles that significant flooding of the cavity is precluded by design as continuous leak detection allows for sensing a thimble evaporator leak and taking an action to mitigate the leak (e.g., isolating a DHRS train or shutting down the reactor)

Insertion of Excess Reactivity Beyond Rate Assumed in Postulated Events

Kairos evaluates the maximum reactivity insertion rate in PSAR Section 13.1.2. The staff notes that the maximum control element withdrawal rate is limited by the RCSS mechanical hardware, and staff notes that the maximum withdrawal rate of one control element is evaluated as part of the PSAR Chapter 13.1.2 postulated event methodology. The staff also notes that the insertion of excess reactivity methodology described in PSAR Section 13.1.2 includes the evaluation of a range of reactivity insertions to determine the limiting insertion of excess reactivity event as some withdrawals may bypass the safety related flux rate trip. Kairos stated that control element withdrawal rates beyond the maximum mechanical capability of the RCSS, such as an ejected element, are not considered. The staff notes that based on the low differential pressure across the reactor coolant boundary there is not a high enough driving force to eject a control element. An insertion of excess reactivity due to a potential increase in packing fraction during a seismic event is discussed in SE Section 13.1.9 and is not expected to be worse than that analyzed in PSAR Section 13.1.2, though a detailed evaluation based on the final design details should be provided in the OL application.

Insertion of excess reactivity can also be caused by overcooling due to an increase in heat removal. An increase in heat removal can be caused by an overspeed of the PSP or heat rejection blower. As described in PSAR Section 7.2.1.3, “Primary Heat Transport Control System,” the non-safety related primary heat transport control system controls the PSP speed and heat rejection subsystem. The cooldown events caused by a PSP and heat rejection blower over speed condition are limited to their maximum programmed limit as discussed in PSAR Section 7.2, “Plant Control System.” As described in SE Section 13.1.8, the failure of a control system is not expected to be more limiting than the other postulated events evaluated in Section 13.1 of this SE. While the staff does not expect overcooling events to be more limiting than the results described in PSAR Section 13.1.2, the overcooling events caused by pump overspeed or potential cold Flibe addition should be addressed as part of the OL application. Based on the staff’s evaluation, the staff finds that insertions of excess reactivity beyond that already evaluated in PSAR Section 13.1.2 are not expected for the Hermes design because the associated cooldown is expected to be relatively small.

Criticality Occurrence External to Reactor Core

Areas where fuel pebbles are stored or handled external to the core are designed to preclude a critical geometry as required by PDC 62, “Prevention of criticality in fuel storage and handling.” This design requirement applies to fresh and spent fuel storage as well handling by the PHSS. In addition, the PHSS line break analysis in PSAR Section 13.1.5 also assumes the number of pebbles spilled precludes criticality. An illustration of the fresh and spent fuel storage system is provided in PSAR Figure 9.3-2, “Pebble Handling and Storage System.” The PSAR does not provide design details of the PHSS and fresh and spent fuel storage areas other than statements to limit pebble numbers (fissile material amount) and the use of appropriate storage container spacing to preclude criticality. A detailed criticality evaluation of the PHSS, fresh, and spent storage facilities is expected to be provided as part of the OL application. The staff finds that criticality external to the reactor can be precluded by adequate limits on fissile amounts and/or adequate spacing (non-critical geometries), including the consideration of potentially enhanced moderation conditions, and that the preliminary design of the systems is consistent with PDC 62. Final determination that PDC 62 is met will be evaluated as part of the OL application.

Excessive Radionuclide Release from Flibe

PSAR Section 13.1.10.9 states that radionuclide releases are assumed from the Flibe free surfaces as part of the evaluation of postulated events. Specific postulated events, such as the salt spill, allow radionuclides to be transported by evaporation from the Flibe free surface into the reactor building. The amount of evaporation from the Flibe free surface is a function of the initial cover gas conditions such as impurities, pressure, temperature, and gas flow rates. As described in PSAR Sections 9.1.2.1, “Description,” and 9.1.2.4, “Testing and Inspection,” the argon volume and gas purity will be included as a TS LCO and the inert gas system (IGS) system has instrumentation to monitor pressures, temperatures, and gas flow rates and regulate these parameters to meet design requirements. Based on a proposed TS LCO in PSAR Table 14.1-1, Section 3.3, the argon gas purity that Kairos will be required to meet as part of its licensing basis and the IGS system’s ability to monitor and maintain cover gas parameters, the staff finds that limiting cover gas initial conditions can be established for use in postulated events which release radionuclides by in-vessel Flibe evaporation.

Internal or External Events Interfering with SSCs

Section 13.1.10.10, “Internal or External Events Interfering with SSCs,” of the PSAR indicates that the design of the reactor building precludes potential impacts to safety functions performed by safety related SSCs that could be caused by internal or external events. The staff notes from information provided in PSAR Section 13.1.10.10 that safety related and non-safety related systems containing Flibe are assumed to be protected from water and hence these interactions are not evaluated. The assumption that Flibe-water interactions are precluded by design is an important design consideration and is dependent on the final design. The reactor building design features which prevent flooding from external events are described in PSAR Section 3.5. Fire protection system features which preclude Flibe-water interaction are discussed in PSAR Section 9.4. Detailed design features which preclude Flibe-water interaction such as the relative location of water and Flibe sources, including potential water intrusion from non-safety systems into the reactor, are expected to be included as part of the OL application. The staff does expect that such design features are possible; for example, by using double wall construction and leak detection, shields and drain systems, and/or the separation of water containing subsystems or components from Flibe containing sources. Therefore, the staff finds that Flibe-water interactions affecting a safety function can likely be precluded but final determination will be made as part of the OL review.

13.1.9.4 Conclusion

The staff finds that the level of detail provided in PSAR Section 13.1.10, as supplemented by the response to RAI 348, is consistent with the applicable guidance and acceptance criteria in NUREG-1537, Parts 1 and 2, Chapter 13, “Accident Analysis,” and demonstrates an adequate design basis for a preliminary design. Therefore, the staff finds that the information in PSAR Section 13.1.10 is sufficient and meets the applicable regulatory requirements and guidance identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Further technical or design information required to complete the safety analysis may reasonably be left for later consideration during the OL application.

13.2 Accident Analysis and Determination of Consequences

PSAR Section 13.2 provides Kairos’s analysis of the radiological consequences of accidents, including the MHA as bounding for postulated events.

13.2.1 Maximum Hypothetical Accident

13.2.1.1 **Introduction**

In PSAR Section 13.2.1, Kairos describes its evaluation of the radiological consequences of the MHA. The MHA analysis is intended to be bounding for the postulated events described in PSAR Chapter 13, and is performed to demonstrate that the 10 CFR 100.11 dose reference values are met at the EAB and outer boundary of the LPZ in support of the safety analysis requirements in 10 CFR 50.34(a)(1)(i) and the siting evaluation factors in 10 CFR 100, Subpart A.

13.2.1.2 **Regulatory Evaluation**

The applicable regulatory requirements for the evaluation of MHA are as follows:

- 10 CFR 50.34, “Contents of applications; technical information,” paragraph (a), “Preliminary safety analysis report.”
    - 10 CFR 50.34(a)(1)(i), which requires "[a] description and safety assessment of the site on which the facility is to be located, with appropriate attention to features affecting facility design”

- 10 CFR 50.34(a)(4), which requires that each applicant for a CP include “[a] preliminary analysis and evaluation of the design and performance of [SSCs] of the facility with the objective of assessing the risk to public health and safety resulting from operation of the facility and including determination of the margins of safety during normal operations and transient conditions anticipated during the life of the facility, and the adequacy of [SSCs], provided for the prevention of accidents and the mitigation of the consequences of accidents…”
- 10 CFR 50.35, “Issuance of construction permits.”
- 10 CFR 50.40, “Common standards.”
- 10 CFR Part 100, “Reactor Site Criteria.”
  - 10 CFR 100.11, “Determination of exclusion area, low population zone, and population center distance,” which provides radiation dose criteria for the EAB, LPZ, and population center distance for a test reactor for the purposes of site evaluation.

The applicable guidance and acceptance criteria for the evaluation of the radiological consequences of the Hermes MHA is as follows:

- NUREG-1537, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors” Parts 1 and 2, Section 13, “Accident Analyses.”

13.2.1.3 **Technical Evaluation**

PSAR Section 3.1.1, “Design Criteria,” describes the PDC that are applicable to Hermes. These PDC were reviewed and approved by the staff in KP-TR-003-NP-A, Revision 1, “Principal Design Criteria for the Kairos Power Fluoride Salt-Cooled, High Temperature Reactor.” PSAR Table 3.1-3, “Principal Design Criteria,” identifies that KP-FHR PDC 19, “Control Room,” which includes radiological habitability criteria for the control room design, is applicable to Hermes. The staff’s review of the acceptability of the PDCs for Hermes is discussed in SE Section 3.1, “Design Criteria.” PSAR Section 7.4, “Main Control Room and Remote Onsite Shutdown Panel,” includes a discussion of the main control room (MCR), including the design basis for conformance with PDC 19. The MCR is located in an auxiliary building separate from the reactor building. PSAR Section 7.4.3.1, “Main Control Room,” states that the “MCR is located at a distance from the reactor building such that the radiological consequences of unfiltered air in the MCR during postulated events does not exceed 5 rem total effective dose equivalent for the duration of the event.” Consistent with the preliminary nature of the design, the PSAR does not provide detail on the specific location on the site where the MCR will be located, specific design details related to the ventilation systems and other SSCs in the auxiliary building for control room habitability, nor does it provide an MCR radiological consequence analysis for the MHA or other postulated events. Accordingly, the staff makes no finding on conformance with PDC 19 with respect to MCR radiological habitability. The staff will evaluate the description of the control room design with respect to radiological habitability and the associated analysis of the radiological consequences of accidents when such information is provided in the FSAR with the application for an OL. The staff finds that the PSAR discussion of control room radiological habitability, considering preliminary MCR design information, is consistent with PDC 19.

The staff’s review of the postulated MHA scenario is described in Section 13.1.1 of this SE.

PSAR Section 13.2.1 provides a description of the radiological consequence analysis for the MHA and the results. Kairos used the source term methods for design basis accidents as described in the staff approved MST TR. Given that the CP application provides a preliminary safety analysis, the MST TR methodology will not be fully implemented until its use by Kairos in support of the FSAR. The staff will review the final implementation of the MST TR for Hermes, including the limitations and conditions in the MST TR SE, in its review of the OL application. In the MST TR methodology, the development of event-specific radiological releases to the environment is accomplished by modeling the facility as a set of MAR sources, identifying the succession of barriers to release, and applying a release fraction for each barrier that contains the MAR. The staff notes that this system model is consistent with the description of a functional containment in SECY-18-0096, "Functional Containment Performance Criteria for Non-Light-Water-Reactors."

The PSAR describes functionally the sources of radioactive MAR. These sources of MAR used as input to the dose analysis are based on plant initial conditions for the postulated MHA, as described in PSAR Section 13.1.1. The MAR in the TRISO fuel in the reactor at the initiation of the event was determined by conservative estimates of the radionuclides produced during normal operation considering fuel design and plant operation. The radionuclides in the circulating activity MAR for the Flibe and gas space and the structural MAR are based on bounding assumptions and will be controlled by upper bound limits in the TSs to ensure that the assumptions in the MHA are bounding for the facility operating conditions.

Radionuclides are grouped together by similar chemical properties or element class to model transport within the fuel by diffusion. Transport of the radionuclides within a fuel transport group is based on the transport of a representative element which has a complete set of diffusion information (i.e., diffusivities in the kernel, coating layers, and matrix). Diffusivity information is currently available for four elements (Cs, Sr, Ag, Kr). The radionuclides are assumed to be retained completely in the TRISO particle, or completely released depending on the element class, as described in the MST TR.

The staff's review of the modeling of radionuclide generation and transport in TRISO, Flibe, and graphite structures is described above in "Initial Conditions Assumptions" under SE Section 13.1.1. The staff's review of the MHA scenario, as related to development of the source term, including modeling of the barrier transport and release fractions, is described above in "Transient Assumptions" under SE Section 13.1.1. The MHA radiological consequence analysis models gravitational settling of aerosols in the reactor building using the Henry correlation for aerosol deposition implemented in the SNAP/RADTRAD code as described in the approved MST TR methodology. Therefore, the staff finds that Kairos used a reasonable assumed release height based on the preliminary Hermes design as input to the aerosol deposition correlation in the computer code.

PSAR Table 13.2-1, "Site-Specific χ/Q Values," provides the site characteristic short term atmospheric dispersion factors used in the MHA analysis to estimate doses at the EAB distance of 250 m, and at the outer boundary of the LPZ at 800 m from the reactor building. The staff's review of the determination of the site characteristic atmospheric dispersion is discussed in Section 2.3, "Meteorology," of this SER.

During the Accident Analysis Audit, the staff reviewed the documentation of the MHA radiological consequences analysis calculation and supporting documents, including methodology, inputs, and assumptions. Through this audit, the staff confirmed that Kairos's analysis assumptions and methods were consistent with the description in the PSAR and are consistent with the approved MST TR methodology.

