Kairos Power

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

Subject: Testing and Development Program Overview for the Kairos Power Fluoride Salt-Cooled, High Temperature Reactor

This letter submits the subject technical report which provides an overview of the testing and development program for the Kairos Power Fluoride Salt-Cooled, High Temperature Reactor (KP-FHR). This report is provided for information and is intended to familiarize NRC staff with development activities and provide backgound for future Kairos Power licensing reports.

Portions of this technical report are considered proprietary, and Kairos Power requests it be withheld from public disclosure in accordance with the provisions of 10 CFR 2.390. Enclosure 1 provides the proprietary version of the report and Enclosure 2 provides the non-proprietary report. An affidavit supporting the withholding request is provided in Enclosure 3.

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.

If you have any questions or need any additional information, please contact Darrell Gardner at gardner@kairospower.com or (704) 957-5754.

Sincerely,

Peter Hastings, PE
Vice President, Regulatory Affairs and Quality

Enclosures:

1) Testing and Development Program Overview for the Kairos Power Fluoride Salt-Cooled, High Temperature Reactor (Proprietary)
2) Testing and Development Program Overview for the Kairos Power Fluoride Salt-Cooled, High Temperature Reactor (Non-Proprietary)
3) Affidavit Supporting Request for Withholding from Public Disclosure (10 CFR 2.390)

xc (w/enclosure):

J. P. Segala, Chief, NRO Advanced Reactor and Policy Branch
J. F. Williams, Project Manager, NRO Advanced Reactor and Policy Branch
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Enclosure 2

Testing and Development Program Overview for the Kairos Power

Fluoride Salt-Cooled, High Temperature Reactor

(Non-Proprietary)

(Note that the enclosed information is preliminary and pre-decisional and is subject to change during detailed planning and project execution. It is provided for planning and familiarization purposes in support of pre-application discussions with the NRC Staff.)

KP-TR-002

Kairos Power

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Testing and Development Program Overview for the Kairos Power Fluoride Salt Cooled, High Temperature Reactor

Revision No. 0
Document Date: November 2018

Non-Proprietary

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Rev	Description of Change	Date
0	Initial Issuance	November 2018

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Executive Summary

Kairos Power is pursuing the design, licensing, and deployment of a Fluoride Salt Cooled, High Temperature Reactor (FHR). The KP-FHR design relies on a combination of tri-structural isotropic (TRISO) particle fuel coupled with molten fluoride salt coolant. This combination enables a high-temperature, low-pressure reactor with robust, passive safety features.

Kairos Power is pursuing an extensive testing and development program to enhance the design process and also to confirm aspects of the final design. The "design-build-test" approach used by Kairos Power is an iterative process that will enhance the quality of the final design.

The design testing and development program efforts are focused in five principal areas:

- Fuel Development and Qualification
- Fluoride Salt Coolant Development
- High-Temperature Materials Qualification
- Component Development and Testing
- Safety Analysis Methods, Codes, and Validation

This report provides a summary and overview of plans in each of these areas. In addition to reliance on past domestic operational experience and testing data, and existing national testing capabilities, Kairos Power testing facilities have been developed or are planned to facilitate the program execution. A description of the planned Kairos Power testing facilities is also provided in this report.

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1 INTRODUCTION

Kairos Power is pursuing the design, licensing, and deployment of a Fluoride Salt Cooled, High Temperature Reactor (FHR). To enable these objectives, Kairos Power is pursuing an extensive design testing and development program. Note that the design testing and development program described herein is separate from the initial construction and pre-operational testing program which supports plant startup and operation.

The Kairos Power design development program relies on testing, synchronized with modeling and simulation activities, to enable accelerated advanced reactor development and to evaluate reactor performance characteristics and safety features. Kairos Power is using its testing program to enhance the design process (design-build-test) and also to confirm aspects of the final design. The "design-build-test" is an iterative process that Kairos believes will enhance the quality of the final design.

