Kairos Power

KP-NRC-2007-003

July 31, 2020

Project No. 99902069

US Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, DC 20555-0001

Subject: Kairos Power LLC
Topical Report Submittal
Reactor Coolant for the Kairos Power Fluoride Salt-Cooled High Temperature Reactor, KP-TR-005-P-A, Revision 1

References:
1. Letter Kairos Power LLC to Document Control Desk, "Reactor Coolant for the Kairos Power Fluoride Salt-Cooled High Temperature Reactor Topical Report," Revision 0, March 8, 2019 (ML19079A325)
2. Letter Kairos Power LLC to Document Control Desk, "Reactor Coolant for the Kairos Power Fluoride Salt-Cooled High Temperature Reactor Topical Report, Revision 1," January 16, 2020 (ML20016A486)
3. Nuclear Regulatory Commission, Letter from Benjamin Beasley to Peter Hastings, "Safety Evaluation for Kairos Power LLC Topical Report "Reactor Coolant for the Kairos Power Flouoride Salt Cooled High Temperature Reactor (Revision 1)," July 16, 2020 (ML20140A134)

Kairos Power submitted Revision 0 of the subject topical report for Nuclear Regulatory Commission (NRC) review on March 8, 2019 (Reference 1). Revision 1 of the topical report was submitted on January 16, 2020 (Reference 2). On July 16, 2020 the NRC provided the final safety evaluation of this topical report (Reference 3).

Portions of the Reactor Coolant Topical Report for the Kairos Power Methodology Program are considered proprietary, and Kairos Power requests it be withheld from public disclosure in accordance with the provisions of 10 CFR 2.390. Additionally, the information indicated as proprietary has also been determined to contain Export Controlled Information. This information must be protected from disclosure pursuant to the requirements of 10 CFR 810.

Enclosures 1 and 2 to this report provide the approved propriety and non-proprietary versions of this report, designated as KP-TR-005-P-A and KP-TR-005-NP-A respectively. Both approved versions include the July 16, 2020 letter from the NRC and the final safety evaluation report. An affidavit supporting the withholding request is provided in Enclosure 3. Kairos Power authorizes the NRC to reproduce and distribute the submitted non-proprietary content, as necessary, to support the conduct of their regulatory responsibilities.

If you have any questions or need any additional information, please contact Darrell Gardner at gardner@kairospower.com or (704)-769-1226.

Sincerely,

Peter Hastings, PE
Vice President, Regulatory Affairs and Quality

Enclosures:

1) Reactor Coolant for the Kairos Power Fluoride Salt-Cooled High Temperature Reactor Topical Report, Revision 1 (Proprietary)
2) Reactor Coolant for the Kairos Power Fluoride Salt-Cooled High Temperature Reactor Topical Report, Revision 1 (Non-Proprietary)
3) Affidavit Supporting Request for Withholding from Public Disclosure (10 CFR 2.390)

xc (w/enclosure):

Benjamin Beasley, Chief, Advanced Reactor Licensing Branch
Stewart Magruder, Project Manager, Advanced Reactor Licensing Branch

Enclosure 2

Reactor Coolant for the Kairos Power Fluoride Salt-Cooled High Temperature Reactor Topical Report, Revision 1 (Non-Proprietary)

CONTENTS

Section A

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

July 16, 2020

Mr. Peter Hastings
Vice President, Regulatory Affairs
and Quality
Kairos Power LLC
707 W Tower Ave
Alameda, CA 94501

SUBJECT: SAFETY EVALUATION FOR KAIROS POWER LLC TOPICAL REPORT "REACTOR COOLANT FOR THE KAIROS POWER FLUORIDE SALT COOLED HIGH TEMPERATURE REACTOR" (REVISION 1) (EPID NO. L-2019-TOP-0010/CAC NO. 000431)

Dear Mr. Hastings:

By letter dated March 8, 2019 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML19079A325), Kairos Power LLC (Kairos Power, the applicant) submitted for U.S. Nuclear Regulatory Commission (NRC) staff review, "Reactor Coolant for the Kairos Power Fluoride Salt-Cooled High Temperature Reactor," (reactor coolant report). The NRC staff provided initial feedback and questions to Kairos Power on January 10, 2020 (ADAMS Accession No. ML20013G733). In response to these questions and following a teleconference between the NRC staff and Kairos Power, the applicant submitted an updated topical report (Revision 1) by letter dated January 16, 2020 (ADAMS Accession No. ML20016A486), on which this safety evaluation (SE) is based.

The NRC staff documented its review in the enclosed SE which was previously provided to you for comments only related to the identification of proprietary information and factual errors on February 7, 2020 (ADAMS Accession No. ML20035E009, non-public). You provided comments to the NRC staff on February 13, 2020 and confirmed the proprietary information in the SE on February 25, 2020 (ADAMS Accession No. ML20134J000). The NRC staff has incorporated your comments, as appropriate, in the enclosed SE. In addition, the Advisory Committee for Reactor Safeguards (ACRS) was briefed on this topical report on February 21, 2020, and April 9, 2020. The ACRS endorsed the publication of this SE in a letter dated June 1, 2020 (ADAMS Accession No. ML20148M230).

The enclosed SE is final, and a redacted version will be made publicly available as specified in your comments.

The Enclosure to this letter contains Proprietary information. When separated from the Enclosure, this document is DECONTROLLED.

In accordance with the guidance provided on the NRC website, we request that Kairos publish accepted proprietary and non-proprietary versions of this TR within three months of receipt of this letter. The accepted versions shall incorporate this letter and the enclosed final SE after the title page. The accepted versions shall include an "-A" (designating accepted) following the TR identification symbol.

If you have any questions, please contact Stewart Magruder at 301-348-5766 or by e-mail at Stewart.Magruder@nrc.gov.

Sincerely,

Benjamin Beasley

Benjamin Beasley, Chief
Advanced Reactor Licensing Branch
Division of Advanced Reactors and Non-Power Production and Utilization Facilities
Office of Nuclear Reactor Regulation

Project No. 99902069

Enclosure:
Final SE

SUBJECT: SAFETY EVALUATION FOR KAIROS POWER LLC TOPICAL REPORT "REACTOR COOLANT FOR THE KAIROS POWER FLUORIDE SALT COOLED HIGH TEMPERATURE REACTOR" (REVISION 1) (EPID NO. L-2019-TOP-0010/CAC NO. 000431) DATED JULY16, 2020

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BBeasley, NRR
MHayes, NRR

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gardner@kairospower.com
price@kairospower.com

ADAMS Accession Nos.: Pkg. ML20139A224; Non-Public ML20140A134, Public ML20140A147 ***via e-mail**

OFFICE	NRR/DANU/UARL/PM*	NRR/DANU/UARL/LA*	NRR/DNRL/NCSG/BC*
NAME	SMagruder	SLent	SBloom
DATE	05/14/2020	05/19/2020	06/03/2020
OFFICE	NRR/DANU/UART/BC*	OGC NLO*	NRR/DANU/UARL/BC*
NAME	MHayes	OMikula	BBeasley
DATE	06/15/2020	07/01/2020	07/16/2020

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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

RELATED TO "REACTOR COOLANT FOR THE KAIROS POWER FLUORIDE SALT

COOLED HIGH TEMPERATURE REACTOR"

KAIROS POWER, LLC

PROJECT NO. 99902069

1.0 INTRODUCTION

By letter dated March 8, 2019 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML19079A325), Kairos Power LLC (Kairos Power, the applicant) submitted for U.S. Nuclear Regulatory Commission (NRC) staff review, "Reactor Coolant for the Kairos Power Fluoride Salt-Cooled High Temperature Reactor," (reactor coolant report). On August 9, 2019 (ADAMS Accession No. ML19221B585), the NRC staff found that the material presented in the Topical Report (TR) provides the technical information in sufficient detail to enable the staff to conduct a detailed technical review.

Kairos Power requested NRC staff review and approval of the reactor design characteristics represented by the thermophysical properties provided in Table 1, "Thermophysical Properties of the KP-FHR Primary Coolant," and the reactor coolant specification provided in Table 4, "Design Specification for the KP-FHR Reactor Coolant," of the reactor coolant report. This is to be used by applicants of the Kairos Power Fluoride Salt-Cooled, High Temperature Reactor (KP-FHR) design for future licensing submittals under Title 10 of *Code of Federal Regulations* (10 CFR) Parts 50 or 52. As part of the review, the NRC staff provided initial feedback and questions to the applicant on January 10, 2020 (ADAMS Accession No. ML20013G733). In response to these questions and following a teleconference between the NRC staff and Kairos Power, the applicant submitted an updated TR (Revision 1) via letter (ADAMS Accession No. ML20016A486), on which this safety evaluation (SE) is based.

2.0 REGULATORY EVALUATION

Section 50.34(a) of 10 CFR, "Preliminary safety analysis report," requires applicants for construction permits under 10 CFR Part 50 to provide a preliminary safety analysis report (PSAR) which describes reactor design characteristics. Additionally, applicants for a limited work authorization (LWA) are required to submit a safety analysis meeting 10 CFR 50.34 for the scope of the LWA in accordance with 10 CFR 50.10(d)(3)(i), "Request for limited work authorization."

Enclosure

Specifically, the following regulations apply to the Reactor Coolant TR:

- 10 CFR 50.34(a)(1)(ii)(C), which states that reactor design characteristics and proposed operation including "[t]he extent to which the reactor incorporates unique, unusual or enhanced safety features having a significant bearing on the probability or consequences of accidental release of radioactive materials," will be considered by the Commission.

- 10 CFR 50.34(a)(1)(ii)(D), which states that reactor design characteristics and proposed operation that will be considered by the Commission includes safety features and barriers that must be breached before a radiological release can occur. This includes a requirement for an applicant to perform an evaluation and analysis of postulated fission product release along with systems intended to mitigate the consequences of accidents.

- 10 CFR 50.34(a)(2), which requires an applicant to provide "[a] summary description and discussion of the facility, with special attention to design and operating characteristics, unusual or novel design features, and principal safety considerations."

- 10 CFR 50.34(a)(3)(i), which requires a facility licensed under 10 CFR 50 to describe principal design criteria (PDC) in its PSAR. The PDC applicable to the Kairos Power KP-FHR design are described later in this section.

Note that the design characteristics descriptions related to these regulations are required to be updated as part of application for an operating license per 10 CFR 50.34(b)(4).

Additionally, applicants for combined licenses under 10 CFR Part 52 are required to provide a final safety analysis report that provides a safety assessment of the facility as well as a description of reactor design characteristics.

Specifically, the following regulations pertain to the Reactor Coolant TR:

- 10 CFR 52.79(a)(2), which requires a description and analysis of certain structures, systems, and components sufficient to allow understanding of system designs and the relationship to SSCs.

- 10 CFR 52.79(a)(2)(iii), which states unique, unusual or enhanced safety features with a significant bearing on the probability or consequences of an accidental release of radioactive materials will be considered by the Commission.