PSAR Table 13.2-2, “Maximum Hypothetical Accident Dose Consequences,” provides the results of Kairos’s radiological consequence analysis. For the EAB, Kairos calculated the dose from exposure to the release plume for the first two hours of the MHA to compare to the 10 CFR 100.11 dose reference values of 25 rem whole body dose and 300 rem to the thyroid. For the LPZ, Kairos calculated the dose from exposure to the release plume for 30 days to compare to the 10 CFR 100.11 dose reference values of 25 rem whole body dose and 300 rem to the thyroid. The calculated dose consequences of the MHA are substantially below the regulatory dose reference values for test reactor siting in 10 CFR 100.11. The staff will confirm these calculations, including any revisions to the MHA, as part of the OL review, but the results do not need to be confirmed for issuance of a CP. Because the assumptions of the scenario are bounding, the doses calculated will likely not be exceeded by any accident considered credible. Therefore, based upon its review of Kairos’s analysis of the MHA, the staff finds that the public health and safety with respect to the radiological consequences of accidents will be protected.

13.2.1.4 **Conclusion**

The staff finds that the level of detail provided on the evaluation of the radiological consequences of the MHA is consistent with the applicable guidance and acceptance criteria in NUREG-1537, Parts 1 and 2, Section 13, “Accident Analysis” and demonstrates an adequate design basis for a preliminary design.

Based on the technical evaluation discussed above, the staff finds that the preliminary analysis of the radiological consequences of the MHA, as described in PSAR Chapter 13 and confirmed during the staff’s audit of supporting documents, is sufficient and meets the applicable regulatory requirements identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Further technical or design information required to complete the safety analysis may reasonably be left for later consideration. The staff will confirm that the final design conforms to the design basis during the evaluation of the FSAR as part of the OL application review.

Additionally, the staff finds that the discussion of design bases and preliminary design for control room radiological habitability, as described in Hermes PSAR Sections 3.1 and 7.4, is sufficient and meets the applicable regulatory requirements and guidance identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Further technical or design information required to complete the safety analysis may reasonably be left for later consideration. The staff will confirm that the final design conforms to the design basis during the evaluation of the FSAR as part of the OL application review.

13.2.2 Postulated Event Methodology

13.2.2.1 **Introduction**

PSAR Section 13.2.2 describes Kairos’s use of KP-TR-018-NP to derive the figures of merit and associated acceptance criteria which ensure that the radiological consequences of the MHA are bounding for the postulated events described in PSAR Chapter 13. PSAR Table 13.1-1 provides the figures of merit and acceptance criteria for each postulated event category. For each postulated event, the results of the transient analysis are to be compared to the relevant figure of merit and associated acceptance criterion derived from the MHA analysis.

The referenced technical report, KP-TR-018-NP, describes the postulated events, transient analysis methods including evaluation models, and the methodology to be used to ensure that the final design features of the Hermes facility are sufficient to mitigate the effects of the postulated events and keep the potential consequences of the events bounded by the MHA. The technical report summarizes the MHA only to provide context for the derivation of the figures of merit for the postulated events.

13.2.2.2 Regulatory Evaluation

- 10 CFR 50.34, "Contents of applications; technical information," paragraph (a), "Preliminary safety analysis report," including:
  - o 10 CFR 50.34(a)(1)(i), which requires "[a] description and safety assessment of the site on which the facility is to be located, with appropriate attention to features affecting facility design."
  - o 10 CFR 50.34(a)(4), which requires that each applicant for a CP include "[a] preliminary analysis and evaluation of the design and performance of [SSCs] of the facility with the objective of assessing the risk to public health and safety resulting from operation of the facility and including determination of the margins of safety during normal operations and transient conditions anticipated during the life of the facility, and the adequacy of [SSCs], provided for the prevention of accidents and the mitigation of the consequences of accidents…"
- 10 CFR 50.35, "Issuance of construction permits."
- 10 CFR 50.40, "Common standards."
- 10 CFR 100.11, "Determination of exclusion area, low population zone, and population center distance."

The applicable guidance and acceptance criteria for the evaluation of the Hermes postulated event methodology is as follows:

- NUREG-1537, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors" Parts 1 and 2, Section 13, "Accident Analyses."

13.2.2.3 Technical Evaluation

The staff reviewed the information in PSAR Chapter 13 and KP-TR-018-NP to determine if the figures of merit and the associated acceptance criteria ensure that the potential radiological consequences of postulated events are bounded by the evaluation of the MHA. PSAR Table 13.1-1 describes the acceptance criteria but does not provide the specific values from the MHA for criteria that refer to the MHA releases.

Section 1.1 of KP-TR-018-NP describes the KP-FHR key design features that provide the basis for the transient analysis methods described in the report. Through comparison of the information in the PSAR and KP-TR-018-NP, Section 1.1, the staff finds that the key design features of the Hermes facility are consistent with those in the technical report, and therefore the postulated event methodology, including the transient analysis methods, is applicable to the Hermes.

Appendix A to KP-TR-018-NP provides sample transient calculations for many of the events using preliminary design information to show an example of use of the methods in the report. The postulated event analyses will be performed using detailed final design information to support the OL application. Accordingly, the staff did not make a finding with respect to the sample analyses in the appendix to KP-TR-018-NP.

KP-TR-018-NP, Chapter 3, “Capability of Evaluation Models,” provides information on the evaluation models used in the transient analyses for postulated events. The list of postulated events categories in the technical report are the same as given in PSAR Chapter 13. The staff’s evaluation of the details of the transient analysis methods for each of the postulated events for the Hermes is discussed is more detail above in the relevant subsection for each postulated event category within Section 13.1 of this SE.

KP-TR-018-NP, Section 3.4.2, describes the development of the postulated event figures of merit as a surrogate for dose to ensure and demonstrate that a postulated event is bounded by the MHA. The figures of merit and associated acceptance criteria for each postulated event are developed to show that the radionuclide releases from the postulated events through the same release pathways as the MHA would be less than the release assumed in the MHA analysis. For postulated events with release pathways that do not exist in the MHA, the KP-TR-018-NP methodology uses a method using both a dose calculation for those additional pathways and figures of merit for the pathways that exist in the MHA.

PSAR Table 13.1-1 provides the figures of merit to be assessed in the postulated event transient analysis, the associated acceptance criterion based on a comparison to the MHA analysis, and the applicable events for the specific figure of merit. Figure of merit acceptance criteria that refer to the MHA hypothetical temperature-time curve in PSAR Figure 13.2-1 will be compared to the results of the final transient analysis for the relevant postulated event to show that the temperatures assumed in the MHA analysis are higher. The staff finds that the figures of merit and acceptance criteria related to temperature in PSAR Table 13.1-1 are acceptable because the phenomena that cause radionuclide release are diffusion processes which are a function of temperature, with higher temperatures resulting in larger releases.

Other figures of merit and associated acceptance criteria are based on showing that the total radionuclide release assumed in the MHA is bounding for the postulated event. One type of acceptance criterion is that for the relevant postulated event additional sources of MAR, TRISO failure probability, or releases are negligible or bounded by the MHA analysis (e.g., negligible amount of additional volatile products formed through Flibe-air reaction). Another acceptance criterion provides an airborne release fraction limit to bound total releases of the postulated event to less than the total releases in the MHA. There are other acceptance criteria to show that mass loss of graphite in the pebbles or structural graphite due to oxidation is less than in the MHA analysis. The staff finds the figures of merit and acceptance criteria in PSAR Table 13.1-1 are acceptable because they account for physical phenomena and additional release pathways that are not part of the MHA and ensure that the total releases from the postulated event will be shown to be less than in the MHA analysis.

As discussed above in SE Section 13.2.1, the staff finds that the radiological consequences of the MHA are consistent with the criteria in 10 CFR 100.11. Because the figures of merit and associated acceptance criteria ensure that the MHA releases remain bounding, the staff finds that the radiological consequences of the postulated events will also be consistent with the criteria in 10 CFR 100.11 with respect to the radiological consequences of accidents.

13.2.2.4 **Conclusion**

The staff finds that the level of detail provided on the postulated event evaluation methodology is consistent with the applicable guidance and acceptance criteria in NUREG-1537, Parts 1 and 2, Section 13, “Accident Analysis” and demonstrates an adequate design basis for a preliminary design. Based on the technical evaluation discussed above, the staff finds that the methodology used to show that the radiological consequences of the postulated events are bounded by the MHA analysis is sufficient and that the methodology meets the applicable regulatory requirements and guidance identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Further technical or design information required to complete the safety analysis may reasonably be left for later consideration. The staff will confirm that the final design conforms to the design basis during the evaluation of the FSAR as part of the OL application review.

13.3 Summary and Conclusions on Accident Analyses

The staff evaluated the information regarding the Hermes accident analysis, as described in PSAR Chapter 13, as supplemented, and finds that the accident analysis of the preliminary design, including the PDC, design bases, information relative to materials of construction, general arrangement, and approximate dimensions; and preliminary analysis and evaluation of the design and performance of SSCs of the facility: (1) provides reasonable assurance that the final design will conform to the design basis, (2) meet all applicable regulatory requirements, and (3) meet all applicable acceptance criteria discussed in NUREG-1537. Based on these findings, the staff concludes the following regarding the issuance of a CP in accordance with 10 CFR 50.35 and 50.40:

- Kairos has described the proposed design of the systems supporting the accident analysis, including, but not limited to, the principal architectural and engineering criteria for the design, and has identified the major features or components incorporated therein for the protection of the health and safety of the public.
- Such further technical or design information as may be required to complete the safety analysis, and which can reasonably be left for later consideration, will be supplied in the FSAR as part of the OL application.
- There is reasonable assurance that, taking into consideration the site criteria contained in 10 CFR Part 100, the proposed facility can be constructed and operated at the proposed location without undue risk to the health and safety of the public.
- There is reasonable assurance: (i) that the construction of the facility will not endanger the health and safety of the public, and (ii) that construction activities can be conducted in compliance with the Commission’s regulations.
- The issuance of a permit for the construction of the facility would not be inimical to the common defense and security or to the health and safety of the public.

13.4 References

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-----. “Submittal of the Preliminary Safety Analysis Report for the Kairos Power Fluoride Salt-Cooled, High Temperature Non-Power Reactor (Hermes), Revision 2,” February 24, 2023, Pkg. ML23055A672. (Includes KP-TR-018, “Postulated Event Analysis Methodology,” Revision 2 (redacted version), as Enclosure 3.)

-----. “Submittal of the Preliminary Safety Analysis Report for the Kairos Power Fluoride Salt-Cooled, High Temperature Non-Power Reactor (Hermes), Revision 3,” May 31, 2023, Pkg. ML23151A743.

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-----. “Summary Report for the Regulatory Audit of Kairos Power LLC Hermes Construction Permit Preliminary Safety Analysis Report Chapters 4 and 13 (Accident Analysis),” June 2023, ML23160A287.

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14 TECHNICAL SPECIFICATIONS

The principal purpose of technical specifications (TSs) is to maintain system performance and ensure safe reactor operation. This is accomplished by including in the TSs limiting or enveloping conditions of design and operation, ensuring that emphasis is placed on the safety of the public, the facility staff, and the environment. TSs are typically derived from the facility descriptions and safety considerations contained in the facility safety analysis report.

This chapter of the Kairos Power LLC (Kairos) Hermes construction permit (CP) safety evaluation describes the U.S. Nuclear Regulatory Commission (NRC) staff's (the staff's) technical review and evaluation of the probable subjects of TSs for the Hermes facility as presented in preliminary safety analysis report (PSAR), Revision 3, Chapter 14, "Technical Specifications."

14.1 Introduction

Hermes PSAR Chapter 14 provides preliminary information on Hermes facility TSs that will be applicable for various operating modes during Hermes operation. In PSAR Section 14.1, "Introduction," Kairos discusses the general format and content of the TSs as well as variables and conditions that are expected to be the subjects of TSs. Kairos also discusses some probable subjects of TSs in other PSAR chapters. Kairos does not provide actual TSs in the PSAR; PSAR Section 14.1 states that the Hermes TSs will be provided in an operating license (OL) application. In PSAR Section 14.2, "Operating Modes," Kairos summarizes the five different Hermes operating modes for the Hermes TSs.

14.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of the Hermes TSs are as follows:

- Title 10, Code of Federal Regulations (10 CFR) 50.34, "Contents of applications; technical information," paragraph (a), "Preliminary safety analysis report," including 10 CFR 50.34(a)(5), which requires that the PSAR include "[a]n identification and justification for the selection of those variables, conditions, or other items which are determined as the result of preliminary safety analysis and evaluation to be probable subjects of technical specifications for the facility, with special attention given to those items which may significantly influence the final design…."
- 10 CFR 50.35, "Issuance of construction permits."
- 10 CFR 50.40, "Common standards."

The applicable guidance for the evaluation of the Hermes TSs is as follows:

- NUREG-1537, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors," Part 1, "Format and Content," and Part 2, "Standard Review Plan and Acceptance Criteria," Chapter 14, "Technical Specifications."
- ANSI/ANS-15.1-2007, "The Development of Technical Specifications for Research Reactors."

14.3 Technical Evaluation

PSAR Section 14.1 states that the format and content of the Hermes TSs, which will be submitted with a Hermes OL application:

1. will address the requirements in 10 CFR 50.36 (consistent with the 10 CFR 50.34(b)(6)(vi) requirement that TSs be included in an OL application),
2. will be consistent with the guidance provided in ANSI/ANS-15.1-2007, and
3. will include safety limits (SLs), limiting safety system settings (LSSSs), limiting conditions for operation (LCOs), surveillance requirements (SRs), design features, and administrative controls.

In PSAR Table 14.1-1, Kairos provides variables and conditions that it expects to be subject to TSs, based on its preliminary safety analysis described in other PSAR chapters. PSAR Table 14.1-1 also summarizes Kairos's basis for each listed TS variable or condition.