The design testing and development efforts are focused in five principal areas:

- Fuel Development and Qualification
- Fluoride Salt Coolant Development
- High-Temperature Materials Qualification
- Component Development and Testing
- Safety Analysis Methods, Codes, and Validation

This report provides a summary and overview of design testing and development plans in each of these areas. In addition to reliance on past domestic operational experience and testing data, and existing national testing capabilities, Kairos Power testing facilities are being developed or planned to facilitate the program execution. A description of the planned Kairos Power testing facilities is provided in this report.

This report is provided for information, and the Kairos Power plans and testing facilities described herein are subject to change as additional information is acquired during the execution of the design testing and development program.

1.1 Design Overview

The Kairos Power Fluoride Salt Cooled, High Temperature Reactor (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 FHR designs with different fuel geometries, core configurations, heat transport system configurations, power cycles, and power levels. More recently, the University of California, Berkeley developed the Mark 1 pebble-bed FHR (Mk1 PB-FHR), incorporating lessons learned from the previous decade of pre-conceptual designs (Reference 1). Kairos Power builds on the foundation laid by DOE-sponsored university Integrated Research Projects (IRPs) to develop the KP-FHR.

The KP-FHR design relies on a combination of tri-structural isotropic (TRISO) particle fuel coupled with molten fluoride salt coolant. This combination enables a high-temperature, low-pressure reactor with robust, passive safety features. The fuel in the KP-FHR is based on the TRISO high-temperature carbonaceous-matrix coated particle fuel originally developed for high-temperature gas-cooled reactors. Layers in the fuel particle provide retention of fission products. The reactor coolant is a chemically stable, low-pressure molten fluoride salt mixture, $2LiF:BeF_2$ (also referred to as Flibe) which also provides

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retention of fission products that might escape from the fuel via defects or failures. The combination of extremely high-temperature tolerant fuel and low-pressure, single-phase, chemically stable coolant minimizes potential fuel damage scenarios, simplifying the design and reducing the cost of safety systems. The coated particle fuel and low-pressure primary system design also enhance safety and eliminate the need for expensive high-pressure containment structures. The high reactor outlet temperatures allow the KP-FHR to leverage high-efficiency power conversion systems. These factors lead to improved safety, operations, and economics.

Additional design information is provided in the "Design Overview of the Kairos Power Fluoride Salt Cooled, High Temperature Reactor (KP-FHR)" Technical Report (Reference 2).

1.2 Testing Overview

The Kairos Power approach to rapid and predictable design, development, commercialization, and deployment includes engineering design activities along with development activities, such as testing, fabrication, and qualification necessary to successfully license and deploy the KP-FHR. Licensing and quality assurance considerations are integrated with testing and design activities. This approach reduces development risk through a "rapid iteration" product development process which leverages modern tools and methods used in aerospace, automotive, and medical device industries. Kairos Power also utilizes systems engineering practices which provide a standardized platform for documentation of requirements and design basis information. Rapid iteration between design and testing (design-build-test) applies modern product development processes for iterative prototyping, testing, analyzing, and refining design features to meet functional requirements.

Testing requirements and needs are evaluated at the overall plant architecture level. Combined tests on multiple components or subsystems are utilized where feasible to provide representative safety and performance insights and reduce the burden of the overall testing program. [[

]] Similarly, validation of safety analysis codes through separate effects tests (SETs) and integral effects tests (IETs) is [[
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A graded quality assurance program is utilized in the Kairos Power testing program. [[

]] Testing performed to confirm, validate, or demonstrate conformance to specific design requirements or validate safety analysis codes is conducted using the applicable portions of the Kairos Power Quality Assurance Program.

1.3 Testing Facilities

Kairos Power will utilize several testing facilities to execute the testing and development program objectives. The NRC documents, "Nuclear Power Reactor Testing Needs and Prototype Plants for

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Advanced Reactor Designs" and SECY-91-074 (References 3 and 4), as well as Regulatory Guide 1.203 were considerations in the development of Kairos Power testing needs. The testing facilities managed or primarily directed to support Kairos Power program objectives include the following:

- Rapid Analysis, Prototyping and Iterative Design Laboratory (R-Lab)
- Salt Handling and Loop Testing Laboratory (S-Lab)
- Component Test Facility (T-Facility)
- User Operations and Maintenance Facility (U-Facility)

The relationship of the test facilities is shown in Figure 1-1.