- 10 CFR 52.79(a)(2)(iv), which states safety features and barriers to a radioactive release during an accident will be considered by the Commission.

As described in the Kairos Power topical report KP-TR-003, "Principal Design Criteria for the Kairos Power Fluoride Salt-Cooled High Temperature Reactor," Revision 1 (ADAMS Accession No. ML19212A756), and the NRC staff SE documenting approval of Revision 1 of this TR (ADAMS Accession No. ML20015A424), Kairos has developed PDC for its KP-FHR design. The specific PDC that pertain to the Reactor Coolant TR are described below:

- PDC 11, “Reactor inherent protection,” which requires the KP-FHR reactor core and associated systems contributing to reactivity feedback be designed so that, while in power operating range, the net effect of prompt inherent nuclear feedback characteristics compensate for a rapid increase in reactivity. The properties of the reactor coolant, in part, relate to this PDC as the neutronic characteristics of the reactor coolant allow the KP-FHR reactor core to be designed with a negative coolant temperature coefficient of reactivity.

- PDC 14, “Reactor coolant boundary,” which requires safety significant elements of the reactor coolant boundary to have an extremely low probability of abnormal leakage, rapidly propagating failure, or gross rupture. Control of reactor coolant chemistry and the associated corrosion controls relate to PDC 14.

- PDC 16, “Containment design,” which requires a reactor functional containment to control the release of radioactivity to the environment to ensure safety significant functional containment design conditions are not exceeded for as long as postulated accident conditions require. The ability of the reactor coolant to retain fission products is related to PDC 16.

- PDC 26 “Reactivity control systems,” which requires, in part, a reactivity control system or means to insert negative reactivity at a sufficient rate and amount to assure, with appropriate margin for malfunctions, that the design limits for fission product barriers are not exceeded and safe shutdown is achieved and maintained during normal operation, including anticipated operational occurrences.

- PDC 31 “Fracture prevention of reactor coolant boundary,” which requires, in part, the reactor coolant boundary to behave in a nonbrittle manner and to minimize the probability of rapidly propagating failure of the reactor coolant boundary, accounting for effects of coolant composition (including contaminants and reaction products) on material properties.

- PDC 60, “Control of releases of radioactive materials to the environment,” which requires a means to control the release of radioactive materials. The ability of the reactor coolant to retain fission products is related to PDC 60.

- PDC 70 “Reactor coolant purity control,” which requires that systems are provided to maintain the purity of the reactor coolant within design limits based on chemical attack, fouling or plugging of passages, radionuclide concentrations, and air or moisture ingress. The initial reactor coolant purity limits for the KP-FHR described in Table 4, as well as chemistry control provisions to maintain the required purity are related to PDC 70.

- PDC 73, “Reactor coolant system interfaces,” which describes requirements for separation of chemically compatible and incompatible primary and secondary coolants. The compatibility of the reactor coolant to the nitrate salt (secondary coolant) is related to PDC 73.

3.0 TECHNICAL EVALUATION

3.1 Introduction

To support future licensing action regarding the KP-FHR under 10 CFR Parts 50 or 52, Kairos Power submitted this TR to engage with the NRC regarding the development of its reactor coolant.

As requested by Kairos Power in Section 1, "Introduction," of the Reactor Coolant TR, the NRC staff has reviewed the thermophysical properties provided in Table 1, and reactor coolant specification provided in Table 4, of the Reactor Coolant TR. The applicant stated that these properties and specifications will be used in potential future licensing actions as well as safety analyses required for the KP-FHR reactor. The remainder of the Reactor Coolant TR was not evaluated by the staff. It was only reviewed as technical background and to identify any potential impacts on the portions of the Reactor Coolant TR for which Kairos Power requested staff review.

Because the TR is requesting approval of certain characteristics of the reactor coolant without the full scope of knowledge of detailed system specifications, there may be instances where the design features as outlined in the TR change between submittal of this TR and a future licensing submittal. Accordingly, the staff added conditions and limitations to the TR contingent on the design features provided for in Section 1.1.2 of the TR. This is discussed in the Limitations and Conditions section of this SE (Section 4.0).

3.1.1 Design Features

Section 1.1 of the TR provides an overview of the key design features of the KP-FHR. The applicant stated that these features are not expected to change during the design and development of the KP-FHR. The applicant also stated that these features provide the basis for the safety review of the Reactor Coolant TR and that if fundamental changes occur to the key design features, or new or revised regulations are issued, these changes would be reconciled and addressed in future submittals (see Limitation and Conditions 2 and 3).

The KP-FHR is a molten fluoride salt cooled high temperature reactor that operates at "near-atmospheric pressure." The fuel proposed for this reactor is based on the tri-structural isotropic (TRISO) pebble fuel element. The applicant has stated that the coatings on the particle fuel will provide retention of fission products, as will the molten fluoride salt mixture $2LiF:BeF_2$ (Flibe) for any fission products that escape via fuel defects. The KP-FHR design includes a primary coolant loop that transfers heat to an intermediate coolant loop which utilizes a nitrate salt, that is "compatible with the reactor coolant," to transfer heat to a steam generator. Additionally, the KP-FHR includes a normal decay heat removal system, as well as a passive decay heat removal system.

Rather than a traditional containment building, the KP-FHR utilizes a functional containment approach, consistent with that discussed in SECY-18-0096, "Functional Containment Performance Criteria for Non-Light-Water-Reactors," (Reference 6) which has been approved by the Commission in its Staff Requirements Memorandum to the SECY (Reference 7). The applicant states the ultimate design objective of the functional containment is to meet offsite dose requirements at the plant's exclusion area boundary with margin.

The TRISO fuel particles are the first and primary barrier to ensure that radionuclides are not released beyond limits, and the coolant is also capable of retaining fission products. Additionally, the applicant has stated that the additional retention provided by the reactor coolant "…is a key feature of the enhanced safety and reduced source term in the KP-FHR."

3.2 Heat Transport System Fluids

Section 2 of the TR describes the fluids used in the KP-FHR primary heat transport system (PHTS) and the intermediate heat transport system (IHTS). The PHTS uses Flibe as noted earlier in this SE, and the IHTS uses a nitrate salt that is a blend of sodium nitrate and potassium nitrate. Potential interactions between these salts are not evaluated as part of this SE. Kairos noted that this TR doesn't explicitly consider the fission product retention properties of the Flibe and states that these properties, as well as methods to predict retention, will be addressed in a separate source term TR (see Limitation and Condition 10).

3.2.1 Flibe Specification

Flibe was chosen as the reactor coolant for the KP-FHR. Table 1 of the Reactor Coolant TR contains a summary of the nominal thermophysical properties of the reactor coolant as well as associated uncertainties. Table 4 of the Reactor Coolant TR contains the design specification for the reactor coolant. **[[**

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3.2.2 TABLE 1, "THERMOPHYSICAL PROPERTIES OF THE KP-FHR PRIMARY COOLANT"

Table 1 of the Reactor Coolant TR, "Thermophysical Properties of the KP-FHR Primary Coolant," provides **[**

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As stated in Section 2.2.1, "Thermophysical Properties," and Section 3.2, "Limitations," Kairos Power will perform data corroboration of the thermophysical properties found in Table 1 of the TR in order to bring this data under the Kairos Power Quality Assurance (QA) program.

Additionally, Kairos Power stated that **[**

]]
Kairos Power stated that the measurements would be done under the Kairos QA program. [[

]

NRC Staff Evaluation

For the Flibe to be suitable as a reactor coolant it must have certain thermophysical properties that support operation of the reaction and certain safety analyses. As described below, the NRC staff reviewed the [[ ]] of the reactor coolant as described in Table 1 of the Reactor Coolant TR. The NRC staff has also compared values given for the thermophysical properties in Table 1 to other literature sources to determine whether the proposed values represent reasonable nominal values for these parameters.

The NRC staff determined that the [

]] Therefore, the staff concludes that the correlations and parameters provided in Table 1 of the Reactor Coolant TR [[ ]] to start Kairos Power safety analyses are, in part, consistent with the relevant PDCs as described in Section 3.2.4 of this SE.

As noted in Section 2.2.1, “Thermophysical Properties,” and Section 3.2, “Limitations,” Kairos Power will perform data corroboration of the thermophysical properties found in Table 1 of the TR in order to bring this data under the Kairos Power QA program. [

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[[

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Based on the discussion above, the staff approves the parameters found in Table 1 of the Reactor Coolant TR for use in safety analyses for the KP-FHR. The staff's approval of Table 1 of the Reactor Coolant TR is contingent upon the Limitations and Conditions that are described in Section 4.0 of this SE. Although the entirety of the KP-FHR design has not been submitted to the NRC, based on the discussion above, these values are reasonable to use in safety analyses because **[[ ]]** and because the Kairos Power safety analyses and system design must be able to bound these parameters and associated uncertainties and still maintain appropriate safety margins per Limitation and Condition 5.

3.2.3 TABLE 4, "DESIGN SPECIFICATION FOR KP-FHR REACTOR COOLANT"

Table 4 of the Reactor Coolant TR, "Design Specification for KP-FHR Reactor Coolant," provides: **[[ ]]**

The composition of the reactor coolant is described in Table 4 of the Reactor Coolant TR as **[[ ]]**

[[ ]]

In Section 2.2 of the Reactor Coolant TR, Kairos states that a **[[ ]]**

The TR states that Flibe purity and chemistry will have an impact on material compatibility of the reactor coolant with the structural materials, moderator, and fuel pebbles. It also states that because the MSRE found no attack of the graphite moderator, the structural materials are the basis for setting the KP-FHR corrosion requirements. However, the proposed high temperature materials program still includes carbon-based materials (moderator and fuel pebbles), as well as the proposed structural materials.

Section 2.2.2 of the Reactor Coolant TR, "Corrosion Requirements," states that oxidation of Chromium (Cr) is the primary corrosion mechanism of 316H stainless steel (SS) which contains 16-18 weight percent Cr. The KP-FHR design proposes to use 316 H SS as its structural material. **[**

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[[

]] Additionally, Kairos Power stated that the neutronics of the KP-FHR require an enrichment of ^{7}Li in the reactor coolant**.** **[[**

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NRC Staff Evaluation

The NRC staff evaluated the design specification for the KP-FHR reactor coolant as detailed in Table 4, "Design Specification for KP-FHR Reactor Coolant," of the Reactor Coolant TR. The staff evaluated **[**

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The NRC staff evaluated the **[[**

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[[

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The NRC staff also evaluated [[

the

]].

When considered together, these factors allow the staff to conclude that the approach provided by Kairos in this TR is consistent with the appropriate PDCs as described in Section 3.2.4, "Technical Evaluation Conclusions," of this SE.