PSAR Table 14.1-1 indicates that SLs will be placed on certain process variables, specifically fuel temperature and reactor vessel surface temperature, to ensure fuel and vessel integrity are maintained consistent with the safety analyses. LSSSs will be established for core exit reactor coolant temperature(s), coolant level, neutron flux (i.e., reactor power), and rate of change of neutron flux (i.e., reactor period), to ensure that the SLs are not exceeded and that the reactor will trip prior to reaching a SL.

During the General Audit (ML23160A287), Kairos confirmed that the exact number of separate LSSSs (i.e., one or more) for core exit reactor coolant temperature, as well as the specific location(s) of associated monitors and their setpoints, will be provided in an OL application and will be based on a final thermal-hydraulic analysis that will also be provided in an OL application. Kairos also confirmed that these details of LSSSs for core exit reactor coolant temperature in an OL will also consider that the defueling chute, rather than the outlet plenum, could have the highest coolant temperatures. In addition, Kairos confirmed that in an OL application it will demonstrate by a final thermal-hydraulic analysis that its proposed LSSSs are comprehensive and, specifically that LSSS(s) for vessel temperature are not necessary to ensure that the SLs will not be exceeded.

PSAR Table 14.1-1 indicates that LCOs, which are the lowest functional capability or performance level required for safe operation of the Hermes facility, will be provided in the TSs, will be derived from the safety analyses, and will be implemented administratively or by control and monitoring systems to ensure safe operation of the facility. Proposed subjects of LCOs listed in PSAR Table 14.1-1 include:

- reactor core parameters (pebble wear and reactor power).
- reactor control and safety systems (reactivity coefficients that ensure the severity of reactivity transients is limited, and reactor protection system operability).
- coolant systems (reactor coolant chemical composition, coolant radionuclide inventory, primary heat transport system (PHTS) pressure and flow rate, inert gas system pressure, cover gas purity, PHTS gas space materials at risk (i.e., gas space radionuclide inventory available for release), and quantity of air in the reactor system).
- engineered safety features (decay heat removal system operability).
- radiation monitoring systems and effluents.

Other PSAR chapters discuss additional probable subjects of TSs (which could include LCOs, but also design features) including shutdown margin, moderator pebble to fuel pebble ratio, and fuel enrichment (PSAR Section 4.5.4.2), and pebble burnup limits (PSAR Section 9.3.4).

PSAR Table 14.1-1 indicates that SRs relating to test, calibration, or inspection to ensure the necessary quality of systems and components is maintained; design features, which if altered or modified, could have a significant effect on safety; and administrative controls necessary to ensure safe Hermes facility operation, will be provided in the TSs included in an application for an OL.

PSAR Section 14.2 and PSAR Table 14.2-1 describe five operational modes for the Hermes TSs, which are defined in terms of combinations of core reactivity, reactor power, and nominal reactor coolant outlet temperature.

The staff evaluated the sufficiency of the preliminary information on Hermes TSs, as described in PSAR Chapter 14, using the guidance and acceptance criteria from Chapter 14 of NUREG-1537, Parts 1 and 2. In its evaluation, the staff also considered the preliminary safety analysis information and discussions of the probable subjects of TSs in other PSAR chapters. The staff finds that Kairos's probable subjects of TSs are consistent with important parameters determined as a result of the preliminary safety analyses in the PSAR, with special attention given to items (e.g., SLs, LSSSs, and LCOs) that may significantly influence the final design, and that the probable subjects of TSs are supported by appropriate bases. Regarding Kairos's probable LSSS for rate of change of neutron flux, the staff finds that such an LSSS would provide a defense-in-depth to limit the temperature difference between the kernel and pebble surface limiting the fission gas pressure increase (even if SL temperatures are not reached), consistent with limitations in Kairos's fuel qualification topical report, "Fuel Qualification Methodology for the Kairos Power Fluoride Salt-Cooled, High Temperature Reactor (KP-FHR), Revision 2" (see Section 4.2.1 of this safety evaluation). The staff expects that additional subjects of TSs, including additional LCOs on reactor core parameters (e.g., excess reactivity and core reactivity) and reactor control and safety systems (e.g., control elements) will likely be needed, but finds that other probable subjects of TSs beyond those specifically listed in PSAR Chapter 14 are, in general, less likely to significantly influence the final design. Therefore, based on the information in PSAR Chapter 14 and other PSAR chapters, the staff finds that Kairos's identification and justification of the preliminary subjects of TSs meets the applicable acceptance criteria in NUREG-1537 and is sufficient for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. The staff will perform a detailed evaluation of the complete and finalized TSs for Hermes, including SLs, LSSSs, LCOs, SRs, design features, and administrative controls, during its review of a Hermes OL application.

14.4 Conclusion

Based on its findings above, the staff concludes the information in PSAR Chapter 14 is sufficient and meets the applicable guidance and regulatory requirements identified in this section for the issuance of a CP in accordance with 10 CFR 50.35 and 50.40. Further information, including a complete set of Hermes TSs and associated bases, as may be required to complete the review of a Hermes OL application can reasonably be left for later consideration in a final safety analysis report since this information is not necessary for the review of a CP application.

14.5 Summary and Conclusions on Technical Specifications

The staff evaluated the information on the Hermes TSs as described in PSAR Chapter 14, and finds that the preliminary TS methodology: (1) meets all applicable regulatory requirements, and (2) meets the applicable acceptance criteria in NUREG-1537, Part 2. Based on these findings, the staff makes the following conclusions regarding issuance of a CP in accordance with 10 CFR 50.35 and 10 CFR 50.40:

- Kairos has described the proposed design of the facility, including, but not limited to, the principal engineering criteria for the design, and has identified the major features or components incorporated therein for the protection of the health and safety of the public.

- Such further technical or design information as may be required to complete the safety analysis of the Hermes TSs, and which can reasonably be left for later consideration, will be provided in the final safety analysis report.
- There is reasonable assurance: (i) that the construction of the facility will not endanger the health and safety of the public, and (ii) that construction activities will be conducted in compliance with the Commission's regulations.

- The issuance of a permit for the construction of the Hermes facility would not be inimical to the common defense and security or to the health and safety of the public.

14.6 References

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Kairos Power LLC, "Fuel Qualification Methodology for the Kairos Power Fluoride Salt-Cooled High Temperature Reactor (KP-FHR)," KP-TR-011-NP-A, Revision 2, June 2022, ML23089A398 (redacted version).

-----. "Submittal of the Preliminary Safety Analysis Report for the Kairos Power Fluoride Salt-Cooled, High Temperature Non-Power Reactor (Hermes), Revision 3," May 31, 2023, Pkg. ML23151A743.

Nuclear Regulatory Commission (U.S.) (NRC). NUREG-1537, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors," Part 1, "Format and Content," and Part 2, "Standard Review Plan and Acceptance Criteria." NRC: Washington, D.C. February 1996. ADAMS Accession Nos. ML042430055 and ML042430048.

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15 FINANCIAL QUALIFICATIONS

Financial qualifications establish whether an applicant is financially qualified to own, construct, operate, and decommission a non-power production or utilization facility. Financial qualifications related to the issuance of a construction permit (CP) include estimates of construction costs, estimates of fuel cycle costs, and sources to cover costs.

This chapter of the Hermes CP safety evaluation describes the U.S. Nuclear Regulatory Commission (NRC) staff's review and evaluation of Kairos's financial qualifications as presented in Chapter 15, "Financial Qualifications," of the Hermes Preliminary Safety Analysis Report, Revision 3.

15.1 Financial Ability to Construct the Hermes Facility

15.1.1 Introduction

In a proprietary enclosure with the application, Kairos provided information concerning whether Kairos Power LLC is financially qualified to, among other things, construct the Hermes facility. The application includes required financial information for a CP, as set forth by the NRC in 10 CFR 50.33(f), which demonstrates that Kairos possesses or has reasonable assurance of obtaining the necessary funds to cover estimated construction costs and related fuel cycle costs. The application includes estimates of the total construction costs of the facility and related fuel cycle costs and indicates the sources of funds to cover these costs.

15.1.2 Regulatory Evaluation

The applicable regulatory requirements for the evaluation of Kairos's financial ability to construct the Hermes facility are as follows:

- 10 CFR 50.33, Contents of Applications; General Information, paragraph (f)(1) requires that Kairos "submit information that demonstrates that the applicant possesses or has reasonable assurance of obtaining the funds necessary to cover estimated construction costs and related fuel cycle costs. The applicant shall submit estimates of the total construction costs of the facility and related fuel cycle costs and shall indicate the source(s) of funds to cover these costs."
- 10 CFR, Part 50, Appendix C, II.A.1, "Estimate of construction costs" refers to Appendix C, I.A.1 for the information required to be submitted with an application. Appendix C, I.A.1 requires that the estimate "be itemized by categories of cost in sufficient detail to permit an evaluation of its reasonableness."
- 10 CFR, Part 50, Appendix C, II.A.2, "Source of construction funds" requires that the application "specifically identify the source or sources upon which the applicant relies for the funds necessary to pay the cost of constructing the facility and the amount to be obtained from each."

The applicable guidance for the evaluation of Kairos's financial qualifications is:

- NUREG-1537, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors," Part 2, Section 15.1, "Financial Ability to Construct a Non-Power Reactor."

15.1.3 Technical Evaluation

15.1.3.1 Construction Costs

Pursuant to 10 CFR 50.33(f)(1) and 10 CFR Part 50, Appendix C, Section II.A.1, "Estimate of construction costs," which references the requirements in Appendix C, Section I.A.1, Kairos provided the projected costs for the construction of the proposed test reactor in a proprietary enclosure to the application. The costs included estimates for coolant, fuel for the initial core, and overnight capital. The Kairos estimates are proprietary and are not provided in this public safety evaluation.

As part of the General Audit (ML23115A480), the staff reviewed the Hermes overnight capital cost (OCC) and fuel cost target model, including the basis for each element of the estimate and associated statistical analyses. According to Kairos, the estimate for OCC, excluding fuel, is based on a top-down cost model and validated through a bottoms-up cost model, which incorporates experience from manufacturing, procurement, contracting, and construction costs for Kairos's Engineering Test Unit. The staff reviewed the detailed OCC model inputs and found that the OCC target for the Hermes reactor is reasonable.

Based on a detailed review of the cost to construct the facility and the supporting bases and assumptions discussed above, the staff finds that the Kairos's cost estimate is reasonable.

15.1.3.2 Sources of Construction Funds

According to the application, funding for the design and construction costs (including reactor coolant and initial fuel load) relies on raised equity funding, grants, and other state and local incentives. As of the time of this evaluation, Kairos has secured funding from the following sources:

- Equity financing raised (including a Department of Energy Advanced Reactor Demonstration Program Award)
- State of Tennessee Employment, Franchise, Sales, and Property Tax Credits
- State of Tennessee FastTrack Economic Development Grant

The amount of funding available exceeds the estimated cost to construct the facility, creating a contingency allowance. The application states that this contingency allowance by Kairos investors is available, if needed, for Hermes. The staff finds that the contingency allowance provides additional assurance that Kairos has, or can obtain, the required funding for the project.

During the General Audit, staff reviewed a verification letter from an investment firm that manages assets for Kairos Power LLC investors, stating that these investors have sufficient financial resources to fund a project of this scale. Staff considered the letter and finds that it provides additional assurance that the funding is, in fact, in place and can be made available to fund the project.

The staff compared the total estimated cost to the total secured funding available to complete the project and found that the available funding, including contingency funding, exceeded the estimated cost. Therefore, based on the general financial plan described in the application and financial commitments currently in place, the staff finds that Kairos’s financial plan is reasonable.

15.1.4 Conclusion

Kairos has supplied financial information for construction and nuclear fuel inventory cost. The staff reviewed the financial ability of Kairos to construct the proposed facility and to cover fuel cycle costs. The staff finds that the financial information provided satisfies the applicable acceptance criteria of NUREG-1537, Part 2, Section 15.1, and demonstrates adequate financial assurance for construction. The staff concludes that there is reasonable assurance that funds will be made available to construct and cover fuel cycle costs for the facility and that the financial status of Kairos regarding construction and fuel cycle costs is in accordance with the requirements of 10 CFR 50.33(f). Therefore, the staff concludes that Kairos’s financial qualifications for construction of the Hermes facility and associated fuel cycle costs are acceptable.

Based on its findings and conclusions above, the staff concludes the information on financial ability to construct the Hermes facility is sufficient and meets the applicable guidance and regulatory requirements identified in this section for the issuance of a construction permit in accordance with 10 CFR 50.40.

15.2 Financial Ability to Operate the Hermes Facility

Information related to Kairos’s financial qualifications to operate the Hermes facility will be reviewed as part of the operating license (OL) application review process.

15.3 Financial Ability to Decommission the Hermes Facility

Information related to funds that be available to decommission the Hermes facility will be reviewed as part of the OL application review process.

15.4 Foreign Ownership, Control, or Domination

15.4.1 Introduction

Section 104 of the Atomic Energy Act (AEA) of 1954, as amended, prohibits the Commission from issuing a license to an alien, a foreign corporation, or other entity if the Commission knows or has reason to believe it is owned, controlled, or dominated by an alien, a foreign corporation, or a foreign government.

15.4.2 Regulatory Evaluation

The regulations in 10 CFR 50.38, “Ineligibility of certain applicants,” implements the Foreign Ownership, Control, or Domination (FOCD) provisions of the AEA. The staff evaluates licensing applications in a manner that is consistent with the guidance provided in the NRC “Final Standard Review Plan on Foreign Ownership, Control, or Domination” published in the *Federal Register* on September 28, 1999 (64 FR 52355), to determine whether an applicant is owned, controlled, or dominated by an alien, a foreign corporation, or a foreign government. The NRC’s position on FOCD, outlined in the review plan, states that “the foreign control limitation should be given an orientation toward safeguarding the national defense and security.” Further, the review plan on FOCD outlines how the effects of foreign ownership may be mitigated through implementation of a “negation action plan” to ensure that any foreign interest is effectively denied control or domination over the licensee.