Design and manufacturing considerations for major KP-FHR structures, systems and components (SSCs) will be supported by testing activities [[

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Some testing and development program activities will be accomplished at supplier facilities separate from the facilities described below [[

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1.3.1 R-Lab

R-Lab is an innovative, state-of-the-art testing facility in Alameda, CA, co-located with the Kairos Power headquarters. The facility provides for co-location of design, modeling and simulation capabilities with testing and experimental capabilities. [[

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1.3.2 S-Lab

S-Lab is a testing facility dedicated to performing evaluations in a Flibe environment. S-Lab will be located in a supplier facility qualified to safely handle Flibe. The facility will enable development of materials, chemistry controls, and [[

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Table 1-1 lists example test systems that may be performed at S-Lab and their objectives. Performance data acquired from these tests [[

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1.3.3 T-Facility

The *T-Facility* will be a component test facility to conduct qualification testing for key components. A location for this facility has not been established at this time. The T-Facility will be designed to support [[

]] Table 1-2 shows the testing facility relationship between the R-Lab, S-Lab, and T-Facility for these components.

1.3.4 U-Facility

The *U-Facility* is envisioned to be a user operations and maintenance training facility. A location for this facility has not been established at this time. [[

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1.4 Summary of Testing Facility Relationship to Component Development Process

Figure 1-2 describes the Kairos Power component development and testing process for an example component, a notional primary salt pump. [[

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]] The pump would be installed at the first KP-FHR where it would go through standard startup testing and nuclear operations.

2 FUEL DEVELOPMENT AND QUALIFICATION

2.1 Overview

As noted in Section 1.1, the KP-FHR utilizes spherical "pebble" fuel elements with TRISO fuel particles embedded in a carbonaceous matrix. As part of the KP-FHR design and licensing process, these fuel elements will be tested under an appropriate quality assurance program to be qualified for service. Fuel element performance will be demonstrated through laboratory and irradiation testing together with computer models as indicated by the qualification program outlined in Table 2-1.

The information and knowledge gained from the fuel qualification program is intended to support initial reactor operation. [[

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2.2 Laboratory Testing

Laboratory tests consist of [[

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2.3 Irradiation Testing

The TRISO particle failure proportion, along with the fission product transport and release behavior from the fuel to the coolant, during normal operation should be conservatively characterized by the irradiation test. [[

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2.4 Post Irradiation Testing

Post irradiation tests are performed for the KP-FHR fuel to understand the fuel particle failure proportion and fission product behavior under design basis accident conditions as well as determine design margin to failure. [[

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2.5 Licensing Reports

The planned fuel development and qualification program supports licensing and deployment of the KP-FHR. [[

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3 FLUORIDE SALT COOLANT DEVELOPMENT

3.1 Overview

The KP-FHR removes the heat from the reactor core and transfers it to the power conversion unit using both a primary and intermediate heat transport loop, each with different heat transfer fluids. The thermophysical properties of the two heat transport fluids are provided in Table 3-1. The primary heat transport loop transports heat from the TRISO particle-based fuel pebbles to the intermediate heat transfer loop using a lithium fluoride (LiF), beryllium fluoride (BeF_2) salt (Flibe). Thermal power is transferred from Flibe to the intermediate heat transfer loop through an intermediate heat exchanger (IHX). The intermediate heat transfer loop is responsible for moving heat from the primary system using a nitrate-based salt coolant to the water-based steam generators.

The following sections will provide an overview of primary heat transport coolant (Flibe) and intermediate heat transport coolant (nitrate salt).