Table 4 of the Reactor Coolant TR provides a **[[**

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As noted in the TR, **[[**

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Kairos Power has stated that **[[**

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Kairos Power has recognized that the presence of parasitic neutron absorbers in the Flibe will reduce the magnitude of the negative coolant temperature reactivity feedback, if not make it positive, and decrease fuel utilization. Kairos Power stated that **[[**

]] The TR did not provide any analyses to support this statement but stated that **[[**

]].

Accordingly, based on the information provided in the TR, NRC staff cannot make any findings associated with the neutronic behavior of the Flibe coolant.

3.2.4 Technical Evaluation Conclusions

Kairos Power stated that the properties and characteristics of the reactor coolant satisfy, in part, requirements of PDCs 11, 14, 26, 31, 70, and 73, as established in the Kairos Power PDC TR (Reference 5). Additionally, Kairos requested NRC review and approval of the reactor coolant specification in Table 4 and the thermophysical properties in Table 1 of the Reactor Coolant TR for use in performance of safety analyses by licensing applicants referencing the KP-FHR design. These safety analyses will be provided within separate specific licensing application documents as required by regulation.

NRC Staff Evaluation

The NRC staff finds that the reactor coolant specification in Table 4 and the thermophysical properties in Table 1 of the Reactor Coolant TR are acceptable, subject to the Limitations and Conditions found in Section 4.0 of the staff's SE below. Additionally, the design parameters provided in these tables are consistent with the PDCs for the KP-FHR as follows:

- PDC 11, The staff makes no conclusions regarding the PDC 11. **[**

  ]

- PDCs 14 and 31 **[[**

  ]]

- PDC 26, The staff makes no conclusions regarding the PDC 26. **[**

  ]

- PDC 70, **[[**

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Although Kairos Power also cited this report to partially satisfy PDCs 16 and 60, Kairos Power noted that the properties of the Flibe which demonstrate its ability to retain radionuclides will be described in a future TR. Therefore, the staff will assess the properties of the Flibe which retain radionuclides in the TR in which these properties are discussed, subject to Limitation and Condition 10. The PDC 73 was also cited by Kairos Power as being partially addressed by this TR. However, because the staff was requested to review only Tables 1 and 4 of this TR, the staff did not review the compatibility of the primary and secondary salts. As noted by Kairos Power in Section 3.2 of the TR, the interaction between the reactor coolant and the nitrate salt will be evaluated in a separate TR. Therefore, the staff will evaluate this in a separate TR or license application in which these properties are discussed, subject to Limitation and Condition 11.

4.0 LIMITATIONS AND CONDITIONS

The staff imposes the following limitations and conditions with regard to the TR:

1. (**Section 1.0**) As stated by Kairos Power in the TR, NRC review and approval of Tables 1 and 4 was requested. Therefore, a KP-FHR design referencing this TR may only use this TR for purposes related to the information found in these tables subject to the specific Limitations and Conditions found in the NRC staff SE below. All other information related to the reactor coolant will be evaluated in separate documents and licensing actions.

2. (**Section 1.1.1**) Because there is information that has not yet been developed and/or reviewed as part of this TR, a KP-FHR design referencing this TR must provide information that completely and accurately describes the design of the reactor coolant (and associated systems) and any associated functions it is credited to perform for NRC review and approval. As stated in the TR, if key design features of the KP-FHR change, or if new or revised regulations are issued that impact descriptions and conclusions in this TR, these changes would be reconciled and addressed in future license application submittals. Due to the potential for design changes and new or revised regulations, a KP-FHR applicant referencing this TR must demonstrate that all regulatory and safety requirements related to the characteristics of the reactor coolant are met when considering the final design of the KP-FHR.

3. (**Section 1.1.2**) As presented in the TR, there are key design features without which the proposed reactor coolant design and associated properties may not be supported. Therefore, a KP-FHR design referencing this TR must have the following:

   - A “chemically stable molten fluoride salt mixture” coolant with enrichment of the ^{7}Li isotope

   - TRISO fuel particles and fuel pebbles that, combined with other design features as applicable, including the ability of the reactor coolant to retain fission products, 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

- "Near-atmospheric" primary coolant pressures

These key design features of the KP-FHR, if added to or changed, could necessitate changes to the parameters discussed in the Reactor Coolant TR and would be subject to NRC staff review.

4. (**Section 2.2.1**) A KP-FHR design referencing this TR shall submit to the NRC, for review and approval, results from confirmatory testing to measure the thermophysical properties in Table 1 of the TR, in order to confirm the data under the Kairos QA program. A KP-FHR design that does not perform such testing shall provide the justification for not conducting confirmatory testing or provide a combination of test results and the justification for only testing certain parameters, to the NRC for review and approval. If testing of parameters outside previously reported ranges of conditions is necessary to support KP-FHR design, the results of this testing shall be submitted to the NRC for review and approval. A KP-FHR design referencing this TR must provide, subject to NRC review and approval, the **[[**

   ]] As per the discussion in Sections 2.2.1, "Thermophysical Properties," and 3.2, "Limitations," and Appendix C, "Thermophysical Property Confirmation," of the TR, confirmatory measurements will be done under the applicable quality assurance provisions in 10 CFR Appendix B. Results of this testing shall be submitted to the NRC for review and approval.

5. (**Section 2.2.1**) A KP-FHR design referencing this TR must demonstrate, subject to NRC review and approval, that the thermophysical properties of the reactor coolant described in Table 1 of the TR and any associated uncertainties over the range of KP-FHR operating conditions are considered in its safety analyses. Additionally, the effect of the reactor coolant specification in Table 4 of the TR **[[**

   ]] on thermophysical properties of the reactor coolant, shall be considered in safety analyses.

6. (**Sections 2.2.2 and 3.2**) The Reactor Coolant TR states that high temperature materials qualification activities will be used to confirm corrosion performance of 316H stainless steel in Flibe and corrosion allowances used in engineering and design considerations consistent with the impurity limits specified in Table 4 of the Reactor Coolant TR. A KP-FHR design referencing this TR must demonstrate in its submittal, subject to NRC review and approval, that any materials (including 316H stainless steel) in contact with the reactor coolant that are relied upon to meet a safety or regulatory requirement can do so when exposed to the impurity limits in Table 4 of the TR. The design must demonstrate that material corrosion performance in Flibe is acceptable, subject to NRC review and approval. Additionally, as noted in Section 2.2.2 of the TR, **[**

]] will be determined as part of the high temperature materials TR.

7. (**Section 2.5**) The Reactor Coolant TR states that **[[** **]]** Therefore, a KP-FHR design referencing this TR must be able to measure, subject to NRC review and approval, **[[** **]]**

8. (**Section 2.2.2**) A KP-FHR design referencing this TR must demonstrate, subject to NRC review and approval, that **[[** **]]** These control methods are subject to NRC review and approval.

9. (**Section 2.2**) A KP-FHR design referencing this TR must demonstrate in its submittal, subject to NRC review and approval, that the **[[** **]]** if different from what is described in Revision 1 of the Reactor Coolant TR.

10. (**Section 2.1**) A KP-FHR design referencing this TR will demonstrate, subject to NRC review and approval, the ability of the reactor coolant to retain fission products and methods for predicting retention in a separate TR.

11. (**Section 3.2**) A KP-FHR design referencing this TR will characterize, subject to NRC review and approval, reactor coolant and intermediate coolant mixing in license application documents, and through testing, modeling, and validation as stated in Section 2.6 of the TR.

12. (**Section 2.4**) A KP-FHR design refencing this TR will provide a description of the KP-FHR reactor coolant purification system as part of future license application documents for NRC review and approval.

5.0 CONCLUSION

Based on the evaluation above, the staff concludes that Kairos Power has provided sufficient information in Tables 1 and 4 of the Reactor Coolant TR to demonstrate that KP-FHR PDCs 14, 16, 31, 60, 70, and 73 as described above, would be satisfied, in part, subject to the Limitations and Conditions in Section 4.0 of this SE. Additionally, the staff concludes the thermophysical properties found in Table 1 and the reactor coolant specification in Table 4 of the TR can be used in safety analyses, subject to the Limitations and Conditions in Section 4.0 of this SE. The information provided in Tables 1 and 4 of the TR establishes certain characteristics of the reactor coolant that will support unique design and safety features of the KP-FHR.

6.0 REFERENCES

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Principal Contributors: Alexander Chereskin, NRR
Timothy Drzewiecki, NRR

Date: July 16, 2020

Section B

KP-TR-005-NP-A

Kairos Power LLC
707 W. Tower Ave
Alameda, CA 94501

Reactor Coolant for the Kairos Power Fluoride Salt-Cooled High Temperature Reactor

Topical Report

Revision No. 1
Document Date: January 2020

Non-Proprietary

Rev	Description of Change	Date
0	Initial Issuance	March 2019
1	Revised to address NRC questions, provided by email dated November 21, 2019 on the initial revision.	January 2020

Executive Summary

This topical report describes the specification limits and thermophysical properties of the reactor coolant for the Kairos Power Fluoride Salt-Cooled, High Temperature Reactor (KP-FHR).

The reactor coolant is a mixture of lithium fluoride (LiF) and beryllium fluoride (BeF_2) in the nominal composition of 2LiF:BeF_2. The reactor coolant specification includes limits on the ratio of LiF to BeF_2 along with limits on impurities that affect corrosion and neutronic behavior. Methods and assumptions for setting the specification limits are provided within this report.

The reactor coolant is a key design feature of the KP-FHR technology and supports the enhanced safety performance, including limiting the consequences of accidental release of radioactive materials to the environment. Kairos Power is requesting Nuclear Regulatory Commission review and approval of the reactor coolant specification and thermophysical properties for the performance of design and safety analysis by license applicants under 10 CFR 50 or 10 CFR 52.

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ABREVIATIONS

Abbreviation or Acronym	Definition
ASTM	American Society for Testing and Materials
AOO	Abnormal Operating Occurrence
CSP	Concentrated Solar Power
DOE	Department of Energy
DPRA	Dynamic Probabilistic Risk Assessment
EAB	Exclusion Area Boundary
FHR	Fluoride Salt-Cooled High Temperature Reactor
FSAR	Final Safety Analysis Report
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
IHTS	Intermediate Heat Transport System
IHX	Intermediate Heat Exchanger
IRP	Integrated Research Projects
KP-FHR	Kairos Power Fluoride Salt-Cooled, High Temperature Reactor
MHTGR	Modular High Temperature Gas Reactor
MSRE	Molten Salt Reactor Experiment
NRC	Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
PDC	Principal Design Criteria
PHTS	Primary Heat Transport System
PSAR	Preliminary Safety Analysis Report
ROM	Reduced Order Model
TRISO	Tri-structural Isotropic

1. INTRODUCTION

Kairos Power LLC (Kairos Power) is pursuing the design, licensing, and deployment of the Kairos Power Fluoride Salt-Cooled, High Temperature Reactor (KP-FHR). To support these objectives, Kairos Power is developing this report to describe the reactor coolant properties used in the KP-FHR. These include the design specification, physical properties, nuclear properties, and chemical factors relevant for use as a reactor coolant.