15.4.3 Technical Evaluation

Kairos states that it is a limited liability company formed in the State of Delaware with a principal place of business in Alameda, California. Kairos is a privately held company with a limited number of investors, all of whom are U.S. citizens or entities owned or controlled by U.S. citizens. Additionally, Kairos states that employees with the options to hold future shares totaling one percent or more of Kairos’s stock or options are U.S. citizens or entities owned or controlled by U.S. citizens. Finally, Kairos Power LLC key management personnel, specifically the Chief Executive Officer, is a U.S. citizen and may be contacted through the Kairos Power LLC headquarters address.

The staff conducted an independent analysis, including open-source research and verification of the information provided in the application related to ownership of Kairos Power LLC, and found no evidence of FOCD.

15.4.4 Conclusion

Based on its own research and independent analysis of the information provided in the application, the staff does not know or have reason to believe that Kairos is owned, controlled, or dominated by a foreign interest.

Based on its findings above, the staff concludes the information on foreign ownership, control, or domination is sufficient and meets the applicable guidance and regulatory requirements identified in this section for the issuance of a CP in accordance with 10 CFR 50.40.

15.5 <u>Nuclear Insurance and Indemnity</u>

15.5.1 Introduction

The Price-Anderson Act, found in Section 170 of the AEA, provides a system to pay funds for claims by members of the public for personal injury and property damage resulting from any nuclear incident. The Price-Anderson Act provides coverage in varying degrees. The Price-Anderson Act implementing regulations are found in 10 CFR Part 140. The staff evaluated the sufficiency of Kairos’s nuclear insurance and indemnity considerations, as described in Hermes Preliminary Safety Analysis Report Section 15.5, “Nuclear Insurance and Indemnity.”

15.5.2 Regulatory Evaluation

The regulations in 10 CFR 140.13 require that:

> Each holder of a Part 50 construction permit, or a holder of a combined license under Part 52 of this chapter before the date that the Commission had made the finding under 10 CFR 52.103(g), who also holds a license under Part 70 of this chapter authorizing ownership, possession and storage only of special nuclear material at the site of the nuclear reactor for use as fuel in operation of the nuclear reactor after issuance of either an operating license under 10 CFR Part 50 or combined license under 10 CFR Part 52, shall, during the period before issuance of a license authorizing operation under 10 CFR

Part 50, or the period before the Commission makes the finding under § 52.103(g) of this chapter, as applicable, have and maintain financial protection in the amount of $1,000,000. Proof of financial protection shall be filed with the Commission in the manner specified in § 140.15 of this chapter before issuance of the license under Part 70 of this chapter.

15.5.3 Technical Evaluation

As stated in its application, Kairos intends to obtain insurance and financial protection consistent with the requirements of the Price-Anderson Act, pursuant to Section 170 of AEA and the requirements in 10 CFR Part 140. After receipt of the CP and 10 CFR Part 70 license to possess fuel, Kairos will obtain financial protection of $1 million in insurance consistent with 10 CFR 140.13. Prior to operation, Kairos will obtain the full financial protection required by 10 CFR 140 using the formula provided in 10 CFR 140.12(b). The amounts of financial insurance required by 10 CFR 140.12(b) and documentation required by 10 CFR 140.15 will be provided with the application for an OL.

15.5.4 Conclusion

The staff reviewed Kairos's intent to obtain $1 million in financial protection in accordance with 10 CFR 140.13 prior to the possession of fuel. Because the CP does not authorize the possession of fuel, this item can reasonably be left for later consideration and is identified in Appendix A. Additionally, an OL application will need to identify the amounts needed for full financial protection. Proof of financial protection and execution of an indemnity agreement as required by Section 170 of the AEA will be required before an OL is issued.

Based on its findings above, the staff concludes the information on nuclear insurance and indemnity is sufficient and meets the applicable regulatory requirements identified in this section for the issuance of a CP in accordance with 10 CFR 50.40.

15.6 <u>Summary and Conclusions on Financial Qualifications</u>

The staff evaluated the information on Kairos's financial qualifications as described in PSAR Chapter 15 and proprietary documents supporting the application. Based on the information provided, the staff finds: (1) that Kairos's financial qualifications for construction of the Hermes facility and associated fuel cycle costs are acceptable and meet the requirements of 10 CFR 50.33(f), and (2) staff does not know or have reason to believe that Kairos is owned, controlled, or dominated by a foreign interest. Such further information as may be required to assess financial qualifications for operation and decommissioning, as well as proof of financial protection and execution of an indemnity agreement, which can reasonably be left for later consideration, will be supplied in the FSAR as part of the (OL) application.

Therefore, based on its review, the staff finds that the information on financial qualifications: (1) meets all applicable regulatory requirements, and (2) meets the applicable acceptance criteria in NUREG-1537, Part 2. Based on these findings, the staff makes the following conclusion regarding issuance of a construction permit in accordance with 10 CFR 50.40:

- Kairos is financially qualified to engage in the construction of its proposed facility in accordance with the Commission's regulations.

15.7 References

Kairos Power LLC. “Financial Information (Proprietary).” September 2021. ML21272A380. (proprietary information, not publicly available).

-----. “Submittal of the Preliminary Safety Analysis Report for the Kairos Power Fluoride Salt-Cooled, High Temperature Non-Power Reactor (Hermes), Revision 3,” May 31, 2023, Pkg. ML23151A743.

Nuclear Regulatory Commission (U.S.) (NRC). NUREG-1537, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors,” Part 1, “Format and Content,” and Part 2, “Standard Review Plan and Acceptance Criteria.” NRC: Washington, D.C. February 1996. ADAMS Accession Nos. ML042430055 and ML042430048.

-----. “Final Standard Review Plan on Foreign Ownership, Control, or Domination.” *Federal Register.* September 28, 1999 (64 FR 52355).

-----. “Summary Report for the Regulatory Audit of Kairos Power LLC Hermes Construction Permit Preliminary Safety Analysis Report – General Audit,” June 2023, ML23160A287.

16 OTHER LICENSE CONSIDERATIONS

The Kairos Power LLC (Kairos) preliminary safety analysis report (PSAR), Revision 3, Chapter 16, “Other License Considerations,” Section 16.1, “Prior Use of Facility Components,” states that the Hermes facility will be “constructed of new and appropriately qualified structures, systems, and components to conduct operations. Discussions regarding used systems and components are not applicable to the facility.” Additionally, in PSAR Section 16.2, “Medical Use of Non-Power Reactors,” Kairos states that the Hermes facility will “not contain equipment or facilities associated with direct medical administration of radioisotopes or other radiation-based therapies and [Kairos] has no plans at this time to support medical uses. Therefore, discussions involving medical use of the facility are not applicable.” PSAR Chapter 16 does not identify any other special license considerations that are not discussed elsewhere in the PSAR.

The U.S. Nuclear Regulatory Commission (NRC) staff (the staff) evaluated the information on the Hermes facility in the PSAR and finds that the preliminary design of the Hermes facility does not include prior use components and that the Hermes facility will not be used for direct medical therapy. Furthermore, the staff did not identify any other special license considerations relevant to Hermes that are not addressed elsewhere in the PSAR and considered in other chapters of this safety evaluation (SE), as appropriate. The staff concludes that an evaluation using the guidelines of NUREG-1537, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors,” Part 2, “Standard Review Plan and Acceptance Criteria,” Chapter 16, “Other License Considerations,” is not necessary because:

1. All equipment to be installed in the Hermes facility will be new and purpose-built. No prior use components will be used in the construction of the reactor or support systems.
2. The Hermes facility will not contain equipment or facilities associated with the direct medical administration of radioisotopes or other radiation-based therapies.
3. There are no identified license considerations relevant to Hermes that are not considered elsewhere in this SE.

16.1 References

Kairos Power LLC. “Submittal of the Preliminary Safety Analysis Report for the Kairos Power Fluoride Salt-Cooled, High Temperature Non-Power Reactor (Hermes), Revision 3,” May 31, 2023, Pkg. ML23151A743..

The U. S. Nuclear Regulatory Commission (NRC). NUREG-1537, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors,” Part 2, “Standard Review Plan and Acceptance Criteria.” NRC: Washington, D.C. February 1996. ML042430048.

17 DECOMMISSIONING AND POSSESSION-ONLY LICENSE AMENDMENTS

The Kairos Power LLC (Kairos) preliminary safety analysis report (PSAR), Revision 3, Chapter 17, “Decommissioning and Possession Only License Amendments,” Section 17.1, “Decommissioning,” states that a decommissioning report for the Hermes facility will be provided with an operating license application, as required by Title 10 of the *Code of Federal Regulations* (10 CFR) Section 50.33, “Contents of applications; general information,” paragraph (k). Furthermore, PSAR Section 17.2, “Possession-Only License Amendments,” states that possession-only licenses are not applicable to the construction and operation phases of the Hermes facility. Kairos’s construction permit application did not include a decommissioning report or plan, or a possession-only license amendment request.

The U.S. Nuclear Regulatory Commission (NRC) staff (the staff) notes that 10 CFR 50.33(k) requires an applicant for an operating license for a utilization facility to submit a decommissioning report but does not require an applicant for a construction permit for a utilization facility to submit a decommissioning report or plan. The guidance of NUREG-1537, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors,” Part 2, “Standard Review Plan and Acceptance Criteria,” Chapter 17, Decommissioning and Possession-Only License Amendments,” indicates that decommissioning plans and applications for possession-only licenses “are submitted by nonpower reactor licensees who wish to terminate operations and decommission their facilities.” The staff evaluated PSAR Chapter 17 considering these requirements and guidance. Because Kairos’s application seeks a construction permit for a utilization facility, and because Kairos is not seeking a possession-only license, the staff concludes that no decommissioning information or possession-only license amendment request needs to be provided in the PSAR or evaluated by staff for the issuance of a construction permit for a utilization facility under 10 CFR Part 50, “Domestic Licensing of Production and Utilization Facilities.”

17.1 References

Kairos Power LLC. “Submittal of the Preliminary Safety Analysis Report for the Kairos Power Fluoride Salt-Cooled, High Temperature Non-Power Reactor (Hermes), Revision 3,” May 31, 2023, Pkg. ML23151A743.

The U. S. Nuclear Regulatory Commission (NRC). NUREG-1537, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors,” Part 2, “Standard Review Plan and Acceptance Criteria.” NRC: Washington, D.C. February 1996. ML042430048.

18 HIGHLY ENRICHED TO LOW-ENRICHED URANIUM CONVERSION

The Kairos Power LLC (Kairos) preliminary safety analysis report (PSAR), Revision 3, Chapter 18, “Highly Enriched to Low Enriched Uranium Conversion,” states that the Hermes reactor fuel will be high-temperature graphite-matrix coated tristructural isotropic (TRISO) particles using high-assay, and low-enriched uranium (LEU). The Hermes facility will not utilize highly enriched uranium (HEU), i.e., uranium that is enriched to 20 percent or more in uranium-235.

The U.S. Nuclear Regulatory Commission (NRC) staff (the staff) evaluated the information on the Hermes facility in the PSAR and finds that the preliminary design of the Hermes facility does not utilize HEU. Therefore, the staff concludes that an evaluation of HEU to LEU conversion using the guidelines of NUREG-1537, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors,” Part 2, “Standard Review Plan and Acceptance Criteria,” Chapter 18, “Highly Enriched to Low-Enriched Uranium Conversions,” is not necessary.

18.1 References

Kairos Power LLC. “Submittal of the Preliminary Safety Analysis Report for the Kairos Power Fluoride Salt-Cooled, High Temperature Non-Power Reactor (Hermes), Revision 3,” May 31, 2023, Pkg. ML23151A743..

The U. S. Nuclear Regulatory Commission (NRC). NUREG-1537, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors,” Part 2, “Standard Review Plan and Acceptance Criteria.” NRC: Washington, D.C. February 1996. ML042430048.

APPENDIX A
POST CONSTRUCTION PERMIT ACTIVITIES - CONSTRUCTION PERMIT CONDITIONS AND ADDITIONAL ITEMS FOR THE OPERATING LICENSE APPLICATION

A.1 Construction Permit Conditions

The U.S. Nuclear Regulatory Commission (NRC) staff (the staff) has determined that a construction permit (CP) needs to be conditioned to require that Kairos will perform analysis of excavations for safety related structures at the site, and implement its quality assurance program during construction. Therefore, the staff recommends that, should the permit be granted, the CP include the conditions set forth below. Additional details on the basis for each of these conditions appears in Chapter 2, "Site Characteristics," and Chapter 12, "Conduct of Operations," of the Hermes CP safety evaluation (SE).