3.2 Primary Heat Transport Coolant (Flibe)

3.2.1 Coolant Selection Considerations

The Flibe used for the KP-FHR primary coolant is compositionally $2LiF{:}BeF_2$, [[ ]] Flibe is a peritectic which melts at 459°C. Flibe was also used as the base salt for the molten salt reactor experiment (MSRE) (Reference 5). Flibe was chosen for the KP-FHR because it satisfies considerations that are desirable for a high temperature reactor coolant. These considerations include:

- Stability at high temperatures (>800°C)
- High boiling temperature (1430°C) and low vapor pressure
- Stability under radiation
- Melting point below 500°C
- Materials compatibility
- Effective solvent for fissile material and solid fission products
- Negative coolant reactivity
- Low long-term activation

Stability at high temperatures is desirable because it precludes chemical degradation and remains stable under radiation. Flibe does not decompose at the expected operating temperatures and, owing to its high boiling temperature, has very low vapor pressure at normal and accident temperatures which facilitates the salt remaining in the liquid phase and reduces the potential for vapor condensing and plugging cover gas vent lines.

A low melting point is an important consideration to enable use of salts as a coolant. System designs must ensure the heat transport fluid remains liquid during operation and, as melting temperatures increase, system design solutions become complex and costly to implement. Lower melting point

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compositions using ternary or higher salt constituents is possible but creates increasingly complex phase behavior and may lead to unexpected chemical reactions. Therefore, a binary mixture was selected to obtain a low melting point (below 500°C) while minimizing chemistry complexity.

Operating experience from MSRE using a clean fluoride salt intermediate coolant demonstrated negligible corrosion of Hastelloy-N structural materials. Subsequent to the experience with MSRE, it was shown that the addition of small amounts of beryllium could protect alloys with higher chromium content (i.e., stainless 316) such that annual material loss was below 30 microns (Reference 8). Having a clean salt, free of moisture, is also important and will be a consideration in the coolant specification.

Fission product retention in the molten salt provides a reduction in the source term and is credited in the safety case. Some of the key nuclides of interest for source term analysis, taken from the NGNP mechanistic source term white paper, are iodine (I), cesium (Cs), and strontium (Sr) (Reference 9). Results from MSRE found that many of these were readily soluble in the melt (Reference 10 and Reference 11). MSRE indicates that Flibe is an effective solvent for retaining these and other fission products which could arise in the KP-FHR from incipient fuel failures. [[

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Neutronic considerations were a key deciding factor in selecting enriched Flibe as the primary coolant. Not only does Flibe enable a negative coolant temperature and void reactivity coefficient, which is a safety benefit, the low parasitic neutron absorption allows for effective fuel utilization and also has minimal long-term activation of the coolant. The activation products (except tritium) are all short lived. Activation products that produce gamma radiation are all short lived and disappear shortly after reactor shut down. These neutronic factors in combination with the other positive benefits of Flibe described above led to its selection as the primary coolant choice.

3.2.2 Flibe Specification Development

The considerations discussed above led to the selection of Flibe as the primary coolant. To implement the selection, a Flibe specification will be developed for use in the KP-FHR. [[

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Thermophysical properties are known, based on work for the MSRE program and as part of fusion research and development (Reference 12) and are primarily ensured by maintaining the ratio of $2LiF:BeF_2$. This ratio tolerance is driven primarily by changes in thermophysical properties that result as either LiF or BeF_2 content deviates from the peritectic (Reference 13). A summary of the thermophysical properties are provided in Table 3-1. [[

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3.2.3 Flibe Production

Flibe requires additional purification steps prior to use. Impurities within the salt arise from different causes, ranging from raw materials to environmental contaminants. Raw materials, even at relatively high grades, can have a variety of metal fluoride impurities (NiF_2, FeF_2, CdF_2, PbF_2, etc.), sulfur, and others. Environmental contaminants are primarily moisture which produces oxides, hydroxides, and hydrofluoric acid. Impurities primarily cause corrosion, through preferential fluorination of chromium, and must be removed for materials compatibility.