NRC regulations in 10 CFR 50 and 10 CFR 52 require reactor license applicants provide a safety analysis report that in part requires a description of features that are unique, unusual or having a significant bearing on the probability or consequences of accidental release of radioactive materials; and barriers that must be breached as a result of an accident before a release of radioactive material to the environment can occur. The reactor coolant for the KP-FHR is a feature which performs or supports the performance of these functions. The properties and characteristics of the reactor coolant also satisfy portions of the Principal Design Criteria (PDC) established in the Kairos Power Topical Report, Principal Design Criteria for the Kairos Power Fluoride Salt Cooled High Temperature Reactor (Reference [1]).

Kairos Power requests NRC review and approval of reactor design characteristics represented by the reactor coolant specification in Table 4 and the thermophysical properties in Table 1 of this topical report to be used in the performance of safety analyses by licensing applicants of the KP-FHR design requesting standard design certifications, combined licenses, standard design approvals, and manufacturing licenses under the applicable regulations in 10 CFR 52; and limited work authorizations, construction permits, and operating licenses under 10 CFR 50. Safety analyses which rely on or credit the use of the KP-FHR reactor coolant specification and thermophysical properties to satisfy regulatory requirements will be provided within specific licensing application documents (e.g., safety analysis reports) required to be submitted by the cited regulations.

1.1 DESIGN FEATURES

1.1.1 DESIGN BACKGROUND

To facilitate NRC review and approval of this report, key design features are provided in this Section 1.1.2 which are considered inherent to the KP-FHR technology. These features are not expected to change during the design development by Kairos Power and provide the basis to support the safety review of this report. Should fundamental changes occur to these key design features or new or revised regulations be promulgated that affect the description and conclusions in this report, such changes would be reconciled and addressed in future license application submittals.

The KP-FHR is a U.S.-developed Generation IV advanced reactor technology. In the last decade, U.S. national laboratories and universities have developed pre-conceptual Fluoride High-Temperature Reactor (FHR) designs with different fuel geometries, core configurations, heat transport system configurations, power cycles, and power levels. More recently, University of California at Berkeley developed the Mark 1 pebble-bed FHR (Mk1 PB-FHR), incorporating lessons learned from the previous decade of pre-conceptual designs (Reference [2]). Kairos Power has built on the foundation laid by Department of Energy (DOE)-sponsored university Integrated Research Projects (IRPs) to develop the KP-FHR.

Although not intended to support the findings necessary to approve this report, additional design description information is provided in the "Design Overview of the Kairos Power Fluoride Salt Cooled, High Temperature Reactor (KP-FHR)" Technical Report (Reference [3]).

1.1.2 KEY DESIGN FEATURES OF THE KP-FHR

The KP-FHR is a high temperature reactor with molten fluoride salt coolant operating at near-atmospheric pressure. The fuel in the KP-FHR is based on the tri-structural isotropic (TRISO) high-temperature, carbonaceous-matrix coated particle fuel (originally developed for high-temperature gas-cooled reactors) in a pebble fuel element. Coatings on the particle fuel provide retention of fission products. The reactor coolant is a chemically stable molten fluoride salt mixture, $2LiF{:}BeF_2$ (Flibe with [[ ]]) which also provides retention of fission products that escape from any fuel defects. A primary coolant loop circulates the reactor coolant using pumps and transfers the heat to an intermediate coolant loop via a heat exchanger. The pumped flow intermediate coolant loop utilizes a nitrate salt, compatible with the reactor coolant, and transfers heat from the reactor coolant to the power conversion system through a steam generator. The design includes two decay heat removal systems. A normal decay heat removal system is used following normal shutdowns and anticipated operational occurrences. A separate passive decay heat removal system, which along with natural circulation in the reactor vessel, removes decay heat in response to a design basis accident and does not rely on electrical power.

The KP-FHR design uses a functional containment approach similar to the MHTGR instead of the typical LWR low-leakage, pressure retaining containment structure. The KP-FHR functional containment design objective is to meet 10 CFR 50.34 (10 CFR 52.79) offsite dose requirements at the plant's exclusion area boundary (EAB) with margin. A functional containment is defined in RG 1.232 as a "barrier, or set of barriers taken together, that effectively limit the physical transport and release of radionuclides to the environment across a full range of normal operating conditions, AOOs, and accident conditions." RG 1.232 includes an example design criterion for the functional containment (MHTGR Criterion 16). As also stated in RG 1.232, the NRC has reviewed the functional containment concept and found it "generally acceptable," provided that "appropriate performance requirements and criteria" are developed. The NRC staff has developed a proposed methodology for establishing functional containment performance criteria for non-LWRs, which is presented in SECY-18-0096. This SECY document has been approved by the Commission.

The functional containment approach for the KP-FHR is to control radionuclides primarily at their source within the coated fuel particle under normal operations and accident conditions without requiring active design features or operator actions. The KP-FHR design relies primarily on the multiple barriers within the TRISO fuel particles and fuel pebble to ensure that the dose at the site boundary as a consequence of postulated accidents meets regulatory limits. However, in contrast to the MHTGR, the KP-FHR molten salt coolant also serves as a distinct barrier providing retention of fission products that escape the fuel particle and fuel pebble barriers. This additional retention is a key feature of the enhanced safety and reduced source term in the KP-FHR.

1.2 REGULATORY REVIEW

Applicants for construction permits for facilities licensed under 10 CFR 50 are required to provide a preliminary safety analysis report (PSAR) which provides a safety assessment of the facility, including a description of reactor design characteristics, in accordance with 10 CFR 50.34(a). Applicants for a limited

work authorization (LWA) are required to submit a safety analysis that meets 10 CFR 50.34 for the scope of the LWA per 10 CFR 50.10(d)(3)(i). Subsections within 10 CFR 50.34(a) relevant to the requirement to describe design characteristics of the KP-FHR reactor coolant are listed below (note these are required to be updated as part of the operating license application in the FSAR per 10 CFR 50.34(b)(4)):

> *50.34(a)(1)(ii)(C) The extent to which the reactor incorporates unique, unusual or enhanced safety features having a significant bearing on the probability or consequences of accidental release of radioactive materials*
>
> *50.34(a)(1)(ii)(D) The safety features that are to be engineered into the facility and those barriers that must be breached as a result of an accident before a release of radioactive material to the environment can occur. Special attention must be directed to plant design features intended to mitigate the radiological consequences of accidents*
>
> *50.34(a)(2) A summary description and discussion of the facility, with special attention to design and operating characteristics, unusual or novel design features, and principal safety considerations.*

Similarly, applicants for combined licenses for facilities licensed under 10 CFR 52 are required to provide a final safety analysis report (FSAR) which provides a safety assessment of the facility, including a description of reactor design characteristics, in accordance with 10 CFR 52.79. Subsections relevant to the requirement to describe reactor design characteristics of the reactor coolant are listed below:

> *52.79(a)(2) A description and analysis of the structures, systems, and components of the facility with emphasis upon performance requirements, the bases, with technical justification therefor, upon which these requirements have been established, and the evaluations required to show that safety functions will be accomplished. It is expected that reactors will reflect through their design, construction, and operation an extremely low probability for accidents that could result in the release of significant quantities of radioactive fission products. The descriptions shall be sufficient to permit understanding of the system designs and their relationship to safety evaluations. Items such as the reactor core, reactor coolant system, instrumentation and control systems, electrical systems, containment system, other engineered safety features, auxiliary and emergency systems, power conversion systems, radioactive waste handling systems, and fuel handling systems shall be discussed insofar as they are pertinent…*
>
> *52.79(a)(2)(iii) The extent to which the reactor incorporates unique, unusual or enhanced safety features having a significant bearing on the probability or consequences of accidental release of radioactive materials;*
>
> *52.79(a)(2)(iv) The safety features that are to be engineered into the facility and those barriers that must be breached as a result of an accident before a release of radioactive material to the environment can occur. Special attention must be directed to plant design features intended to mitigate the radiological consequences of accidents…*

Similar requirements to these are also included in 10 CFR 52.47 for Standard Design Certifications; 10 CFR 52.137 for Standard Design Approvals; and 10 CFR 52.157 for Manufacturing licenses.

The design characteristics of the KP-FHR reactor coolant are unique from the typical water-based coolant used in light water reactors typical of the operating fleet. The design and thermophysical properties of the KP-FHR reactor coolant enhances the safety of operations and reduces the probability

of events by providing significant thermal capacity while remaining in a liquid phase. The design and thermophysical properties of the KP-FHR reactor coolant also provides additional functional containment protection, beyond that provided by the TRISO fuel particle, by absorbing fission products that escape the TRISO protective layer. This design feature reduces the probability of accidental release of radioactive materials. This report describes the thermophysical properties and characteristics of the KP-FHR coolant that are relevant for demonstrating these enhanced safety features as required by the requirements in 10 CFR 50 and 10 CFR 52 cited above. The demonstration of fission product retention capabilities of the KP-FHR reactor coolant will be provided in a separate topical report describing the source term. Safety analyses which rely on or credit the use of the KP-FHR reactor coolant specification and thermophysical properties to satisfy regulatory performance requirements will be provided within specific licensing application documents (e.g., safety analysis reports) required to be submitted by the cited regulations.

Facilities licensed under 10 CFR Part 50 are also required to describe principal design criteria (PDC) in their preliminary safety analysis report supporting a construction permit and operating license application as described in 10 CFR 50.34(a)(3)(i). Likewise, applicants for standard design certifications, combined licenses, standard design approvals, and manufacturing licenses must include the PDC for a facility as described in 10 CFR 52.47(a)(3)(i), 10 CFR 52.79(a)(4)(i), 10 CFR 52.137(a)(3)(i), and 10 CFR 52.157(a). The PDC for the KP-FHR have been established in the Kairos Power Topical Report, Principal Design Criteria for the Kairos Power Fluoride Salt Cooled High Temperature Reactor (Reference 1). The specific PDC in this report which rely on or credit the design and performance of the KP-FHR reactor coolant include PDC 14, 16, 26, 31, 60, 70, and 73. The design characteristics of the reactor coolant which satisfy, in part, these PDC are identified below.

Corrosion of structural materials is important consideration for maintaining the integrity of the safety-significant portions of the reactor coolant boundary (PDC 14 and PDC 31). The KP-FHR reactor coolant design characteristics related to acceptable corrosion controls which satisfy PDC 14 and PDC 31 as discussed in Section 2 of this report.

The design characteristics of the reactor coolant mix enables the KP-FHR core to be designed with a negative coolant temperature coefficient of reactivity. This is a key feature of the coolant which supports inherent reactor protection to compensate for rapid increases in reactivity (PDC 11). The neutronic characteristics of the KP-FHR reactor coolant design which satisfy PDC 11 are discussed in this report.