Proposed Permit Condition	SE Section	Description
1	2.5, Geology, Seismology, and Geotechnical Engineering	In order to confirm that the exposed bedrock does not show signs of karstic dissolution when the excavations are complete and before the foundation is prepared, Kairos shall perform detailed geologic mapping of excavations for safety related engineered structures; examine and evaluate geologic features discovered in those excavations; and notify the Director of the Office of Nuclear Reactor Regulation, or the Director's designee, as specified in Title 10 of the *Code of Federal Regulations* (10 CFR), Section 50.4, "Written communications," once excavations for safety related structures are open for examination by Staff.
2	12.9, Quality Assurance	In order to provide reasonable assurance that regulatory requirements and license commitments for Quality Assurance (QA) are adequately included in the design, procurement, and construction of the Hermes facility, Kairos shall implement the QA program described, pursuant to 10 CFR 50.34(a)(7), in Chapter 12, Appendix B, of Revision 3 of the Hermes Preliminary Safety Analysis Report (PSAR), including revisions to the QA program in accordance with the provisions below. Kairos may make changes to its previously accepted QA program description without prior Commission approval, provided the changes do not reduce the commitments in the QA program description as accepted by the Commission. Changes to the QA program description that do not reduce the commitments must be submitted to the Commission within 90 days. Changes to the QA program description that do reduce the commitments must be submitted to the Commission and receive Commission approval prior to implementation, as follows:

		• Changes must be submitted as specified in 10 CFR 50.4. • The submittal of changes to the QA program description must include all pages affected by the changes and must be accompanied by a forwarding letter identifying the changes, the reason for the changes, and the basis for concluding that the revised program incorporating the changes continues to satisfy the PSAR Revision 3 QA program description commitments previously accepted by the NRC (the letter need not provide the basis for changes that correct spelling, punctuation, or editorial items). • A copy of the forwarding letter identifying the changes must be maintained as a record by Kairos for three years. • Changes to the QA program description shall be regarded as accepted by the Commission upon Kairos's receipt of a letter to this effect from the appropriate reviewing office of the Commission or 60 days after Kairos's submittal to the Commission, whichever occurs first.

A.2 Additional Items for an Operating License Application

The Hermes CP application provided a preliminary design. In the PSAR and during audit meetings, Kairos identified elements of design, analysis, and administration that require additional development or resolution. The staff determined that resolution of these items is not necessary for the issuance of a CP, but that Kairos should ensure that these items are fully addressed in the Final Safety Analysis Report (FSAR) supporting an operating license (OL) application. The staff is tracking these items to ensure that significant issues are considered during the review of an OL application for the Hermes test reactor.

These items constitute information needs but do not form the only acceptable set of information for the FSAR. In addition, these items do not relieve Kairos from any requirement in the regulations that governs the application. After issuance of an OL, these items are not controlled by NRC requirements unless such items are restated in the FSAR.

PSAR Section and/or Related Audit Question	Associated Documents	Description
Section 1.7, Compliance with the Nuclear Waste Policy Act of 1982		In PSAR Section 1.7, Kairos stated that it will provide additional information in the OL application regarding the disposition of high-level waste and spent nuclear fuel.
Section 2.2.3, Analysis of Potential Accidents at Facilities		In PSAR Section 2.2.3, Kairos stated that the location and quantities of onsite chemical storage have not yet been determined, so the effects of potential hazards from onsite chemicals will be evaluated in the OL application.
Section 2.2.3.4, Fires		In PSAR Section 2.2.3.4, Kairos stated that effects of potential brush or forest fires will be evaluated in the OL application.
Section 2.3.5, Long-Term Atmospheric Dispersion Estimates for Routine Releases		In PSAR Section 2.3.5, Kairos stated that details regarding the long-term dispersion modeling, modeling inputs, and analysis will be provided in the OL application.
Section 2.4, Hydrology		In PSAR Section 2.4, Kairos stated that additional information relevant to stream blockage and diversion flows will be provided in the OL application.
Section 2.4.2, Floods, and Section 2.4.3, Credible Hydrological Events and Design Basis		PSAR Sections 2.4.2 and 2.4.3 stated that a probable maximum flood (PMF) study will be discussed with the application for an OL. The PMF evaluation should consider flood elevations induced by local intense precipitation and watershed wide probable maximum precipitation events.

PSAR Section and/or Related Audit Question	Associated Documents	Description
Section 2.4.4, Groundwater		In PSAR Section 2.4.4, Kairos stated that seasonal changes to groundwater levels will be addressed in the OL application.
Section 2.5.2.1, Karst, and Section 2.5.4.3, Karst; Site Characteristics Audit (ML22143B016) Question 2.5-11		In PSAR Sections 2.5.2.1 and 2.5.4.3, Kairos stated that it will supplement the karst investigations with a set of tests and surveys in the OL application. These tests and surveys include site reconnaissance, light detection and ranging imaging, and inventory of surface depressions in the site area. In addition, deeper boreholes will be drilled at the reactor location selected. Rock cores recovered will be analyzed in the laboratory to characterize the karst features. A site model of the karst features will be developed and presented with the OL application.
Section 2.5.2.3, Soil Borings; Site Characteristics Audit Question 2.5-3		In PSAR Section 2.5.2.3, Kairos presented results from preliminary laboratory testing of site soil layers limited to soil index properties. Kairos stated that a more comprehensive characterization of the geotechnical properties of both soil and rock layers present at the proposed site will be provided in the OL application. The network of rock fractures (e.g., rock joints, bedding planes, small faults, etc.) will be characterized and used to evaluate the bearing capacity and expected settlement of the reactor foundation.
Section 2.5.3, Vibratory Ground Motion; NRC Preliminary Question 2.5-1 (ML22024A492)	KP-NRC-2202-002 (ML22040A336)	PSAR Section 2.5.3 relies on the information of the Clinch River Early Site Permit application's earthquake catalog, which ends in 2013. In KP-NRC-2202-002, Kairos stated that an updated earthquake catalog will be provided in the OL application to demonstrate that the assumptions and conclusions in the Clinch River probabilistic seismic hazard analysis (PSHA) remain valid.
Section 2.5.3, Vibratory Ground Motion		In PSAR Section 2.5.3, Kairos stated the design response spectra will be supplemented with site response spectra analyses that rely on in-situ shear wave velocity measurements derived from the Clinch River PSHA and updated as appropriate in the OL application.

PSAR Section and/or Related Audit Question	Associated Documents	Description
Section 2.5.4.1, Surface Faulting		In PSAR Section 2.5.4.1, Kairos stated that information on surface faulting will be provided in the OL application.
Section 2.5.4.2, Liquefaction Potential; Site Characteristics Audit Question 2.5-16		In PSAR Section 2.5.4.2, Kairos proposed to place the Hermes non-safety related foundation mat over a fill. Kairos will address the effects of potential liquefaction on the foundations of the non-safety related structures surrounding the reactor in the OL application.
Section 2.5.5.2.1, Bearing Capacity; Site Characteristics Audit Question 2.5-5		In PSAR Section 2.5.5.2.1, Kairos proposed to provide additional details on the bearing capacity and expected settlement of the safety related reactor foundation and the non-safety related structures in the OL application. In addition, additional details will be provided on the lateral pressure on the reactor structure and non-safety related structures.
Section 3.4.1.5, Structural Model, and Section 3.4.1.6, Response Analysis		In PSAR Sections 3.4.1.5 and 3.4.1.6, Kairos stated that additional details on the models, including the structural model finite element results, assignment of the structural mass, and modeling methods and assumptions for the soil-structure interaction analysis and seismic response analysis, will be provided in the OL application.
Section 3.5.3.2.1, External Flood Design Features		In PSAR Section 3.5.3.2.1, Kairos stated that it will provide the description of the specific grading and drainage features in the OL application. The impacts of the site grading and drainage on the safety related structures, systems, and components (SSCs) should be addressed.
Section 3.5.3.2.2, Internal Flood and Spray Design Features		In PSAR Section 3.5.3.2.2, Kairos stated that it will specify automatic or a manual termination of flow for water sources external to the safety-related portion of the Reactor Building (e.g., fire water) in the OL application.
Section 3.5.3.2.2, Internal Flood and Spray Design Features		In PSAR Section 3.5.3.2.2, Kairos stated further information on the analysis of the impacts of internal flooding and spraying will be provided in the OL application.

PSAR Section and/or Related Audit Question	Associated Documents	Description
Section 3.5.3.3.2, Seismic Isolation System		In PSAR Section 3.5.3.3.2, Kairos stated that it will provide further details of the base isolation system and associated structural analysis in the OL application.
Section 3.5.3.4, Conformance with PDC 2 for Other Hazards		In PSAR Section 3.5.3.4, Kairos stated additional detail about the structural design features for the safety-related portion of the Reactor Building, informed by the results of the hazards analysis, will be provided in the OL application.
Table 3.6-2, Design and Construction Codes and Standards for Fluid Systems		In footnote 6 to PSAR Table 3.6-2, Kairos stated that departures from American Society of Mechanical Engineers (ASME) Code requirements, if needed, will be identified in the OL application.
General Audit (ML22039A336) Question 3.6-1	KP-TR-013-NP, Revision 4 (ML22263A456)	Kairos stated during the audit that the OL application will document that safety related metallic components in the reactor vessel system are bounded by testing conditions in referenced topical report KP-TR-013-NP, "Metallic Materials Qualification for the Kairos Power Fluoride Salt-Cooled High-Temperature Reactor," Revision 4.
Section 4.2.1.2, Fuel Qualification	EPRI-AR-1(NP)-A (ML20336A052)	In PSAR Section 4.2.1.2, Kairos stated that it will demonstrate that the fuel meets the conditions and limitations of the NRC SE for EPRI-AR-1(NP)-A, "Uranium Oxycarbide (UCO) Tristructural (TRISO)-Coated Particle Fuel Performance" as part of the OL application.
Section 4.2.1.6, Evaluation of Fuel Design Bases		In PSAR Section 4.2.1.6, Kairos stated that the results of a laboratory testing program to confirm that the fuel's physical form is maintained during operation, the pebble remains buoyant, and there is no significant salt infiltration into the pebble will be provided in the OL application.
Section 4.2.2.3, System Evaluation		In PSAR Section 4.2.2.3, Kairos stated that the Reactivity Control and Shutdown System shutdown element insertion versus time will be provided in the OL application.
Section 4.3, Reactor Vessel System;		PSAR Section 4.3 stated that coolant purity limits will be established with consideration

PSAR Section and/or Related Audit Question	Associated Documents	Description
General Audit question 4.3-6		given to chemical attack and fouling of the vessel. During the audit Kairos indicated the OL application will provide relevant coolant purity limits and describe the bases for establishing the limits, required actions, and time to complete these actions.
Section 4.3 Reactor Vessel System; General Audit question 4.3-8		PSAR Section 4.3 stated the graphite reflector will be qualified and designed to meet ASME Boiler and Pressure Vessel Code Section III Division 5 requirements. During the audit, Kairos indicated the OL application will describe how all applicable requirements of the ASME Boiler and Pressure Vessel Code Section III Division 5 are met.
Section 4.3 Reactor Vessel System; General Audit question 4.3-11		PSAR Sections 4.3.1.1 and 4.3.1.2 state that the vessel and vessel internals are designed to support on-line monitoring, inspection, and maintenance activities. Kairos stated during the general audit (ML23160A287) that the OL application will provide additional details on how vessel integrity will be assured through monitoring and inspection programs and confirm the vessel is designed to allows for those programs.
Section 4.3.4, Testing and Inspection		In PSAR Section 4.3.4, Kairos stated that an inservice inspection program that includes the reactor vessel and internals will be provided in the OL application.
Section 4.4.3, Biological Shield - Evaluation		In PSAR Section 4.4.3, Kairos stated that an evaluation of the performance of the biological shield to meet 10 CFR Part 20, “Standards for Protection Against Radiation,” will be provided in the OL application.
Section 4.5.1.1, Overview of Core Nuclear Design		In PSAR Section 4.5.1.1, Kairos stated that initial startup and power ascension will be discussed in the OL application.
Section 4.5, Nuclear Design; Accident Analysis Audit (ML22041B665) question 67		Kairos stated during the audit that the OL application will provide specific details of the pebble burnup monitoring.

PSAR Section and/or Related Audit Question	Associated Documents	Description
Section 4.6.1.2, Coolant Flow Path		In PSAR Section 4.6.1.2, Kairos stated that qualification or functional testing plans and results needed to validate performance assumed in the safety analysis will be provided in the OL application.
Section 4.6.3, System Evaluation		In PSAR Section 4.6.3, Kairos stated that the results of analyses supporting the inherent stability of the reactor will be provided in the OL application.
Section 4.7.4, Testing and Inspection		In PSAR Section 4.7.4, Kairos stated that an inservice inspection program that includes the reactor vessel support system will be provided in the OL application.
Section 5.1.1.1, Reactor Coolant; General Audit question 5.1-13	KP-TR-005-NP-A, Revision 1 (ML20219A591)	PSAR Section 5.1.1.1 stated that the properties of the Flibe reactor coolant can be found in KP-TR-005-NP-A, Revision 1. Kairos stated during the audit that the OL application will describe how Flibe properties are confirmed.
Section 5.1.3, Primary Heat Transport System		In PSAR Section 5.1.3, Kairos stated that thermodynamic data to calculate transport of radionuclides through Flibe will be justified in the OL application.
Section 5.1.3, Primary Heat Transport System; General Audit question 5.1-4		PSAR Section 5.1.3 describes a postulated air ingress event. Kairos stated during the audit that the OL application will provide results of material qualification testing related to postulated air ingress into the primary heat transport system (PHTS) and its effects on materials used in the reactor vessel system, including graphite components.
Section 5.1.4, Primary Heat Transport System		In PSAR Section 5.1.4, Kairos stated that descriptions of testing and inspection of PHTS will be provided with the OL application.
Section 6.2, Functional Containment		In PSAR Section 6.2, Kairos stated that the specified acceptable system radionuclide release design limits and technical specifications supporting the functional containment concept will be provided in the OL application.
Section 6.3, Decay Heat Removal System (DHRS) Audit		Kairos stated during the audit that the OL application will evaluate the magnitude and

PSAR Section and/or Related Audit Question	Associated Documents	Description
(ML22039A226) question 6.3-10		effects of thermal gradient asymmetry in the event of loss of inventory in one DHRS train.
Section 6.3.4, Decay Heat Removal System		In PSAR Section 6.3.4, Kairos stated that descriptions of testing and inspection of DHRS will be provided with the OL application.
Section 7.2.3, System Evaluation		In PSAR Section 7.2.3, Kairos stated that further analysis of the timeliness of Plant Control System (PCS) signals will be provided in the OL application.
Section 7.2.3, System Evaluation		In PSAR Section 7.2.3, Kairos stated that specific design features and the SSCs to which they are applied will be provided in the OL application.
Section 7.2.3, System Evaluation		In PSAR Section 7.2.3, Kairos stated that additional information on the PCS that is dependent on the final design of reactor SSCs, such as hardware and software specifics, software flow diagrams, a description of how the operation and support requirements will be met, and the basis for PCS system reliability and reliability targets, will be provided in the OL application.
Section 7.3, Reactor Protection System		In PSAR Section 7.3, Kairos stated that the final design for the neutron flux monitoring will be provided in the OL application.
Section 7.3, Reactor Protection System		In PSAR Section 7.3, Kairos stated that the Reactor Protection System (RPS) alarm signals to the main control room and information on the minimum redundancy in the RPS to permit period testing without compromising RPS function will be provided in the OL application.
Section 7.3, Reactor Protection System		In PSAR Section 7.3, Kairos stated that a description of how the RPS operational and support requirements will be met, including the enclosure housing the RPS cabinets, will be provided in the OL application.
Section 7.4.3.1, Main Control Room		In PSAR Section 7.4.3.1, Kairos stated that a description of the analysis of operator dose will be provided in the OL application.