Operating experience with the MSRE demonstrated the purification process, which was found to remove environmental contamination, moisture and oxygen, and also removes metal fluorides, sulfur, and chloride (Reference 14). MSRE found that a batch chemical reactor, using a multi-step process of co-melting the raw constituents, then gas sparging, adequately removed impurities for reactor use.

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3.2.4 Lithium

The Flibe for the KP-FHR [[

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3.2.5 Primary Coolant Chemistry Control

During reactor operation, impurities will be introduced into the coolant as part of normal operation. Air or moisture ingress may occur in addition to tritium generation through neutron capture in residual ^{6}Li in the salt as well as ^{6}Li produced by transmutation of beryllium. These are the primary sources of tritium which will be managed by the tritium handling systems. HF and F are both corrosive with respect to chromium containing alloys. Clean Flibe has low corrosion rates and small additions of elemental beryllium, as a reducing agent, will reduce corrosion significantly (Reference 8) by converting HF to hydrogen gas and BeF_2. While beryllium has limited solubility in Flibe, a low concentration of metallic beryllium will allow for reduction of HF to hydrogen (Reference 15). In addition to hydrogen reduction dissolved beryllium can also serve to remove oxygen-based impurities out of the system.

These interactions result in the formation of elemental chromium, likely insoluble, and beryllium oxide which has a temperature dependent solubility (Reference 16). [[

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3.3 Intermediate Heat Transport Coolant (Nitrate Salt)

Nitrate (or Solar Salt) was first demonstrated for commercial use during the Solar Two project (Reference 17). The 60/40 $NaNO_3/KNO_3$ ratio was selected by balancing the requirements for melting point, cost, heat capacity, and viscosity. Nitrate salt is an off-eutectic mixture with a liquidus temperature around 240°C. Nitrate salt has a practical minimum use temperature of ~290°C set by the liquidus temperature of the salt, plus a 50°C margin, to avoid freezing.

The Concentrated Solar Power (CSP) industry typically assumes that at 565°C, the nitrate salt degrades into gas and oxide anions, increasing corrosion. Laboratory data indicates higher operating temperatures up to 600°C are possible provided system designers allow for some accumulation of oxide content which impacts materials compatibility (Reference 18).

Chloride impurity causes a dramatic change in corrosion performance. Early compatibility work investigated two primary grades of materials. Technical grade nitrates with chloride content of 0.1wt% were compared against industrial grades nitrates with chloride content of 0.3wt%. While technical grade nitrates had superior performance, the performance margin was not sufficient to outweigh the higher cost, and industrial grade nitrates were selected for Solar Two (Reference 19).

One of the lessons learned during the Solar Two project was the necessity of minimizing magnesium. While present in only small quantities, upon reaching temperatures of ~480°C, it leads to the evolution of nitrogen dioxide which is a concern due to its relative toxicity. The Solar Two project dealt with this reaction using a series of isothermal holds, with nitrogen oxides being diluted with ambient air and then released up a 30-foot stack (Reference 17). This had not been previously observed, but given the experience at Solar Two, subsequent projects include the recommendation for low magnesium

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concentrations. Furthermore, many projects (see Table 3-2) have utilized the 60/40 nitrate salt for many commercial projects with no apparent report of problems related to chemistry (Reference 51).

The use of solar salt as a coolant is considered to be a proven technology [[

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3.4 Licensing Reports

The primary reactor coolant development and qualification activities supports licensing and deployment of the KP-FHR. [[

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4 HIGH TEMPERATURE MATERIALS QUALIFICATION

4.1 Overview

Materials qualification for the KP-FHR includes demonstrating the environmental compatibility of the structural materials as well as, where applicable, tolerance neutron irradiation doses required to meet the expected component service lifetime. Irradiation tolerance involves demonstrating the dimensional stability and acceptable mechanical properties to the required exposures. [[

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4.2 Structural Materials Selection and Evaluation