The design of the reactor coolant mix provides, in part, a means to control the accidental release of radioactive materials during normal reactor operation and anticipated operational occurrences (PDC 60) and supports, in part, demonstration of the functional containment aspects required by PDC 16. The design aspects of the KP-FHR reactor coolant are discussed in this report. The demonstration of the fission product retention capabilities of the reactor coolant will be provided in a separate topical report describing the KP-FHR mechanistic source term.

The purity of the reactor coolant is an important design characteristic for corrosion control and neutronic performance. Chemistry control provisions are specified to maintain the purity of reactor coolant within specified design limits (PDC 70). Reactor coolant purity provisions which satisfy PDC 70 are discussed in this report.

Compatibility of the reactor coolant and intermediate coolants is important with respect to PDC 73. The design characteristics of the reactor coolant which affect chemical compatibility considerations relevant to PDC 73 are discussed in this report and will be demonstrated as acceptable as part of safety analyses within individual license applications.

2 HEAT TRANSPORT SYSTEM FLUIDS

The KP-FHR transfers heat generated by the core to the power conversion unit using both a primary heat transport system (PHTS) and intermediate heat transport system (IHTS), each with different heat transfer fluids as illustrated in Figure 1. The primary heat transport system salt, which transports heat from the TRISO particle-based fuel pebbles to the intermediate heat transfer system, uses a lithium fluoride (LiF), beryllium fluoride (BeF_2) salt. The molar ratio is approximately 2LiF:BeF_2 (i.e., Li_2BeF_4) and is also referred to as "Flibe".

Thermal power is transferred from PHTS fluid to the IHTS system fluid through intermediate heat exchangers (IHX). The intermediate heat transfer system is responsible for moving heat from the primary heat transport system to the steam generators. The Intermediate heat transport system fluid utilizes a blend of 60 weight percent sodium nitrate salt ($NaNO_3$) and 40 weight percent potassium nitrate (KNO_3). This thermal fluid is referred to by several names; solar salt, nitrate salt, or 60/40 salt; in this report it is referred to by the simple term "nitrate salt." Nitrate salt is utilized by the concentrated solar power (CSP) industry and has a well-developed supply chain for raw materials, specific allowable impurities, and components. Although this report focuses on the reactor coolant, interactions between the Flibe and nitrate salts are considered to address PDC 73 for high temperature compatibility if mixed together due to a potential leak in the IHX.

This report does not explicitly consider retention of fission products released into Flibe during operation, which can arise from fuel defects. Fission product retention and methods for predicting retention will be addressed in a separate source term topical report.

2.1 FLIBE FOR PRIMARY HEAT TRANSPORT SYSTEM

As noted above, the Flibe is composed of a nominal 2LiF:BeF_2 (See Figure 2 for the diagram, note the Li_2BeF_4 phase is Flibe, See Table 1 for thermophysical properties), a peritectic with a melting point of 459°C. In the 1960's Oak Ridge National Laboratory (ORNL) was funded by the United States Government through the Atomic Energy Commission for more than a decade to design molten salt reactors. This work served as the basis for the selection of Flibe for use in the Molten Salt Reactor Experiment (MSRE), which is also relevant to the KP-FHR, where the primary criteria is summarized in Table 2 (Reference [4]). MSRE used two salts, a fuel salt in the primary circuit (Flibe + ZrF_4 + UF_3/UF_4 + fission products), and a heat transport salt in the intermediate circuit (Flibe with nominally the same composition as KP-FHR Flibe).

The MSRE fuel salt was a slightly LiF-rich Flibe (0.69[LiF] – 0.31[BeF_2]) with additions of 5 mole% ZrF_4 and 0.9% fissile UF_3/UF_4, resulting in a final composition of 0.65[LiF] - 0.291[BeF_2] - 0.05[ZrF_4] - 0.009[UF_3/UF_4]. The purpose of the ZrF_4 addition was to preferentially react with atmospheric leaks to form ZrO_2 instead of UO_2, mitigating the concern for a criticality accident from UO_2 precipitation and accumulation. The MSRE fuel salt was stable under irradiation, where the uranium and zirconium inventories during operation were nearly perfectly accounted for. ZrF_4 is a volatile species, but as a Lewis acid it receives fluoride ions from LiF (a Lewis base) to form ZrF_6^{2-}, a non-volatile species. Analogously, BeF_2 is a Lewis acid that forms BeF_4^{2-} ions. In the Lewis acid-base sense, substitution of BeF_2 for ZrF_4 changes very little about the salt chemistry. For this reason, pure Flibe is expected to behave nearly identically as MSRE fuel salt during irradiation.

Although there are several important selection criteria, the neutronic considerations were the key deciding factor in selecting Flibe as the primary coolant. Flibe enables the FHR cores to be designed with

a negative coolant temperature coefficient of reactivity, which provides a safety benefit supporting reactivity control (PDC 26), low parasitic neutron absorption that allows for effective fuel utilization, and minimal short-term and long-term activation of the coolant for improved operations and maintenance (only fluorine, with a half-life of less than one minute, is activated). These neutronic factors, in combination with the other positive benefits of Flibe described below, led to its selection as the primary coolant choice for the KP-FHR.

Stability at high temperature is a desirable coolant property criterion because it precludes chemical degradation, ensures low vapor pressures, and increases radiation stability. Flibe does not decompose at operating temperatures and has a very low vapor pressure at operating temperature, approximately $1x10^{-2}$mmHg (~0.6Pa) at 650°C, and increases to 3mmHg (400Pa) at 950°C. Water, as a familiar point of reference, at 25°C is ~23mmHg. A low vapor pressure at and above normal operating conditions is advantageous by limiting “frosting” of the coolant on cooler vapor space structures, where condensation of the vapor salt can result in solid phase formation. These resemble a frosted or snow-like appearance.

Vapor pressure correlations for Flibe, as provided in Table 2, were measured above KP-FHR operational temperatures. Since Flibe has a low vapor pressure below 900°C it was not been measured at the operational temperatures of the KP-FHR PHTS (550-650°C). However, two approaches can be taken to approximate the vapor pressure. First, extrapolation of the correlation to operational temperatures and, second, using Raoult’s Law for ideal mixtures. Raoult’s method can only be used if the partial pressures of the pure component are available, data for LiF, BeF_2 is provided in Table 3. Raoult’s Law is applied as follows:

$$P = 0.667P^*_{LiF} + 0.333P^*_{BeF2} \qquad \textit{Equation 1}$$

*P** are partial pressures, at temperature, for each pure component. Using vapor pressures for LiF and BeF_2 at 650°C, provided in Table 3, this calculated value ($14x10^{-3}$mmHg) is approximately three times higher than calculated value of the extrapolated equation provided in Table 1 ($5x10^{-3}$mmHg). This difference, while relatively large, is within error as provided in Reference [5].

Vapor pressure of Flibe at normal temperatures of KP-FHR operation is low during normal operation. For mechanistic source term considerations, vapor pressures of dilute solutions of fission products released from failed TRISO fuel particles into the Flibe coolant are an important consideration. This consideration will be addressed in a separate source term topical report for the KP-FHR.

An acceptably low melting point is an important criterion to enable the use of molten salts as a suitable reactor coolant. The melting point of single constituent salts are quite high with BeF_2 being the lowest melting at 555°C (Figure 2). System designs must ensure that the selected heat transport fluid remains liquid during operation. As melting point temperatures increase, system design solutions become complex and costly to implement. Lower melting point compositions using ternary or higher salt constituents are possible (an example is LiF-NaF-BeF_2 provided in Figure 3), but introduces elements (e.g., sodium) that increase parasitic neutron capture. As noted above, neutronic considerations are a major performance parameter that motivates the selection of Flibe for FHRs. Therefore, a binary mixture of LiF and BeF_2 was selected to obtain an acceptably low melting point below 500°C, while minimizing chemical and neutronic impacts.

Operating experience from MSRE demonstrated minimal corrosion of structural materials which is important for maintaining the integrity of the safety-significant portions of the reactor coolant boundary.

The primary corrosion reaction of importance is chromium oxidation of the structural alloy. Chromium is oxidized from the elemental form to a soluble fluoride. During reactor operation, there is generation of small amounts of tritium fluoride, which oxidizes chromium through the following reaction (Reference [6]):

$$2TF + Cr^0 \rightarrow T_2 + CrF_2 \qquad \textit{Equation 2}$$

In addition to tritium generation, the MSRE fuel salt was determined to be corrosive due the stoichiometric excess of free fluorine (in the form of fluorine radicals) that were a consequence of the smaller number of fluoride anions needed to satisfy the stoichiometric requirements of fission product cations compared to fluorides released during UF_4 fissioning. MSRE employed a corrosion buffer in the fuel salt, specifically a small concentration of UF_3, allowing the free fluorine to be mitigated through the reactions:

$$2TF + 2UF_3 \rightarrow T_2 + 2UF_4 \qquad \textit{Equation 3}$$

$$UF_3 + F^- \rightarrow UF_4 \qquad \textit{Equation 4}$$

Corrosion control in this way was quite successful and Hastelloy N did not significantly degrade during reactor operation (Reference [7]).

The UF_3/UF_4 ratio was typically < 0.01 in MSRE. When the reserve of UF_3 became too low small, amounts of metallic beryllium were added to the reactor to reduce UF_4 to UF_3 with the formation of BeF_2 thereby recharging the U^{3+}/U^{4+} buffer. It was shown that additions of metallic beryllium protect ferrous alloys with high chromium content (i.e. stainless steel alloy 316) such that the corrosion rate was below 10 microns per year (Reference [6]). Having a clean salt, free of moisture, is important for maintain such low corrosion rates and is discussed in Sections 2.3 and 2.4. MSRE salt observed formation of radiolytic formation of F_2 at temperatures below 100°C and conclusions were that salt temperatures above 200°C prevented radiolysis (Reference [8]). By comparison, frozen KP-FHR salt is not expected to receive a high fluence of radiation causing radiolytic fluorine gas generation. This is due to the relatively low concentration of radioactive species that are expected to accumulate in the reactor coolant under normal operation. Furthermore, under normal conditions, the Flibe coolant is not expected to be in a frozen state and will be on- and off-loaded in the molten state. When off-loaded, it will be trace-heated to remain molten. If the salt freezes in the drain/storage tank, the generation rate of fluorine gas is expected to be low and measures will be taken for mitigation. Lastly, beryllium metal resident in the salt will help arrest radiolytic fluorine, therefore, no dedicated corrosion allowance is included for this phenomenon. Mitigation of the relatively small amount of radiolytic fluorine is easily achieved during storage of frozen KP-FHR Flibe.