PSAR Section and/or Related Audit Question	Associated Documents	Description
Section 7.4.3.2, Remote Onside Shutdown Panel		In PSAR Section 7.4.3.2, Kairos stated that procedures for safe shutdown of the reactor through the remote onsite shutdown panel will be provided in the OL application.
Section 7.5.3, Sensors–System Evaluation		In PSAR Section 7.5.3, Kairos stated that the number and type of RPS sensors needed to be consistent with the safety analysis and their suitability for their operating environment will be provided in the OL application.
Table 7.5-1, Parameter Range for Safety-Related Sensors		In PSAR Table 7.5-1, Kairos stated that the parameter ranges for vessel level, area radiation, source range neutronics, and power range neutronics will be provided in the OL application.
Table 7.5-2, Parameter Range for Non-Safety Related Sensors		In PSAR Table 7.5-2, Kairos stated that the parameter ranges for vessel level, area radiation, pressure, and flow rate in the reactor vessel will be provided in the OL application.
Section 8.3.1.1, Backup Generators		In PSAR Section 8.3.1.1, Kairos stated that a list of the specific essential loads that receive backup power will be provided in the OL application.
Section 9.1.1, Chemistry Control System		In PSAR Section 9.1.1, Kairos stated that a list of the specific essential loads that receive backup power will be provided in the OL application.
Section 9.1.1, Chemistry Control System; General Audit question 9.1-3		Kairos stated during the audit that the OL application will provide all coolant purity specifications, required actions, time to complete these actions if specifications are not met, and how the specifications are consistent with results of material compatibility testing (e.g., metallic material corrosion testing, fuel qualification testing, etc.).
Section 9.1.1, Chemistry Control System; General Audit question 9.1-2	KP-NRC-2208-007 (ML22231B228)	In KP-NRC-2208-007, Kairos stated that the OL application will demonstrate that the Chemistry Control System can measure a well-mixed representative sample of the reactor coolant.
Section 9.1.4.1.1, RV Coolant Level Management Tank		In PSAR Section 9.1.4.1.1, Kairos stated that additional details on the inventory management system vessel level monitoring will be provided in the OL application.

PSAR Section and/or Related Audit Question	Associated Documents	Description
Section 9.3, Pebble Handling and Storage System		In PSAR Section 9.3.1.5, Kairos stated that a summary of the criticality analyses confirming the Pebble Handling and Storage System (PHSS) design maintains a safe geometrical configuration will be provided in the OL application.
Section 9.3, Pebble Handling and Storage System; General Audit question 9.3-2		Kairos stated during the audit that the OL application will provide the detailed spent fuel storage canister design, including how hydrofluoric acid effects will be managed.
Section 9.3.1.5, Pebble Inspection		In PSAR Section 9.3.1.5, Kairos stated that further details related to inspections for wear and damage of moderator and fuel pebbles will be provided in the OL application.
Section 9.4, Fire Protection Systems and Programs		In PSAR Section 9.4, Kairos stated that a description of the fire protection program and a fire hazards analysis will be provided in the OL application.
Section 9.6, Possession and Use of Byproduct, Source, and Special Nuclear Material		In PSAR Section 9.6, Kairos stated that a description of the administrative procedures related to use of byproduct, source, and special nuclear material will be provided in the OL application.
Section 9.7, Plant Water Systems; General Audit question 9.7-2		Kairos stated during the audit that the OL application will identify all auxiliary water systems which connect to a system containing radioactive material and will be designed to meet the requirements of 10 CFR 20.1406.
Section 9.7.3, Component Cooling Water System		In PSAR Section 9.7.3, Kairos stated that, for the Component Cooling Water System, specific design features and the SSCs to which they are applied will be provided in the OL application.
Section 9.8.1, Remote Maintenance and Inspection System		In PSAR Section 9.8.1, Kairos stated that, for the Remote Maintenance and Inspection System, specific design features and the SSCs to which they are applied will be provided in the OL application.
Section 9.8.4, Cranes and Rigging		In PSAR Section 9.8.4, Kairos stated that further information about the design of the superstructure in the event of a fire will be provided in the OL application.

PSAR Section and/or Related Audit Question	Associated Documents	Description
Section 11.1, Radiation Protection		In PSAR Section 11.1, Kairos stated that additional details of the radiation protection (RP) programs will be provided in the OL application.
Section 11.1.1, Radiation Sources		In PSAR Section 11.1.1, Kairos stated that additional details of radiation sources, including activity and external radiation fields in the facility, will be provided in the OL application.
Section 11.1.2, Radiation Protection Program, and Section 11.1.3, ALARA Program		In PSAR Section 11.1.2 and 11.1.3, Kairos stated that additional details for both the RP program and the as low as reasonably achievable (ALARA) program will be provided in the OL application.
Section 11.1.4, Radiation Monitoring and Surveying		In PSAR Section 11.1.4, Kairos stated that additional details of radiation monitoring and surveying, including a description of the equipment, methods, and procedures, will be provided in the OL application.
Section 11.1.5, Radiation Exposure Control and Dosimetry		In PSAR Section 11.1.5, Kairos stated that additional details on dosimetry, radiation exposure control and assess control, including locations of radiological control areas, access controls, shielding, remote handling equipment, and expected annual radiation exposures, will be provided in the OL application.
Section 11.1.5, Radiation Exposure Control and Dosimetry		In PSAR Section 11.1.5, Kairos stated that an effluent analysis corresponding to the final detailed design will be provided in the OL application.
Section 11.1.6, Contamination Control		In PSAR Section 11.1.6, Kairos stated that a description of design features for the control of radioactive contamination at the Hermes facility will be provided in the OL application.
Section 11.1.7, Environmental Monitoring		In PSAR Section 11.1.7, Kairos stated that a description of the radiological environmental monitoring program will be provided in the OL application.
Section 11.2.1, Radioactive Waste Management Program		In PSAR Section 11.2.1, Kairos stated that a detailed description of the radioactive waste management program will be provided with the OL application.

PSAR Section and/or Related Audit Question	Associated Documents	Description
Section 11.2.2, Radioactive Waste Handling Systems and Controls		In PSAR Section 11.2.2, Kairos stated that a description of radioactive waste handling systems design and controls will be provided in the OL application.
Section 11.2.3, Release of Radioactive Waste		In PSAR Section 11.2.3, Kairos stated that a description of the radioactive effluents from the facility, including points of effluent release and effluent monitoring equipment, will be provided in the OL application.
Section 12.1.3, Staffing		In PSAR Section 12.1.3, Kairos stated that specific staffing considerations, minimum staffing levels, allocation of control functions, overtime restrictions, shift turnover, procedures, training, and availability of Senior Operators during routine operations will be provided in the OL application.
Section 12.1.4, Selection and Training of Personnel		In PSAR Section 12.1.4, Kairos stated that a description of the training program and the required minimum qualifications for facility staff will be provided in the OL application.
Section 12.1.5, Radiation Safety		In PSAR Section 12.1.5, Kairos stated that details related to the authority of the RP program staff with respect to facility operations will be provided in the OL application.
Section 12.2, Review and Audit Activities		In PSAR Section 12.2, Kairos stated that details of review and audit activities and who holds the approval authority and how it communicates and interacts with facility and corporate management will be provided in the OL application.
Section 12.3, Procedures		In PSAR Section 12.3, Kairos stated that a description of the facility procedures, including the review, approval, and changes processes, will be provided in the OL application.
Sections 12.4, Required Actions, 12.5, Reports, and 12.6, Records		In PSAR Sections 12.4, 12.5 and 12.6, Kairos stated that technical specifications will be provided in the OL application.
Appendix 12A, Section A.2, Authorities and Responsibilities of		In PSAR Appendix 12A, Section A.2, Kairos stated that additional roles and responsibilities for emergency response personnel emergency classification levels and the associated

PSAR Section and/or Related Audit Question	Associated Documents	Description
Facility Emergency Personnel		protective actions will be provided in the OL application.
Appendix 12A, Section B, Authorities and Responsibilities of Governmental Agencies		In PSAR Appendix 12A, Section B, Kairos stated that the arrangements with the City of Oak Ridge and Oak Ridge Central Fire Station, Oak Ridge Police Department, Oak Ridge Methodist Medical Center, and the State of Tennessee, will be obtained and documented in the OL application.
Appendix 12A, Section F, Training		In PSAR Appendix 12A, Section F, Kairos stated that the details of the training program for emergency response personnel will be provided in the OL application.
Appendix 12A, Section H.2, Assessment Facilities and Equipment		In PSAR Appendix 12A, Section H.2, Kairos stated that a listing of the current locations for emergency equipment cabinets and other emergency equipment storage areas, plus representative equipment inventories for these storage locations, will be provided in the OL application.
Appendix 12A, Section H.5, Instrumentation for Specific Radionuclide Identification and Analysis		In PSAR Appendix 12A, Section H.5, Kairos stated that the actual equipment in the Hermes facility for specific radionuclide identification and analysis will be provided in the OL application.
General Audit question 12.2.7-1	NUREG-0849, Standard Review Plan for the Review and Evaluation of Emergency Plans for Research and Test Reactors, (ML062190191)	Kairos stated during the audit that the OL application will provide additional details and features on the Hermes reactor facility access routes following the guidance in NUREG-0849.
General Audit question 12.2.7-2a	10 CFR 50, Appendix E, Section II.A and NUREG-0849	Kairos stated during the audit that the OL application will provide additional details on the emergency organization and the relationship with other support organizations consistent with NUREG-0849.
General Audit question 12.2.7-2c	10 CFR 50, Appendix E,	Kairos stated during the audit that the OL application will provide additional descriptions

PSAR Section and/or Related Audit Question	Associated Documents	Description
	Section II.A and NUREG-0849	of organizational responsibilities, including the 24-hour on-shift staff positions and lines of succession consistent with NUREG-0849.
General Audit question 12.2.7-3	NUREG-0849	Kairos stated during the audit that the OL application will describe agreements or arrangements with local emergency response agencies that would augment and extend the capability of the Hermes facility's emergency organization and also identify any procedures developed for emergency response coordination consistent with NUREG-0849.
General Audit question 12.2.7-4	NUREG-0849	Kairos stated during the audit that the OL application will provide Hermes emergency classification descriptions as described in NUREG-0849, Section 4.0.
Section 13.1, Initiating Events and Scenarios, and Section 13.2, Accident Analysis and Determination of Consequences, Accident Analysis Audit question 13		Kairos stated during the audit that the OL application will provide dose analyses for events bounded by the maximum hypothetical accident (MHA) release, such as salt spill, PHSS break, and seismic, along with a comparison to the acceptance criteria for the figures of merit in PSAR Table 13.1-1.
Section 13.1.2, Insertion of Excess Reactivity; Accident Analysis Audit question 48		In KP-TR-018-NP Section 4.5.2.2 and during the audit, Kairos stated that the OL application will provide analyses for a range of insertion rates for insertion of excess reactivity scenarios.
Section 13.1.2, Insertion of Excess Reactivity; Accident Analysis Audit question 55		Kairos stated during the audit that the OL application will provide a justification for the conservatism of the decay heat methodology used as part of the postulated event analysis methodology and Chapter 13 calculations.
Section 13.1.2, Insertion of Excess Reactivity; Accident Analysis Audit question 56		Kairos stated during the audit that deviations of component temperatures above the MHA will be addressed and justified case by case in the OL application.
Section 13.1.2, Insertion of Excess Reactivity; Accident		Kairos stated during the audit that the OL application will provide the underlying assumptions for mapping between nuclear

PSAR Section and/or Related Audit Question	Associated Documents	Description
Analysis Audit question 57		design, fuel performance, and safety analysis assumptions.
Accident Analysis Audit question 53-8	KP-TR-018-NP	Kairos stated during the audit that the methodology in KP-TR-018-NP, "Postulated Event Analysis Methodology," will be updated as part of the OL application (or in a separate topical report).
Section 13.1.4, Loss of Forced Circulation		In KP-TR-018-NP, Section 3.2.2.4, Kairos stated that the OL application will provide analyses with a spectrum of reactor decay heat levels and operating power levels for long-term overcooling scenarios.
General Audit question 14-3		Kairos stated during the audit that the OL application will provide analyses demonstrating that vessel temperature is not needed as a Limiting Safety System Setting (LSSS) because the other LSSSs will ensure that unacceptable vessel temperatures will not be reached.
Section 14.1, Technical Specifications Introduction		In PSAR Section 14.1, Kairos stated that the technical specifications and parameter limits will be provided in the OL application.
Table 14.1-1, Proposed Variables and Conditions for Technical Specifications		In PSAR Table 14.1-1, Kairos stated that design features and administrative controls will be provided in the OL application.
Section 15.2, Financial Ability to Operate the Kairos Power Facility		In PSAR Section 15.2, Kairos stated that estimates of the total annual operating costs for each of the first five years of operation of the facility will be provided in the OL application.
Section 15.3, Financial Ability to Decommission the Kairos Power Facility		In PSAR Section 15.3, Kairos stated that information regarding funds to decommission the facility and a site-specific decommissioning plan will be provided in the OL application.
Section 15.5, Nuclear Insurance and Indemnity		In PSAR Section 15.5, Kairos stated that it will obtain $1 million in financial protection in accordance with 10 CFR 140.13 prior to being licensed to possess fuel. Kairos also stated that the amounts of financial insurance required by 10 CFR 140.12(b) and documentation required

PSAR Section and/or Related Audit Question	Associated Documents	Description
		by 10 CFR 140.15 will be provided in the OL application.
Section 17.1, Decommissioning		In PSAR Section 17.1, Kairos stated that a decommissioning report for the facility will be provided in the OL application.
KP-TR-017-NP, KP-FHR Core Design and Analysis Methodology, Section 7.1		In KP-TR-017-NP Section 7.1, Kairos stated that the completion of verification and validation of the core design and analysis codes and methodology, including uncertainties, will be provided in the OL application.