Materials selection assumes ASME code-qualified data applies for design purposes. For the reactor vessel and graphite reflector, the design will follow the applicable ASME code rules for design. Specifically, for the high-temperature reactor vessel components, the design will follow the ASME Boiler & Pressure Vessel Code Section III, Division 5, design requirements. ASME code values provide the time and temperature-dependent properties of materials performance, however, they do not account for environmental effects, specifically the effect of the molten salt environment and the effects of irradiation damage on mechanical properties or material performance. [[

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Component materials degradation considerations are summarized in Figure 4-1, [[

]] A summary of the qualification test programs is provided in Figure 4-2, [[

]] Table 4-1 lists the major KP-FHR components materials selection along with planned tests to qualify the particular component materials. [[

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4.3 Coatings and Cladding

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4.4 Licensing Reports

The high temperature materials qualification program supports licensing and deployment of the KP-FHR. [[
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5 COMPONENT DEVELOPMENT AND TESTING PLAN

5.1 Overview

Many of the KP-FHR technologies were demonstrated by the molten salt reactor program (Reference 21). However, some KP-FHR SSCs utilize new or novel designs with limited nuclear or industrial analogues. These SSCs will have dedicated design, modeling, and testing programs to advance them through technical readiness levels and eventually qualify them for reactor application. [[

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5.2 Design Testing Plans

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5.3 Licensing Reports

The component development and testing plans supports licensing and deployment of the KP-FHR. [[

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6 SAFETY ANALYSIS METHODS, CODES, AND VALIDATION

6.1 Overview of KP-FHR Safety Analysis Methods, Codes, and Validation

6.1.1 Modeling and Simulation Program Overview

The modeling and simulation (Mod/Sim) program is focused on ensuring development and/or procurement of the necessary computational tools required for design and licensing of the KP-FHR consistent with needs and deployment timelines, while satisfying overarching requirements related to software quality assurance (SQA), including code verification and model validation.

The Mod/Sim program will be implemented under a software quality program that complies with the Kairos Power quality assurance program. Software for analysis of KP-FHR systems falls into one of two categories:

- Safety-related: Those software programs/codes that are used to predict the performance and behavior of safety-related SSCs during operation and design basis events to support licensing; and
- Non-safety-related: Those software programs/codes used in support of design of the KP-FHR SSCs. Code-to-code comparisons between results of non-safety related design codes and safety-related licensing codes provides additional verification of results for both types of codes.

These categories determine the process and criteria applied to the software procurement and development through all aspects of the software lifecycle. Safety software programs/codes largely fall into one of four categories when considering the breadth of development:

- New software that will be developed from the beginning by Kairos Power. These codes would exercise the full breadth of the software quality program.
- Commercially available software packages (e.g., ANSYS) that will be managed under a commercial dedication program, while validation of specific use cases falls within the scope of the Kairos Power software quality and testing program.
- Legacy codes that have been previously approved or are generally accepted. The qualification of these codes will need to demonstrate applicability to the KP-FHR design.
- Existing codes that require further development to meet KP-FHR design and safety analysis needs, whether legacy codes, codes developed under DOE's Nuclear Energy Advanced Modeling and Simulation (NEAMS) program or similar programs, or university developed codes. Varying levels of effort are required in this category, according to current code status, use case, and amount of development effort needed.

The latter option of code development can take a number of forms, depending on factors such as the origin of the code (e.g., DOE National Laboratory vs. University). As an example, incorporating codes developed by National Laboratories under the NEAMS program into the overall Kairos Power Development Plan largely requires multi-party development efforts that include, but are not limited to:

- Ensuring previous and new development efforts utilize appropriate and accepted NRC frameworks, including documentation (e.g., evaluation model development and assessment process as described by Regulatory Guide 1.203 for use in the development and assessment of thermal fluid transient analysis evaluation models).

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- Ensuring development efforts are performed in a secure and traceable manner across organizations that are compliant with 10 CFR Part 810 export compliance, including development platforms, storage, and computing environments.
- Ensuring development efforts are performed in accordance with the Kairos Power software quality program or other equivalent 10CFR50 Appendix B compliant program.
- Incorporating code development and testing programs across organizations engaging in co-development efforts to maximize impact of development efforts for KP-FHR licensing requirements.