Flibe was determined to be an excellent solvent for metal fluorides, dissolved fuel, and fission products during MSRE. Credit for fission product retention in the molten salt is an important part of the KP-FHR safety case demonstrating conformance to the functional containment requirements. While the demonstration of fission product retention will occur in a future source term topical report, the key nuclides of interest for source term analysis, taken from the mechanistic source terms white paper for High Temperature Gas Reactors, are iodine (I^-), cesium (Cs^+), and strontium (Sr^{2+}) (Reference [9]). Results from the MSRE found that oxidized or reduced states of many of these were readily soluble in Flibe (Reference [10]) and, in KP-FHR, it is expected that these fission products will remain in the Flibe, either as a metallic or as a salt. The concentration of fission products in the KP-FHR coolant will be orders of magnitude lower than in the MSRE due to retention in the TRISO fuel form (Reference [11]). As a result,

the demonstration of high fission product loading of the MSRE fuel salt strongly suggests that KP-FHR Flibe will be able to retain fuel or fission products, either as a metallic or salt, due to fuel TRISO and pebble fuel failures. The retention properties of fission products from TRISO fuels in Flibe will be addressed in a separate topical report on source term for the KP-FHR.

2.2 FLIBE SPECIFICATION

Based on the considerations described in Section 2.1, Flibe was chosen as the reactor coolant for the KP-FHR. Table 4 establishes the design specification for the KP-FHR reactor coolant to be used for operations and for analysis. [[

]] The limits as defined are for normal

operation. Consideration of off-normal or transient limits and impurities will be informed by material testing, specifically air, water, and nitrate ingress conditions and will be addressed in the KP-FHR High Temperature Materials Topical Report.

2.2.1 Thermophysical Properties

The thermophysical properties for Flibe have been studied extensively, including work for the MSRE program and as part of subsequent fusion energy research (Reference [14]). Thermophysical properties are predominately derived from measurements made in preparation for the MSRE where the resulting correlations, along with expected uncertainties, are provided in Table 1(References [4, 15]), which were measured using $2LiF:BeF_2$ for MSRE.

Molten salts show an exponential decrease in viscosity with reciprocal temperature. Due to this behavior, viscosity varies the most with temperature compared to other thermophysical properties as shown by Cantor (Reference [5]). Furthermore, the large difference in viscosity for the pure components of the binary lithium fluoride – beryllium fluoride system leads to a large viscosity dependence on the binary mixture composition. For this reason, a specification for the mole ratio of LiF to BeF_2 has been established such that the composition-dependent viscosity does not vary by more than the uncertainty associated with the temperature-dependent viscosity (illustrated in Figure F4).

The temperature-dependent viscosity equation in Table 1 was developed by Cantor (Reference [5]). [[

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Data generated by the MSRE research teams are the best available and represent the MSRE program team's depth and breadth of expertise, as well as their ability to validate properties through operational experience and traceable standards where possible. As such, Kairos Power believes that the thermophysical properties of Flibe established by national laboratory research efforts associated with the MSRE are appropriate for use in design and analysis. OPEN ITEM: Kairos Power will perform data corroboration and peer review of the MSRE data used for Table 1 for purposes of bringing the historical thermophysical property data under the Kairos Power QA program.

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2.2.2 Corrosion Requirements

Material compatibility with the reactor coolant (structural materials, moderator, fuel pebbles) are impacted by Flibe purity and chemistry. MSRE found no attack of the graphite moderator during operation, with no change in graphite surface finish after 2.5 years of exposure (Reference [7]) despite the fact that the MSRE fuel salt included a wide range of elements, due to generation of fission products. Therefore, while carbon-based materials (moderator and fuel pebbles) are included as part of the Kairos Power high temperature materials testing programs, the structural materials are the basis for setting the corrosion requirements. Note that the KP-FHR High Temperature Materials Topical Report will address corrosion considerations of graphite and characterization of long-term exposure of graphite in a stainless-steel system with Flibe, The High Temperature Materials Topical Report will also discuss testing that will be to ensure that the degradation of structural components is bounded by design margin.

Corrosion of stainless steels occur primarily through oxidation of chromium (Cr) from metal form (i.e. structural alloy) to a soluble fluoride in hot regions, and transport to cold regions (via precipitation). KP-FHR is pursuing 316H as the structural alloy, which has chromium content ranging from 16-18 weight percent. [[

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2.2.3 Neutronic Requirements

The neutronic requirements of Flibe is defined by both safety and economic considerations. The presence of parasitic neutron absorbers (poisons) in the Flibe will reduce the magnitude of the negative coolant temperature reactivity feedback, if not make it positive, and decrease the fuel utilization. [[

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2.2.4 Impurity Limits Assessment Methodology

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2.3 FLIBE SYNTHESIS AND PURIFICATION

As received raw materials for Flibe, ^7LiF and BeF_2, require additional purification steps prior to utilization in the KP-FHR. Impurities within the salt arise from different sources, ranging from raw materials to environmental contaminants. Raw materials, even relatively high-grade materials, can have a variety of dissolved impurities such as NiF_2, FeF_2, CdF_2, PbF_2, sulfur, chlorine, etc. Environmental contaminants are primarily moisture which produces oxides, hydroxides, and hydrogen fluoride. For reasons provided in Section 2.2.2 they must be removed for materials compatibility.

Operating experience with the MSRE purification process, which removed environmental contamination, moisture and oxygen, and metal fluorides, sulfur, and chloride (Reference [10]) provides a basis for processing KP-FHR Flibe. MSRE used a batch chemical reactor, with a multi-step process of co-melting the raw constituents, gas sparging, and mechanical filtration to adequately remove impurities prior to reactor use. Figure 4 provides a high-level overview of the process along with the approximate temperatures and reason for each process step.

After loading and co-melting solid LiF and BeF_2, an inert gas sparge of argon or helium was introduced into the reaction vessel. The vessel was heated from room temperature to 600°C, removing most of the absorbed moisture and melting Flibe into the pereutectic. Once at temperature, the argon sparge was replaced with a mixture of anhydrous hydrogen fluoride (HF) and hydrogen (H_2) gas.

The mixed gas sparge of HF and H_2 were used to remove oxygen and hydrogen impurities from the melt. These impurities, present as oxides and hydroxides, were removed via a substitution reaction with a metal oxide or metal hydroxide via the following reactions:

$$MO_{(l)} + 2HF_{(g)} \rightarrow MF_{2(l)} + H_2O_{(g)} \qquad \textit{Equation 6}$$

$$M(OH)_{2(l)} + 2HF_{(g)} \rightarrow MF_{2(l)} + 2H_2O_{(g)} \qquad \textit{Equation 7}$$

HF was converted to water in these reactions. Therefore, changes in HF concentration in the effluent gas were used to signify process completion. Additionally, the $HF:H_2$ sparge facilitated removal of sulfur by gas evolution (H_2S), boron by gas evolution (BF_3), and chloride by gas evolution (HCl). The MSRE purification procedure required approximately 94 moles of HF to remove 12 moles of oxide, which equated to roughly a three-day sparge at 0.5 L/min of HF for their 50kg batch reactor (Reference [18]).

Upon completion of the $HF:H_2$ step the HF flow was replaced with an H_2 sparge to enable reduction of metals in the melt. For example, a metal fluoride (i.e. NiF_2), will be reduced to a metal through the following reaction:

$$MF_{2(l)} + H_{2(g)} \rightarrow M_{(s)} + 2HF_{(g)} \qquad \textit{Equation 8}$$

HF was the byproduct generated during this reaction step and will be present in the effluent gas. Reduced metals were insoluble in Flibe and will tend to nucleate to form larger metal agglomerates or deposit on metallic surfaces and are removed via filtration. The final gas sparge step was introduction of argon (or helium) to remove any remaining H_2.

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2.4 SALT CHEMISTRY CONTROL DURING KP-FHR OPERATION

During reactor operation, impurities will be introduced into the coolant as part of normal operation. The main purpose of chemistry control is to ensure reliability of components, through minimizing corrosion. The KP-FHR concept for chemistry control during operation, including reactions of interests and strategies on controlling chemical behavior are described below.

Air or moisture ingress in the reactor coolant may occur in addition to small levels of tritium generation through transmutation of BeF_2 through the following reactions:

$$BeF_2 + n \rightarrow {}^4_2He + {}^6_2He + F_2 \qquad \textit{Equation 9}$$

${}^6_2He$ decomposes through a beta decay which results in ${}^6_3Li$. ^{6}Li then undergoes transmutation via the following:

$$ {}^6_3Li + n \rightarrow {}^4_2He + {}^3_1H \qquad \textit{Equation 10}$$

Both reactions yield species that corrode structures, either as excess fluoride/fluorine (F^- or F_2) or tritium fluoride (${}^3_1HF$). Beryllium additions, supplied through the chemistry control system (Figure 5), will getter either HF or F. Metallic beryllium reduces HF to hydrogen gas and reacts with fluoride ions, where both reactions form BeF_2:

$$Be + 2HF \rightarrow BeF_2 + H_2 \qquad \textit{Equation 11}$$

$$Be + 2F^- \rightarrow BeF_2 + 2e^- \qquad \textit{Equation 12}$$

This approach has been quite effective for controlling corrosion rates of stainless steels, where clean Flibe without metallic beryllium was 10 - 30 microns per year, and Flibe with metallic beryllium was less than 10 microns (References [6, 19, 20]), therefore the need to have metallic beryllium is viewed as an operational consideration for prolonging component lifetime and is not established to address a specific safety requirement. Beryllium has low solubility in Flibe, [[

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A further positive implication in metallic beryllium addition is beryllium's ability to getter oxygen-based impurities that commonly arise from high temperature oxygen-based corrosion:

$$3Be + Cr_2O_3 \rightarrow 3BeO + 2Cr \qquad \textit{Equation 13}$$

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2.5 ANALYTICAL CHEMISTRY METHOD DEVELOPMENT

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2.6 COMPATIBILITY OF FLIBE AND NITRATE SALT

During KP-FHR operation, a heat exchanger leak would result in the mixing of the reactor coolant (Flibe) and the intermediate heat transport loop coolant (nitrate salt). Reference [22] reported that a foaming reaction was observed when LiF-BeF_2-ThF_4 salt was mixed with a nitrate-nitrite salt (HITEC). The salt compositions used in Reference [22] differed from the KP-FHR coolants and cannot be used to predict behavior for the KP-FHR.

Thermodynamic analysis was performed using the KP-FHR coolants. Based on this analysis, it is anticipated that the following endothermic chemical reaction will occur between the KP-FHR reactor coolant salt and intermediate nitrate salt:

$$4NaNO_3 + 2BeF_2 \rightarrow 2BeO + 4NaF + 4NO_2 + O_2 \quad \text{Equation 14}$$

Sodium is shown as the nitrate cation for simplicity; substitution of other alkali or alkaline earth metals changes little about the characteristics of the reaction. Figure 6 plots the Gibbs Free Energy, enthalpy, and equilibrium constant for Equation 14, as predicted by HSC thermodynamic database (Reference [23]). At KP-FHR operating temperatures (550-650^{o}C), the endothermic reaction is

thermodynamically favorable due to the high entropy resulting from five moles of gas (four moles of NO_2 and one mole of O_2) produced for every four moles of nitrate consumed.