A.3 Research and Development Items

The provisions of 10 CFR 50.34(a)(8) require that the PSAR identify those structures, systems, or components of the facility that require additional research and development to confirm the adequacy of their design; and identification and description of the research and development program which will be conducted to resolve any safety questions associated with such structures, systems, or components; and a schedule of the research and development program showing that such safety questions will be resolved at or before the latest date stated in the application for completion of construction of the facility. Kairos stated it will complete the following research and development activities before the latest date of completion of construction activities in December 2026.

PSAR Section	Associated Documents	Description
Section 4.2.1, Reactor Fuel	KP-TR-011-NP-A, Fuel Qualification Methodology for the Kairos Power Fluoride Salt-Cooled High Temperature Reactor (KP-FHR), Revision 2 (ML23089A398)	Perform a laboratory testing program to confirm fuel pebble behavior.
Section 4.3, Reactor Vessel System	KP-TR-013-NP-A, Metallic Materials Qualification for the Kairos Power Fluoride Salt-Cooled High-Temperature Reactor, Revision 4 (ML23102A179)	Perform testing of high temperature material to qualify Alloy 316H and ER16-8-2.
Section 4.3, Reactor Vessel System	KP-TR-014-NP-A, Graphite Material Qualification for the Kairos Power Fluoride Salt-Cooled High-Temperature Reactor, Revision 4 (ML23108A317)	Perform analysis related to potential oxidation in certain postulated events for the qualification of the graphite used in the reflector structure.
Section 4.3.4, Reactor Vessel System Testing and Inspection		Develop a high temperature material surveillance sampling program for the reactor vessel and internals.
Section 4.5, Nuclear Design		Development and validation of computer codes for core design and analysis methodology.
Section 4.6, Thermal-Hydraulic Design		Develop and perform qualification testing for a fluidic diode device.
Section 5.1.3, Primary Heat Transport System – System Evaluation		Justification of thermodynamic data and associated vapor pressure correlations of representative species.

PSAR Section	Associated Documents	Description
Section 7.5.3, Sensors - System Evaluation		Develop process sensor technology for key reactor process variables.
Section 9.1.1, Chemistry Control System		Develop the reactor coolant chemical monitoring instrumentation.

APPENDIX B
PRINCIPAL CONTRIBUTORS

Name	Chapter	Area of Expertise
Adams, Ben	4, 13	Criticality Safety, Nuclear Engineering
Ashcraft, Joseph	7	Instrumentation and Controls
Audrain, Margaret	3, 4, 5	Materials Engineering
Ayegbusi, Odunayo	12	Quality Assurance
Beasley, Benjamin	9	Project Management, Mechanical Engineering
Bielen, Andrew	4	Criticality Safety, Nuclear Engineering
Chereskin, Alexander	4, 5, 9	Chemical Engineering
Cheng, Yuan	2, 3	Hydrology
Cheung, Calvin	7, 9	Instrumentation and Controls
Cuadrado de Jesus, Samuel	1	Project Management
Ghosh, Amitava	2, 3	Geography, Geotechnical Engineering
Goel, Vijay	8	Electrical Engineering
Hart, Michelle	4, 11, 13	Health Physics, Waste Management
Harwell, Shawn	15	Financial Qualifications
Helvenston, Edward	9, 10, 11, 12, 14, 16, 17, 18	Project Management, Radiation Protection
Heeszel, David	2	Seismology
Hiser, Matthew		Project Management
Le, Tuan	3, 4, 5	Mechanical Engineering
Lehman, Bryce	3, 4	Structural Engineering
Lupold, Timothy	3, 4	Mechanical Engineering
Mott, Kenneth	12	Emergency Preparedness
Ray, Sheila	8	Electrical Engineering
Robinson, Jay	9	Fire Protection
Schaperow, Jason	9	Nuclear Engineering
Schmidt, Jeff	4, 6, 13, 14	Lead Reviewer, Accident Analysis, Mechanical Engineering
Siwy, Alex	6	Mechanical Engineering
Thompson, Jenise	2	Geology, Seismic
White, Jason	2	Meteorology

APPENDIX C
REPORT BY THE ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, DC 20555 - 0001

May 16, 2023

Honorable Christopher T. Hanson
Chair
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

SUBJECT: KAIROS NON-POWER REACTOR HERMES CONSTRUCTION PERMIT APPLICATION

Dear Chair Hanson:

During the 705th meeting of the Advisory Committee on Reactor Safeguards, May 3-5, 2023, we completed our review of the Kairos Non-Power Reactor Hermes Construction Permit Application and the associated Safety Evaluation (SE). Dates on which our Kairos Subcommittee reviewed this matter are provided in Appendix I. A list of the topical reports that supported our review of this application is in Appendix II. A listing of the memoranda providing our detailed reviews of the application and associated SE is found in Appendix III. During the meetings, we had the benefit of discussions with NRC staff and representatives from Kairos Power LLC (Kairos). We also had the benefit of the referenced documents. This report fulfills the requirements of Section 182b of the Atomic Energy Act, as amended, and Title 10 of the *Code of Federal Regulations* (10 CFR) 50.58(a).

Conclusions and Recommendations

1. Key attributes of the Hermes design include low thermal power of the reactor, use of TRISO fuel and Flibe coolant as an effective functional containment, and passive heat removal capability. The overall design results in projected dose consequences with large margins to regulatory siting criteria, allowing a unique approach to safety classification.

2. Because of the first-of-a-kind nature of the Fluoride High-Temperature Reactor (FHR) technology, there are performance uncertainties that can most directly be addressed during Hermes operation.

    - A scaled demonstration plant like Hermes will be valuable to test key technical elements, design features, safety functions, and equipment performance for this technology.

    - A key concern is the management of airborne beryllium and tritium in the facility to stay below relevant regulatory limits and protect the safety of workers.

3. As noted by the staff in their SE, there is confidence that the facility can be constructed in accordance with relevant regulations and the design bases outlined in the Preliminary Safety Analysis Report (PSAR). Detailed design, analysis, and technology qualification will be completed prior to the Operating License (OL) review. Combustible gas generation, associated with graphite oxidation, should be included in these evaluations.

4. The construction permit for Hermes should be approved.

Background

The Hermes facility is a 35 MWth test reactor that will be licensed under 10 CFR Part 50.21, "Class 104 licenses; for medical therapy and research and development facilities," paragraph (c). The non-power reactor will serve as a scaled demonstration plant to test and demonstrate key technical elements, design features, safety functions, and equipment performance for the Kairos Power Salt-Cooled, Fluoride High-Temperature Reactor (KP-FHR) technology. As noted in our previous letters, we continue to support a prototype licensing pathway for advanced reactors. This pathway is outlined in the staff's "Regulatory Review Roadmap for Non-Light Water Reactors."

The Hermes test reactor uses TRISO-fueled pebbles in a molten salt, Flibe[1] coolant, resulting in a high-temperature low-pressure system with robust inherent safety characteristics. Key inherent safety features include:

- Functional containment provided by TRISO fuel and Flibe;
- Primary heat transport system that operates near atmospheric pressure;
- Negative reactivity coefficients (fuel, moderator, and coolant temperature); and
- Reactor vessel and other safety-related components located within a seismically isolated structure.

The staff's SE presents a chapter-by-chapter review of the applicant's PSAR in accordance with the guidance provided in NUREG-1537 for non-power reactors. In addition, Appendix A of the staff SE contains a list of additional construction permit conditions and elements of design, analysis, or administration that require additional development. These items must be addressed to support the OL application for Hermes.

This letter discusses the overall safety of the Hermes facility by summarizing (a) novel or unique features in the design; (b) the key safety functions and their implementation in the design; (c) the principal design criteria, safety classification, and defense-in-depth; (d) postulated event selection, analysis results, and safety margin; (e) operational reliability; (f) worker safety; and (g) technology development activities that remain to be completed prior to the OL.

[1] Flibe is a eutectic mixture of LiF and BeF_2.

Novel or Unique Aspects

There are many novel or unique aspects of the Hermes design. These include:

- The first nuclear reactor application with functional containment[2] (as discussed in SRM-SECY-18-0096)
- The first application of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (BPVC), Section III, Division 5 for high temperature materials
- Buoyancy of the fueled pebbles and graphite reflector in the Flibe coolant
- A spherical shell of TRISO particles in a pebble that is smaller than those used in German and Chinese high temperature reactors
- Anti-siphon features that limit the loss of coolant in the event of breaks in the primary heat transport system cold leg
- Four fluidic diodes in the upper plenum that enable natural circulation when forced circulation is lost
- The design of the pebble handling system that provides for handling, sorting, and storing fuel and moderator pebbles

Kairos was able to identify operating experience relevant to their design related to the use of TRISO fuel, Flibe coolant, pebble bed reactor cores, and graphite moderated reactors.

Safety Functions

The applicant has identified three safety functions: limiting radionuclide release, controlling heat removal, and controlling reactivity. Given the passive design of the systems used to address these safety functions, power is not needed during the identified design basis events. This includes electric power from an off-site or any backup power source. Also, operator action is not required to mitigate any design basis events.

Limit Release of Radionuclides

Kairos uses the concept of ‘functional containment’ to limit release of radionuclides. This approach controls radionuclides at their source in the TRISO-coated uranium oxycarbide particle fuel inside the Hermes pebbles. In their evaluation of pebble performance, Kairos assumed a pre-accident level of TRISO fuel particle failure 100 times greater than that observed in the Department of Energy Advanced Gas Reactor TRISO fuel qualification program. The Flibe molten salt serves as an additional inherent barrier to the release of fission products given its strong chemical affinity for several fission product species that may escape the fuel pebble (except noble gases).

Taken together, these two inherent robust retention barriers, combined with the low thermal power of the reactor, result in projected dose consequences with large margins to regulatory siting criteria at the site boundary. In addition, doses at the site boundary are below the Environmental Protection Agency (EPA) Protective Action Guides. The large safety margins,

[2] Functional containment is defined as a barrier, or set of barriers, that when taken together limit the transport and release of radionuclides to the environment under normal operation, anticipated operational occurrences and postulated accidents.

functional containment, passive decay heat removal, fluidic diodes, and anti-siphon features allow a unique approach to structures, systems, and components (SSC) classification, as discussed later in this letter.

Kairos has opted to perform a bounding calculation to estimate annual tritium releases from the facility by assuming that all tritium generated in the Flibe will permeate through the heat exchanger and be directly released to the environment. These conservative simplifying assumptions support demonstrating compliance with 10 CFR Part 20 dose limits. However, this level of annual tritium release is higher than current operating reactors around the world (e.g., AGR, PWR, BWR, and CANDU), and more typical of the magnitude of releases from nuclear reprocessing facilities that treat spent fuel. Kairos has indicated that a tritium cleanup system will be included in the facility. Such a system would be expected to reduce airborne tritium concentrations in the facility to protect workers and should result in annual releases to the environment well below the calculated value presented in the PSAR. This could allay concerns from stakeholders about tritium release from this facility.

Control Heat Removal

The decay heat removal system (DHRS) is a passive cooling system with four independent trains that are actuated once a target level of heat generation in the reactor is reached. The DHRS provides adequate heat removal to ensure that the vessel temperature remains below design limits and fuel integrity is not challenged. The applicant has demonstrated that three of the four trains provide sufficient capacity to remove the decay heat. The ultimate heat sink is provided by water tanks that feed, by gravity, thermosyphon thimbles that remove vessel heat and reject steam to the atmosphere. The decay heat is transferred from the pebbles to the vessel wall by natural circulation of the Flibe coolant and then by conduction through the vessel and radiation to the DHRS. The water tanks are sized to provide passive cooling for up to seven days, and the staff has verified the sizing with their own calculations. Testing is planned to verify operation. The staff specified that certain effects (e.g., corrosion and fouling, flow instability during transitions, and dynamic loads during operation) must be examined in the operational testing program.