Figure 6-1 illustrates a high-level code development and assessment process. [[

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6.1.2 Code Verification, Validation, and Uncertainty Quantification

Verification, validation, and uncertainty quantification (UQ) will be performed for safety codes following the EMDAP guidance. Modern software design and development environments enable code verification through version control, regression testing, line convergence tests, and continuous integration. Advanced numerical methods can minimize numerical errors and allow numerical verification processes for key physical models. SETs and IETs are the foundation for validation of models implanted in simulation codes. They are also used to validate design inputs and assumptions, where applicable. UQ will be performed by using Best Estimate Plus Uncertainty (BEPU) methods.

6.1.3 Code Selections and Development Paths

The software codes necessary to perform the safety analysis of the KP-FHR will be customized for analyzing the KP-FHR design and operational space. The degree of customization requires varying levels of development effort depending on the code. Kairos Power will leverage existing code pedigree and QA certifications along with internal validation efforts. Along with development efforts both internal to Kairos Power and external with co-development partners. At the time of this report, the following code development efforts are underway for the following tracks: [[

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In addition to these code development paths, other codes are utilized in the KP-FHR safety analysis. In many cases, pre-existing codes may exist and have historical precedent/pedigree. Where that is not the case, commercial grade dedication plans will be developed. Table 6-1 summarizes the code development paths, commercial code selections.

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6.2 Code Development Activities

This section provides a brief overview of development efforts for the more significant code development paths from Table 6-1. [[

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6.3 Code Development Environment

Central to an effective and secure Mod/Sim development program is a scalable, efficient, and secure development and analysis pipeline for all of the codes used by Kairos Power. [[

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6.4 Licensing Reports

The planned safety analysis methods and code development activities supports licensing and deployment of the KP-FHR. [[

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Table 1-1. Example S-Lab Tests and Experimental Objectives

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Table 1-2. Testing Matrix with Inputs from R-Lab, S-Lab, and T-Facility

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Table 2-1. Fuel Qualification Program (Page 1 of 2)

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Table 2-1. Fuel Qualification Program (Page 2 of 2)

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Table 3-1. Thermophysical Properties of the KP-FHR Primary and Intermediate Coolants

		Property	Correlation	Unit	Uncertainty
Liquid Phase					
Flibe Li_2BeF_4	T_{melt} = 459°C	Density [46][a]	$\rho = 2413 - 0.4884 \cdot T$	kg/m³	2%
	T_{boil} = 1430°C	Viscosity [47][a]	$\mu = 1.16 \cdot 10^{-4} \cdot e^{3760/T}$	Pa-s	15%
		Heat capacity [49][a]	$c_p = 2386$	J/kg-K	3%
		Thermal conductivity [48][a]	$k = 1.1$	W/m-K	10%
Solar Salt 60wt%NaNO3, 40%KNO3	T_{melt} = 222°C	Density [45][b]	$\rho = 2090 - 0.636 \cdot t$	kg/m³	N/A
		Viscosity [45][b]	$\mu = 22.714 - 0.120 \cdot t + 2.281 \cdot 10^{-4} \cdot t^2 - 1.474 \cdot 10^{-7} t^3$	Pa-s	N/A
		Heat capacity [45][b]	$c_p = 1443 + 0.172 \cdot t$	J/kg-K	N/A
		Thermal conductivity [45][b]	$k = 0.443 + 1.9 \cdot 10^{-4} \cdot t$	W/m-K	N/A
Solid Phase					
		Property	Correlation	Unit	Uncertainty
Flibe		Density [50][c]	$\rho = 2195.3$	kg/m³	N/A
		Latent Heat [47]	$\Delta h = 448$	J/g	3%
		ΔV on melting [50][d]	$\Delta V = \sim 2.1$	%	N/A
Solar Salt		Density [45][c]	$\rho = 2232$	kg/m³	N/A
		Latent Heat [45]	$\Delta h = 161$	J/g	N/A
		ΔV on melting [45]	$\Delta V = 4.6$	%	N/A

a. For all correlations, the temperature *T* is in Kelvin

b. For all correlations, the temperature *t* is in Celsius

c. Solid density calculated by weighted sum of each solid salt constituent. Data to be determined experimentally.

