UNITED STATES
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FINAL SAFETY EVALUATION OF METALLIC MATERIAL QUALIFICATION FOR THE KAIROS POWER FLUORIDE SALT-COOLED HIGH-TEMPERATURE REACTOR (KP-TR-013) KAIROS POWER, LLC EPID NO. 000431 / 99902069 / L-2020-TOP-0050

1.0 SPONSOR INFORMATION

Sponsor: Kairos Power, LLC (Kairos)

Address: 707 West Tower Ave.
Alameda, CA 94501

Project No.: 99902069 (Construction Permit Application Docket No. 05007513)

2.0 SUBMITTAL, CORRESPONDENCE, AND CONTRIBUTORS

2.1. Submittal Information

Revision 0	June 30, 2020	ML20182A799	KP-TR-014, Revision 0
Revision 1	June 30, 2021	ML21181A385	KP-TR-014, Revision 1
Revision 2	April 2, 2022	ML22116A246	KP-TR-014, Revision 2
Revision 3	August 19, 2022	ML22231B221	KP-TR-014, Revision 3
Revision 4	September 20, 2022	ML22263A456	KP-TR-014, Revision 4

*Agencywide Documents Access and Management System (ADAMS) Accession No.

2.2. NRC Correspondence and Communications

Communication Type	Date	ADAMS Accession No.
Acceptance Review(s):	September 3, 2020	ML20224A172
Closed Meeting Notices:	December 6, 2021	ML21336A400
	February 3, 2022	ML22032A336
	February 14, 2022	ML22032A336
	July 18, 2022	ML22196A385
	August 10, 2022	ML22214A131
	September 12, 2022	ML22244A250

*ADAMS Accession No.

2.3. Principal Contributor(s)

- John Honcharik, NRR/DNRL/NPHP
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3.0 BRIEF DESCRIPTION OF REQUEST AND BACKGROUND

Kairos Power, LLC (Kairos, the sponsor) is requesting Nuclear Regulatory Commission (NRC) staff review and approval of topical report (TR) KP-TR-013, "Metallic Materials Qualification for the Kairos Power Fluoride Salt-Cooled, High Temperature Reactor," Revision 2, dated April 2022. The TR could apply to reactors using the Kairos Power Fluoride Salt-Cooled High Temperature Reactor (KP-FHR) designs[1] and could be used to support future licensing actions under Title 10 of *Code of Federal Regulations* (10 CFR) Parts 50 or 52. The TR includes the qualification plan for metallic structural materials used in Flibe-wetted areas for safety-related high temperature components of the KP-FHR power and non-power (test) reactors. Kairos also requested NRC approval of the planned material testing and analyses to address the materials reliability and compatibility in the environment of the KP-FHR designs. The results of these planned tests and analyses will be provided in a future license application that references this TR, along with a detailed description of the design, inspection, and surveillance programs for the KP-FHR designs.

The documents located at the ADAMS Accession number(s) identified in Section 2 of this SE have additional details on the submittal.

4.0 EVALUATION CRITERIA

4.1 Regulatory Requirements

The information Kairos will gather through their metallic material qualification program will satisfy, in part, 10 CFR 50.10, 10 CFR 50.34, 10 CFR 52.47, 10 CFR 52.79, 10 CFR 52.137, 10 CFR 52.157, which describe the requirements for the content of applications of limited work authorizations, construction permits, operating licenses, design certifications, combined licenses, standard design approvals, and manufacturing licenses, respectively.

4.2 Principal Design Criteria for the KP-FHR, Approved by the NRC Staff

The topical report KP-TR-003-P-A, "Principal Design Criteria (PDC) for the Kairos Power Fluoride Salt-Cooled High Temperature Reactor," Revision 1, dated May 2020, provides PDCs for the KP-FHR design that were reviewed and approved by the NRC staff. The PDCs below are applicable to qualification of metallic components for the KP-FHR designs.

KP 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. The continued performance of high temperature structural materials and the associated corrosion within the coolant relate to PDC 14.

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[1] When the term "KP-FHR designs" is referenced in this safety evaluation (SE), it applies to both the power reactor and non-power test reactor, unless otherwise specified.

KP 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 on material properties. The design reflects consideration of service temperatures, service degradation of material properties, creep, fatigue, and other conditions of the boundary material under operating, maintenance, testing, and postulated accident conditions, and the uncertainties in determining: (1) material properties, (2) the effects of irradiation and coolant composition, including contaminants and reaction products, on material properties, (3) residual, steady state, and transient stresses, and (4) size of flaws.

4.3 Codes, Standards, and Guidance Documents

Applicable Codes and Standards:

The NRC staff also considered the following codes and standards and guidance documents during the course of its review:

American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (BPVC) Section III Division 5, “Rules for Construction of Nuclear Power Plant Components, High Temperature Reactors,” 2017 Edition.