Control Reactivity

Two different sets of control elements are used to control reactivity in Hermes. Four control elements in the reflector are used to manage reactor power during operation; whereas three shutdown elements are inserted into the pebble bed to shut down the reactor. Two of the three shutdown elements are sufficient to maintain adequate shutdown margin under postulated event scenarios. Testing is planned to demonstrate adequate performance of both systems. Beyond these systems, the fuel, moderator, and coolant have inherent strong negative temperature coefficients that provide reactivity control.

Principal Design Criteria, Safety Classification, and Defense-in-Depth

Kairos has identified and described the principal design criteria for the SSCs required to ensure reactor facility safety and prevent uncontrolled release of radioactivity. The Kairos licensing approach for the Hermes design does not use a probabilistic approach (e.g., NEI 18-04 or Regulatory Guide 1.233) for identification of licensing basis events, SSC classification, and evaluation of defense-in-depth. Instead, NUREG-1537 deterministic evaluations for postulated events, the single failure criterion, and the maximum hypothetical accident (MHA) are used to evaluate plant safety and classify SSCs. There are only two SSC classifications used in the safety analysis report: “safety-related” and “non-safety related.” Also, a spectrum of “postulated events” (regardless of frequency of occurrence) was considered to verify the MHA was bounding.

The primary safety feature of the design is the unique combination of the TRISO fuel and Flibe reactor coolant. Other safety-related SSCs include the reactor vessel and internals, the reactor shutdown system, the DHRS, the spent fuel storage racks of the pebble handling and storage system, and the safety-related portion of the reactor building structure. The staff found these systems, as described, would comply with the applicable regulations and standards commensurate with their safety classification; however, additional design and performance analyses will be necessary for evaluation of the operating license.

The large safety margins allow a unique approach to safety classification. Our assessment of the validity of this approach is provided below, based on comparing historical practice to important Hermes safety characteristics.

While the reactor vessel and its welds are classified as safety grade, the primary heat transport system (PHTS) is considered non-safety related and is not required to maintain a safe and stable shutdown for any postulated event. This classification is predicated on successful design and the yet-to-be-demonstrated performance of the fluidic diodes and anti-siphon features. The anti-siphon features prevent excessive loss of coolant inventory in the vessel so that the coolant level remains above the active pebble bed core in the event of an ex-vessel pipe rupture. The fluidic diode allows natural circulation in the vessel to transfer heat from the pebble bed core through the reflector to the reactor vessel and the DHRS.

Further, the applicant proposes to use an alternative definition of “safety-related” by changing “integrity of the reactor coolant pressure boundary” to “integrity of portions of the reactor coolant boundary relied upon to maintain the reactor coolant level above the active core.” In the Hermes design, the reactor coolant boundary, except for the reactor vessel, is not credited for fission product retention. As such, the vessel is classified as safety-related while the remainder of the reactor coolant boundary is classified as non-safety related. This revised definition, as applied to design basis events involving a major break in the PHTS, would address the continued cooling of the pebble bed core and passive decay heat removal.

This approach potentially weakens overall defense-in-depth and independence of barriers/safety functions. In addition, classifying the PHTS piping as non-safety related suggests that the system may not survive a design-basis earthquake, potentially challenging reactor vessel integrity with a break at the nozzle/piping interface. (The PSAR states that PHTS failures will not impact safety-related SSCs and the SE notes this will be evaluated in the operating license application).

On the one hand, for this first-of-a-kind reactor, designing, analyzing, and constructing the PHTS to the same quality level as the reactor vessel (ASME BPVC, Section III, Division 5, design and construction, and Section XI testing and inspection) would enhance confidence that the probability of significant pipe rupture (thermally or seismically induced) is low. Making the entire primary coolant boundary safety-grade is historical practice, even in low-pressure systems (e.g., sodium fast reactors).

By contrast, from the safety analysis perspective, no credit is taken in the Hermes safety analysis for the holdup of fission products by the PHTS. Furthermore, since Flibe does not react significantly with humid air, the piping of the PHTS is not needed as a barrier to prevent chemical attack as is done in sodium-cooled reactors. Thus, in this unique situation, the large safety margins to radiological consequences to the public, derived from the combination of low thermal power and functional containment, outweigh the need for safety classification of PHTS based on additional defense-in-depth and historical practice. This may not be the case for other reactor system designs that employ functional containment, and each should be evaluated on a case-by-case basis.

Postulated Event Selection, Analysis Results, and Safety Margin

The Hermes accident analysis evaluated a broad range of postulated events to establish the MHA. These event categories included: (a) insertion of reactivity, (b) salt spills, (c) loss of forced circulation, (d) malfunction of the pebble handling and storage systems, (e) radioactive releases from a subsystem or component, (f) general challenges to normal operation, and (g) internal (fire and flood) and external hazards (seismic, wind, and flood). Within each event category, several specific events were examined to determine the bounding event scenario.

The accident analysis also examined events precluded by the design and the rationale for their exclusion. Events considered include re-criticality or reactor shutdown failure, degraded heat removal, large Flibe spills, in-service failures greater than assumed, significant ingress of air, DHRS cavity flooding, insertion of excess reactivity, criticality external to the core, excessive radionuclide release from Flibe, and internal or external events interfering with safety-related SSCs.

For each included event, conservative assumptions about initial conditions, response of safety-related SSCs (including invoking single failure criterion, as required by principal design criteria in KP-TR-003-P-A), and transient characteristics were used to evaluate the accident system response. Historically, keeping metallic structures within their allowable temperatures in high temperature reactors has been a concern. Transient analyses done by Kairos show about ~ 100 to 150°C margin to stainless steel limits for the core barrel and vessel. The fuel and control rod materials are also well below their associated temperature limits.

The staff performed a thorough review of the event selection and analysis methodology, assumptions, and results. In some cases, the staff performed scoping calculations of the same event to gain additional confidence in the Kairos calculational results. Before completion of the OL review, combustible gas generation, associated with graphite-air oxidation, should be addressed for air ingress events.

The MHA is constructed such that the defined accident time-temperature profiles, boundary conditions, and the radionuclide source term assumptions will result in calculated radiological releases that encompass those from each bounding event scenario in each event category. The MHA event assumes a hypothetical time-temperature history that (a) considers the thermal impacts of conservative trip and actuation delays associated with the reactor protection system and (b) bounds preliminary calculations of reactivity events, overheating events and overcooling events in the reactor, and other less challenging ex-reactor postulated events. Conservative estimates for releases from TRISO fuel, tritium in graphite structures, and Ar-41 from activation of the cover gas were considered in the source term assessment. Even with these assumptions, the MHA results in radiological doses at the site boundary that are well below the siting criteria of 25 rem and also below the EPA Protective Action Guides. Doses were dominated by tritium and Ar-41, not fission products.

The MHA used for research and test reactors does not consider beyond design basis events such as anticipated transient without scram (ATWS) and station blackout. As noted above, station blackout is not a concern because power is not required to execute Hermes' safety functions. For ATWS events, the consequences depend on the severity of the reactivity insertion. However, the strong negative temperature coefficient in the Hermes design and the limited excess reactivity in a pebble bed core should prevent fuel failure. We note that similar inherent safety features were demonstrated by testing in other advanced reactors, such as EBR-II (a metal fueled sodium fast reactor), AVR (a German pebble bed high temperature gas reactor), and HTTR (a Japanese high temperature gas reactor), providing unique data for code validation for these technologies.

Operational Reliability

There are performance uncertainties associated with the FHR technology most directly addressed during Hermes operation. A few key areas include:

- Ability to control the chemical potential (i.e., REDOX) of Flibe in a temperature gradient during irradiation;
- Ability to control the composition of Flibe near the eutectic point within allowable limits to prevent deleterious viscosity changes; and
- Effects of impurities in the salt on fuel performance due to corrosion.

In addition, the presence of uranium impurities and fission products in the Flibe will produce a mixed hazardous waste (hazardous beryllium and radioactive material). Kairos informed us that they have identified a disposition path for the contaminated Flibe.

Worker Safety

Key worker safety concerns in Hermes are related to the ability to control airborne tritium in the facility because of permeation through high temperature components and to contend with beryllium volatility in salt to protect workers during operation, maintenance, and inspection. Thus, two items remain to be considered going forward: (a) whether a system is needed to control airborne beryllium concentrations in the reactor building and reactor cell (during maintenance activities) below the National Institute for Occupational Safety and Health (NIOSH) limit of 0.2 $\mu g/m^3$ for short term exposure and 0.5 $\mu g/m^3$ averaged over 8 hours and (b) whether derived airborne concentrations (DAC) will be below 20 $\mu Ci/m^3$ such that personnel protective equipment will not be needed to protect workers from tritium and beryllium in the reactor building and reactor cell air during maintenance.

Technology Development

Numerous ongoing research and development activities have been identified as necessary to confirm the adequacy of the design of SSCs to resolve safety questions prior to the completion of construction. These are related to confirming fuel pebble behavior; high temperature material qualification and surveillance; oxidation of graphite; validation of computer codes; development of a fluidic diode; justification of thermodynamic and vapor pressure correlations used in source term analysis; development of process sensor technology for key reactor process variables; and development of reactor coolant chemical monitoring instrumentation. Kairos stated these activities will be completed before completion of construction.

Because this is a PSAR to support a construction permit, many of the details of the design and the associated analyses are reasonably left for the Final Safety Analysis Report. In-reactor testing planned during startup, and monitoring and inspection details are not yet available, the analytic tools are not fully validated, and safety analysis uncertainties are not fully assessed. Kairos has acknowledged this situation; the staff has also noted these items in their review and are tracking them to closure as part of the OL review or during initial reactor startup.

Summary

Key attributes of the Hermes design include low thermal power of the reactor, use of TRISO fuel and Flibe coolant as an effective functional containment, and passive heat removal capability. The overall design results in projected dose consequences with large margins to regulatory siting criteria. Because of the first-of-a-kind nature of the FHR technology, there are performance uncertainties that can most directly be addressed during Hermes operation. A scaled demonstration plant like Hermes will be valuable to test key technical elements, design features, safety functions, and equipment performance for this technology. There is confidence that the facility can be constructed in accordance with relevant regulations and the design bases outlined in the PSAR. The construction permit for Hermes should be approved.

Sincerely,

Signed by Rempe, Joy on 05/16/23

Joy L. Rempe
Chairman

APPENDIX I: ACRS Review of Construction Permit Application for Kairos Power Fluoride Salt-Cooled, High Temperature Non-Power Reactor - Hermes

APPENDIX II: ACRS Review of Topical Reports Supporting the Kairos Power Fluoride Salt-Cooled, High-Temperature Reactor Design

APPENDIX III: Lead Member Memoranda on Preliminary SE Chapters on Kairos Power Hermes Non-Power Reactor Preliminary Safety Analysis Report

References

1. Kairos Power LLC, "Submittal of the Preliminary Safety Analysis Report for the Kairos Power Fluoride Salt-Cooled, High Temperature Non-Power Reactor (Hermes)," Revision 2, February 2023 (ML23055A672).

2. Kairos Power LLC, KP-TR-003-NP-A, "Principal Design Criteria for the Kairos Power Fluoride Salt-Cooled, High Temperature Reactor," June 12, 2020 (ML20167A174).

3. Kairos Power LLC, KP-TR-017, "KP-FHR Core Design and Analysis Methodology," September 29, 2021 (ML21272A375).

4. Kairos Power LLC, KP-TR-018, "Postulated Event Analysis Methodology," February 28, 2023 (ML23055A672).

5. USNRC, "SAFETY EVALUATION Related to the Kairos Power LLC Construction Permit Application for the Hermes Test Reactor," 2023 (ML23108A119).

6. USNRC, ACRS letter report, "10 CFR PART 53 Licensing and Regulation of Advanced Nuclear Reactors," October 21, 2020 (ML20295A647).

7. USNRC, ACRS letter report, "Preliminary Proposed Rule Language for 10 CFR Part 53, "Licensing and Regulation of Advanced Nuclear Reactors," Interim Report," May 30, 2021 (ML21140A354).

8. USNRC, NUREG-1537, Part 1, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors, Format and Content," February 1996 (ML042430055).

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10. USNRC, "A Regulatory Review Roadmap for Non-Light Water Reactors," December 2017 (ML17312B567).

11. USNRC, SECY-18-0096, "Functional Containment Performance Criteria for Non-Light-Water-Reactors," September 28, 2018 (ML18114A546).

12. USNRC, SRM-SECY-18-0096, "Staff Requirements – SECY-18-0096 - Functional Containment Performance Criteria for Non-Light-Water-Reactors," December 4, 2018 (ML18338A502).

13. Nuclear Energy Institute, NEI 18-04, "Risk-Informed Performance-Based Technology-Inclusive Guidance for Non-Light Water Reactor Licensing Basis Development," Revision 1.

14. USNRC, Regulatory Guide 1.233, "Guidance for a Technology-Inclusive, Risk-Informed, and Performance-Based Methodology to Inform the Licensing Basis and Content of Applications for Licenses, Certifications, and Approvals for Non-Light Water Reactors," Revision 0, June 2020 (ML20091L698).

15. The National Institute for Occupational Safety and Health (NIOSH), Beryllium compounds (as Be), https://www.cdc.gov/niosh/idlh/7440417.html.

16. Code of Federal Regulations, 10 CFR Part 20 - Standards for Protection Against Radiation.

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