d. This value is provided in reference, but should be confirmed experimentally (calculated value)

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Table 3-2. Operational Solar Power Plants Using Nitrate Salt for Thermal Energy Storage

(Note: only Power Towers use 60/40 solar salt for a heat transfer fluid)

Plant	Technology	Temperature Range (C)	Storage (Hours)	Turbine Capacity (MW)	Heat Transfer Fluid
Gemasolar Thermosolar Plant	Power Tower	290-565	15	20	Solar Salt
SunCan Dunhuang	Power Tower	290-565	15	10	Solar Salt
Crescent Dunes	Power Tower	290-565	10	110	Solar Salt
Andasol-1, 2, 3	Parabolic Trough	293-393	7.5/plant	50/plant	Diphenyl/Diphenyl Oxide
Archimede	Parabolic Trough	290-550	8	5	Solar Salt
Arcosol 50	Parabolic Trough	293-393	8	49.9	Diphenyl/Diphenyl Oxide
Arenales	Parabolic Trough	293-393	7	50	Diphenyl/Diphenyl Oxide
Aste 1A/1B	Parabolic Trough	293-393	8/plant	50/plant	Diphenyl/Diphenyl Oxide
Astexol II	Parabolic Trough	293-393	8	50	Diphenyl/Diphenyl Oxide
Bokpoort	Parabolic Trough	293-393	9.3	55	Diphenyl/Diphenyl Oxide
Casablanca	Parabolic Trough	293-393	7.5	50	Diphenyl/Diphenyl Oxide
Extresol-1, 2, 3	Parabolic Trough	293-393	7.5/plant	50/plant	Diphenyl/Diphenyl Oxide
KaXu Solar One	Parabolic Trough	293-393	2.5	100	Diphenyl/Diphenyl Oxide
La Africana	Parabolic Trough	293-393	7.5	50	Diphenyl/Diphenyl Oxide
La Dehesa	Parabolic Trough	293-393	7.5	50	Diphenyl/Diphenyl Oxide
La Florida	Parabolic Trough	293-393	7.5	50	Diphenyl/Diphenyl Oxide
Manchasol-1, 2	Parabolic Trough	293-393	7.5/plant	50/plant	Diphenyl/Diphenyl Oxide
NOOR I	Parabolic Trough	293-393	3	160	Diphenyl/Diphenyl Oxide
Solana Generating Station	Parabolic Trough	293-393	6	280	Diphenyl/Diphenyl Oxide
Termesol 50	Parabolic Trough	293-393	7.5	50	Diphenyl/Diphenyl Oxide
Termosol 1, 2	Parabolic Trough	293-393	9/plant	50/plant	Diphenyl/Diphenyl Oxide
Xina Solar One	Parabolic Trough	293-393	5.5	100	Diphenyl/Diphenyl Oxide

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Table 4-1. KP-FHR Component Materials Selection and Qualification Considerations

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Table 6-1. Code Selections and Development Activities

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Table 6-2. Example SETs and IETs for Code Validation

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Figure 1-1. Testing Development Strategy

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Figure 1-2. Component Development and Testing Process

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Figure 3-1. Notional "Branch Circuit" Arrangement For the Chemistry Control

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Figure 4-1. Degradation Mechanisms Considered to Inform Materials Testing

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Figure 4-2. Qualification Program Overview for Materials in the KP-FHR

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Figure 6-1. Methodology for Code Development/Assessment

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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 the Kairos' testing and development program, intended among other things to initiate pre-application engagement with NRC staff and to begin familiarizing the staff with Kairos Power technology. These design details could give a competitor 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: November 30, 2018

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Peter Hastings
Vice President, Regulatory Affairs and Quality