The kinetics of the reaction cannot be calculated in the absence of experimental data and details on how the two molten salts are expected to interact must be resolved through testing. It is expected that the rate of gas production from this reaction will be manageable, based upon the endothermic nature of the reaction. Additional characterization of the Flibe-nitrate salt interaction will be addressed through testing, modeling, and validation as part of specific licensing applications.

3 CONCLUSIONS AND LIMITATIONS

3.1 CONCLUSIONS

The design characteristics and thermophysical properties of the reactor coolant are key design features that support the enhanced safety performance of the KP-FHR, including limiting the accidental release of radioactive materials to the environment. The properties and characteristics of the reactor coolant are also used to satisfy, in part, portions of the PDC 14, 16, 26, 31, 60, 70, and 73 established in the Kairos Power PDC Topical Report (Reference [1]).

Kairos Power requests NRC review and approval of the reactor design characteristics represented by the reactor coolant specification in Table 4 and the thermophysical properties provided in Table 1 of this topical report (subject to the limitations described below). The specification and thermophysical propertieswill be used in the performance of safety analyses by licensing applicants of the KP-FHR design requesting standard design certifications, combined licenses, standard design approvals, and manufacturing licenses under the applicable regulations in 10 CFR 52; or construction permits and operating licenses under 10 CFR 50. Safety analyses which rely on or credit the use of the KP-FHR reactor coolant specification and thermophysical properties to satisfy regulatory requirements will be provided within specific license application documents (e.g., safety analysis reports) required to be submitted by the cited regulations.

3.2 LIMITATIONS

As discussed in Section 2.2.1, Kairos Power believes that the thermophysical properties of Flibe established by national laboratory research efforts associated with the MSRE are appropriate for use in design and analysis and form the basis for the content in Table 1. OPEN ITEM: Kairos Power will perform data corroboration and peer review for purposes of bringing the historical thermophysical property data under the Kairos Power QA program.

With respect to the uncertainties in thermophysical properties, safety analysis for the KP-FHR will consider the stated uncertainties in Table 1 in an uncertainty quantification (UQ) analysis and identify the dominant uncertainty parameters associated with anticipated operational occurrences in the KP-FHR. If the uncertainty for a specific thermophysical property is determined safety significant, then additional measurements of that property will be performed to confirm the reported uncertainties. These measurements will be guided by comparable methods reported in Reference [16] to confirm the quality of the data previously acquired and to gather data that is outside the parameter ranges (i.e. temperature) required, as discussed in Appendix C. If confirmatory testing is determined necessary from associated safety analysis, Kairos Power will either present updated thermophysical property data in a revision to this Topical Report or describe the confirmatory measurements as part of a license application.

Corrosion performance of 316H in Flibe, consistent with impurity limits specified in Table 4, will be addressed as part of the KP-FHR High Temperature Materials Topical Report. This will confirm the corrosion allowances used for engineering and design considerations. These development efforts will also include confirming the solubility limit established of metallic beryllium in Flibe.

Characterization of the KP-FHR reactor coolant and intermediate coolant mixing will be addressed in license applications documents which demonstrate conformance to PDC 73.

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Table 1: Thermophysical Properties of the KP-FHR Primary Coolant

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Table 2: ORNL Fluid Selection Criteria Conclusions Applied to KP-FHR Technology

Criteria	KP-FHR Requirements	Flibe Information	References
1. Stability at high temperatures	Low vapor pressure enables high temperature operation.	Vapor pressure is low over operational temperatures.	[4, 5, 26]
2. Stability under radiation	Fluid does not degrade significantly in radiation	Minimal degradation if using ^{7}Li	[4, 26]
3. Melting point below 500°C	Engineering Consideration for system design	The melting point of Flibe is 459°C	[4, 26]
4. Materials compatible	Predictable behavior of structural alloys, graphite moderators, and fuel pebbles	Clean Flibe has low corrosivity. Small additions of metallic beryllium have shown viability in controlling corrosion to less than 30 micron/year	[4, 6, 26, 27]
5. Effective solvent for fissile material and fission products	Safety consideration, radioactive source containment	MSRE fuel salt included Flibe and was able to dissolve both fuel and most fission products. KP-FHR Flibe will retain most fuel and fission products.	[4]
6. Negative coolant reactivity	Safety considerations	Coolant density coefficient: -$0.01 per 100°C Coolant Void Ratio: -$0.11 *Void ratio calculated based upon Advanced Gas Reactor Geometries found in Reference [4]*	[4]
7. Low short-term activation and no long-life activation	Safety considerations	Short-term/long-term activation is small.	[4, 26]
8. Low relative neutron capture	Good fuel utilization	8x neutron capture relative to graphite.	[4]
9. Thermophysical properties	Properties must be acceptable for engineering application	See Table 1.	

Table 3: Vapor Pressures for Individual Species (x10^3Pa) Reported from Reference [28].

Species/Temperature	**500°C**	**550°C**	**600°C**	**650°C**	**700°C**
LiF	0.021 Pa	0.23 Pa	1.9 Pa	12 Pa	63 Pa
BeF_2	28 Pa	200 Pa	1200 Pa	5600 Pa	23000 Pa
1 mmHg = 133.322 Pa, i.e. BeF_2 at 650℃: 5.6Pa =0.042mmHg					

Table 4: Design Specification for KP-FHR Reactor Coolant

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Table 5: List of Corrosive Impurities toward Chromium

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Figure 1: Schematic of KP-FHR

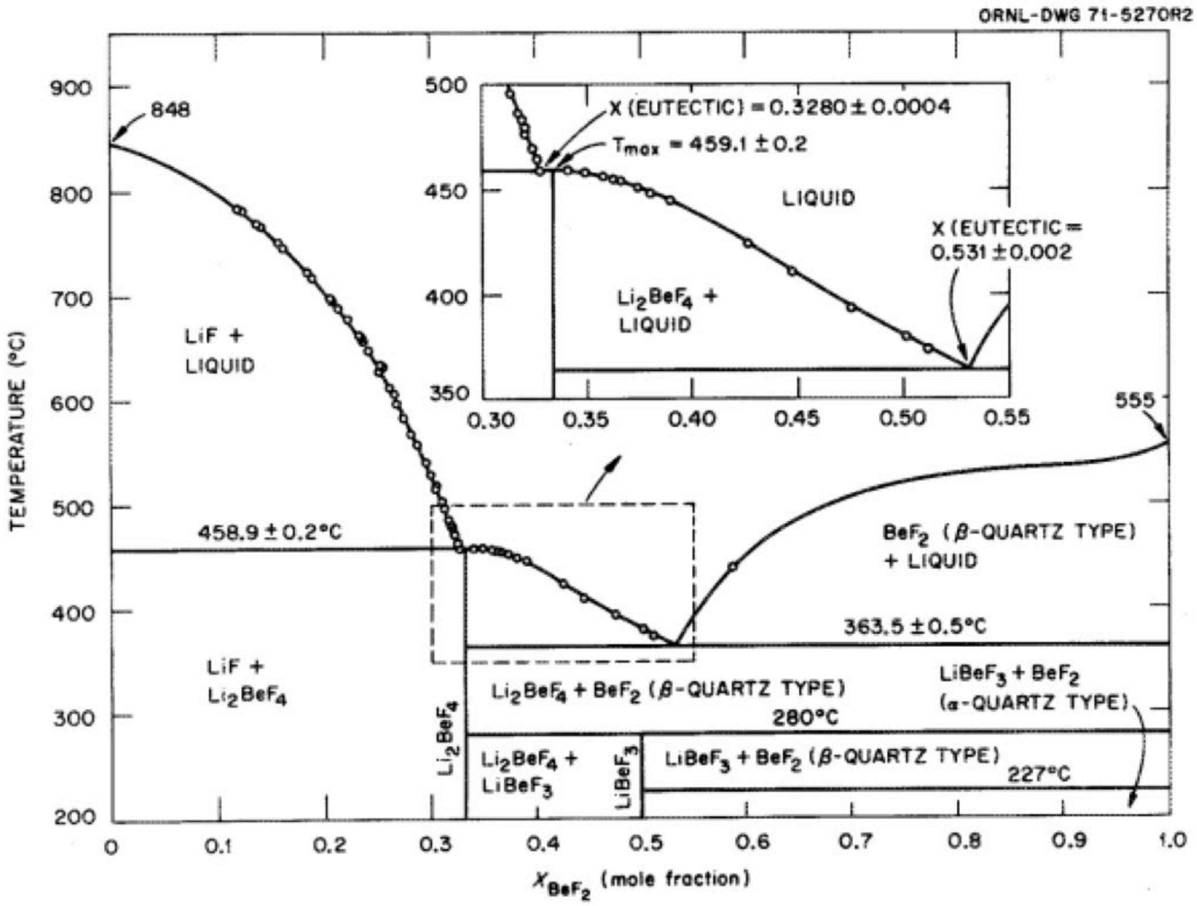

Figure 2: BeF_2, LiF Binary Phase Diagram from Reference [10]

Salt Constituents*	Melting Point (°C)
BeF_2	554
LiF	845
KF	856
ZrF_4	903
NaF	995
NaF-BeF_2 (57-43)	340
LiF-BeF_2 (67-33)	459
NaF-ZrF_4 (59.5-40.5)	500
*molar concentration	

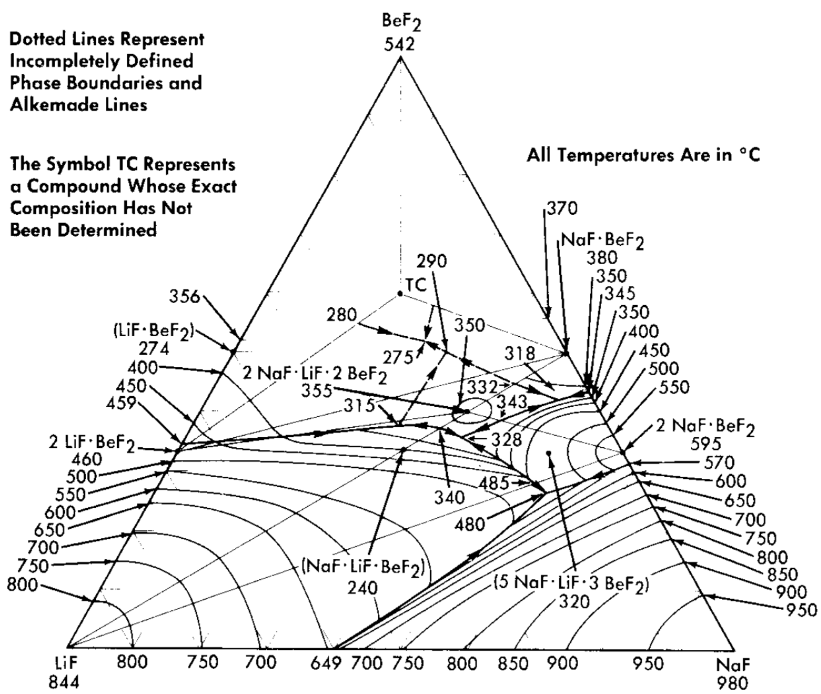

Figure 3: Melting points for Key Compounds and Example of a LiF-NaF-BeF_2 Phase Diagram Taken From Reference [26]

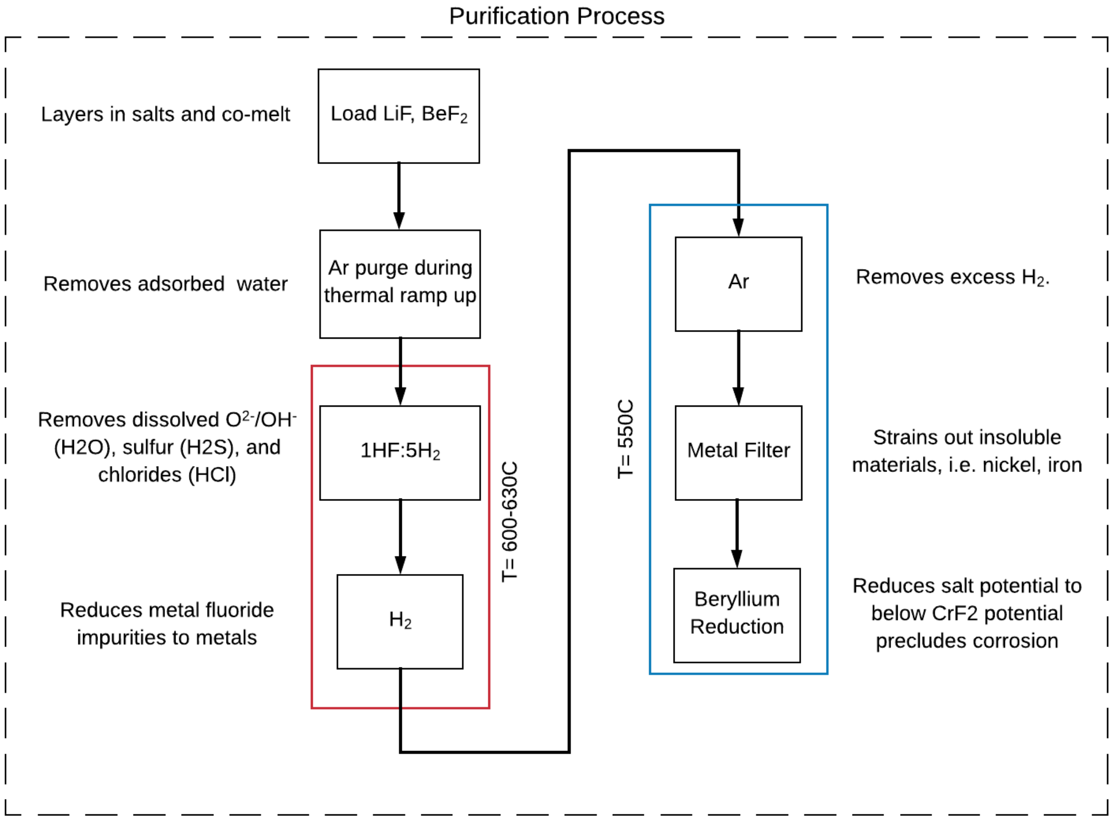

Figure 4: Flow Diagram of Flibe Purification Process Summarized from References [18, 29]

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Figure 5: Schematic of Notional Kairos Power Chemistry Control System

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Figure 6. Enthalpy, Gibbs Free Energy, and the log of Equilibrium Constant for Reaction 14

APPENDIX A. THERMAL NEUTRON ABSORPTION IMPURITIES IN FLIBE

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Table A1: Ranking of the Elements by Specific Thermal Neutron Absorption Cross Section

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Table A2: List of Isotopes in Flibe as a Result of Neutron Irradiation

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APPENDIX B. ELECTROCHEMICAL POTENTIALS OF FLUORIDES

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Table B1: Electrochemical Potentials of Fluorides

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APPENDIX C. THERMOPHYSICAL PROPERTY CONFIRMATION

Flibe thermophysical properties were generated during preparatory work for the MSRE program. The MSRE coolant salt, used to remove heat from the fuel salt, was Flibe in the same composition to be used for the KP-FHR. ORNL performed comprehensive measurements, as complied in Reference [5]. Data generated and compiled during the MSRE report was performed over more than a decade of research, where researchers diligently measured many different molten salts under differing conditions. As errors were found throughout the span of the MSRE preparatory work, it was compiled and refined, so data near the end of the experiment was the best available.

Reference 5 provides the following discussion with regards to uncertainty:

Each contributor has stated what he believes is the error associated with the experimental result or with the estimated quantity. For most cases, the uncertainty represents considerably more than either "goodness of fit" of an interpolation or internal consistency available from thermodynamics. Instead, the uncertainty may be considered as the largest probable combination of systematic and random errors associated with the value given for the property. Where the listing is a property-temperature equation, the uncertainty is for the property calculated at the temperature substituted in the equation.

Although this data was used in the physical design of MSRE, it was not generated through a formal quality assurance program. However, the data were collected by national laboratory researchers, sponsored by the US Government, under controlled research processes. Additionally, some of the properties (heat capacity) were confirmed by independent organizations, such as the National Bureau of Standards. As such, Kairos Power considers this information to be acceptable for engineering and safety analysis application use and intends to perform limited confirmatory measurements, using the applicable quality assurance provisions in 10 CFR Appendix B. These meaurements will utilize comparable methods to confirm the quality of the original data as well as obtain additional data that is outside the parameter ranges (i.e. temperature) required to further the understanding of these properties.

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Heat Capacity:

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APPENDIX D. CHROMIUM OXIDANT ALLOWABLE CALCULATION

Corrosion of structural materials that contain chromium within FHRs are expected to be primarily driven by chromium oxidation based on work from References [6, 19]. Therefore, any species that oxidize chromium should be controlled and limits established to ensure predictable performance within the reactor. Known oxidants are fluorides with a larger free energy of formation or standard reduction potential than chromium fluoride. A list of oxidants is provided in Appendix B. [[

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APPENDIX E. NOT USED

APPENDIX F. EFFECT OF LIF-BEF$_2$ COMPOSITION ON VISCOSITY

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Table F1: Summary of Linear Regression Analyses of the Data in Figure F2

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Figure F1: Viscosity at 600°C vs. Composition for the yLiF-xBeF$_2$ Binary System

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Figure F2: Viscosity vs. %BeF_2 at Indicated Temperatures

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Figure F3: Effect of Flibe Stoichiometry Variation on Viscosity

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Figure F4. Effect of Flibe compositional variation on the temperature-dependent viscosity.

Enclosure 3

Kairos Power LLC Affidavit and Request for Withholding from Public Disclosure (10 CFR 2.390)

I, Peter Hastings, hereby state:

1. I am Vice President, Regulatory Affairs and Quality at Kairos Power LLC ("Kairos"), and as such I have been authorized by Kairos to review information sought to be withheld from public disclosure in connection with the development, testing, licensing, and deployment of the Kairos reactor and its associated structures, systems, and components, and to apply for its withholding from public disclosure on behalf of Kairos.
2. The information sought to be withheld, in its entirety, is contained in Kairos' Enclosure 1 to this letter.
3. I am making this request for withholding, and executing this affidavit in support thereof, pursuant to the provisions of 10 CFR 2.390(b)(1).
4. I have personal knowledge of the criteria and procedures utilized by Kairos in designating information as a trade secret, privileged, or as confidential commercial or financial information. Some examples of information Kairos considers proprietary and eligible for withholding under §2.390(a)(4) include:
    a. Information which discloses process, method, or apparatus, including supporting data and analyses, where prevention of its use by Kairos competitors without license or contract from Kairos constitutes a competitive economic advantage over other companies in the industry;
    b. Information, which if used by a competitor, would reduce his expenditure of resources or improve his competitive position in design, manufacture, shipment, installation, assurance of quality;
    c. Information which reveals cost or price information, production capacities, budget levels, or commercial strategies of Kairos, its customers, its partners, or its suppliers;
    d. Information which reveals aspects of past, present, or future Kairos or customer funded development plans or programs, of potential commercial value to Kairos;
    e. Information which discloses patentable subject matter for which it may be desirable to obtain patent protection; and/or
    f. Information obtained through Kairos actions which could reveal additional insights into reactor system development, testing, qualification processes, and/or regulatory proceedings, and which are not otherwise readily obtainable by a competitor.
5. Kairos' information contained in Enclosure 1 to this letter contains details of Kairos Power's design and testing information intended to support NRC staff review. This information includes details of Kairos Power's design and testing plans that could provide a competitor with a commercial advantage if the information were to be revealed publicly.

6. Pursuant to the provisions of §2.390(b)(4), the following is furnished for consideration by the Commission in determining whether the information sought to be withheld from public disclosure should be withheld:

   a. The information sought to be withheld from public disclosure is owned and has been held in confidence by Kairos.

   b. The information is of a type customarily held in confidence by Kairos and not customarily disclosed to the public. Kairos has a rational basis for determining the types of information customarily held in confidence by it and, in that connection, utilizes a system to determine when and whether to hold certain types of information in confidence. The application of that system and the substance of that system constitute Kairos policy and provide the rational basis required.

   c. The information is being transmitted to the Commission in confidence and, under the provisions of 10 CFR 2.390, it is to be received in confidence by the Commission.

   d. This information is not readily available in public sources.

   e. Public disclosure of this proprietary information is likely to cause substantial harm to the competitive position of Kairos, because it would enhance the ability of competitors to provide similar products and services by reducing their expenditure of resources using similar project methods, equipment, testing approach, contractors, or licensing approaches. This information is the result of considerable expense to Kairos and has great value in that it will assist Kairos in providing products and services to new, expanding markets not currently served by the company.

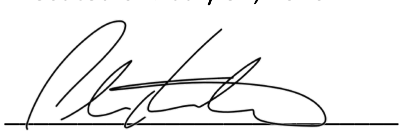
   f. The information could reveal or could be used to infer price information, cost information, budget levels, or commercial strategies of Kairos.

   g. Each component of proprietary information pertinent to a particular competitive advantage is potentially as valuable as the total competitive advantage. If competitors acquire components of proprietary information, any one component may be the key to the entire puzzle, thereby depriving Kairos of a competitive advantage.

   h. Unrestricted disclosure would jeopardize the position of Kairos in the world market, and thereby give a market advantage to the competition in those countries.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on: July 31, 2020



Peter Hastings
Vice President, Regulatory Affairs and Quality