Guidance Documents:

NUREG-2245, “Technical Review of the 2017 Edition of ASME Code, Section III, Division 5, “High Temperature Reactors”” dated January 2023 (ADAMS Accession No. ML23030B636)

Regulatory Guide (RG) 1.87, “Acceptability of ASME Code Section III, Division 5, High Temperature Reactors,” Revision 2, dated January 2023 (ADAMS Accession No. ML22101A263)

5.0 STAFF EVALUATION

5.1 Staff Evaluation Discussion

Kairos submitted this TR regarding the development of its safety-related reactor coolant boundary to support future licensing actions for reactors using the KP-FHR designs under 10 CFR Parts 50 or 52, including KP-FHR power reactors and non-power test reactors. The TR describes the qualification and testing methodology to be used for the metallic structural materials in safety-related components exposed to the high temperature reactor coolant salt (known as Flibe) environment of the KP-FHR designs. The Flibe properties are provided in the Kairos Power TR, "Reactor Coolant for the Kairos Power Fluoride Salt-Cooled High Temperature Reactor," Revision 1 (ML20016A486), which was approved in an NRC staff SE dated July 16, 2020 (ML20139A224).

As stated in Section 5.1 of the TR, the sponsor requested NRC staff to review and approve the qualification requirements for environmental effects of Flibe on the metallic structural materials provided in Section 4 of the TR, which the applicant has proposed will partially satisfy PDC 14 and PDC 31. The qualification requirements provided in Section 4 of the TR are for environmental effects of Flibe on the metallic structural materials, which are in addition to the qualification requirements for mechanical properties of 316H austenitic stainless steel and ER16-8-2 stainless steel weld filler metal required by ASME Code, Section III, Division 5. The applicant stated that a description of how the remaining portions of these PDC are satisfied will be provided in safety analysis reports submitted with license applications for the KP-FHR designs. The applicant stated that these material qualification test results will be used as a basis in future licensing actions to address potential materials reliability and environmental compatibility issues via design, operation, and inspection.

The results of the planned tests and analyses, along with a description of the design, operation, inspection, and surveillance programs to manage the materials performance, will be provided in future license applications. The remainder of the TR was not evaluated by the NRC staff and was only reviewed as technical background and to identify any potential impacts on the portions of the TR for which Kairos requests approval. Therefore, KP-FHR designs referencing this TR may only use this TR for purposes related to the information on 316H and ER16-8-2 material found in Section 4 of the TR, subject to the specific Limitations and Conditions found in Section 6.0 of the NRC staff SE below. All other information related to 316H and ER16-8-2 material will be evaluated in separate documents and licensing actions (see Limitation and Condition 1).

As stated in Sections 1.1.3.2 and 5.1 of the TR, the reactor vessel is **[[**[redacted]**]]** safety-related component exposed to Flibe that is required to keep the fuel covered in Flibe during all normal operations and postulated events. The environmental effects qualification testing in this TR was based on the environment that the reactor vessel would experience. Therefore, the environmental effects qualification testing for the KP-FHR designs in this TR can only be used for other components with environments that are bounded by the environment the reactor vessel would experience and referenced in this TR. For example, other components that would have Flibe on one side of the metallic material and another salt on the other side of the metallic material, or would be exposed to higher irradiation levels than those specified in the TR, or be subject to conditions otherwise not addressed in the TR would not be bounded by this TR (see Limitation and Condition 2.)

The metallic structural materials proposed for the KP-FHR designs are 316H austenitic stainless steel and the associated ER16-8-2 stainless steel weld filler metal which are qualified for use in ASME Code, Section III, Division 5, for high temperature reactors. The NRC staff notes that 316H and ER16-8-2 are materials that can be used in high temperature reactors since these materials are qualified materials listed in ASME Code, Section III, Division 5. ASME Code, Section III, Division 5, provides minimum quality requirements for the materials to ensure the use of the materials will result in an extremely low probability of abnormal leakage, rapidly propagating failure, or gross rupture, which partially satisfies PDC 14 and PDC 31. The NRC staff has endorsed the use of ASME Code, Section III, Division 5 as per NUREG-2245, "Technical Review of the 2017 Edition of ASME Code, Section III, Division 5, "High Temperature Reactors", (ML23030B636) and Regulatory Guide 1.87, "Acceptability of ASME Section III, Division 5, High Temperature Reactors," (ML22101A263).

However, ASME Code, Section III, Division 5, specifies ER16-8-2 weld filler metal as a qualified material for use up to 650°C while 316H is qualified for use up to 816°C. Currently, testing is being performed in accordance with the ASME Code to extend the qualification of ER16-8-2 up to **[[**[redacted]**]]** which includes the extension of the material's stress rupture factors to the higher temperature. This testing is addressed below in further detail.

Although ASME Code, Section III, Division 5, contains stress rupture values up to **[[**[redacted]**]]**, the staff endorsement in RG 1.87 imposes a limitation to not endorse all the stress rupture values found in Table HBB-I-14.6B, "Expected Minimum Stress-to-Rupture Values, 1,000 psi (MPa), Type 316 SS." The NRC staff limitation provides tables to show acceptable use of the stress rupture data based on the amount of time at a specified temperature **[[**[redacted]**]]**. However, because Kairos stated that **[[**[redacted]**]]**. The NRC staff finds this to be acceptable because the time at the specified temperature, for both normal operations and postulated accidents, falls within the NRC staff-endorsed ranges found in Table 2 of Regulatory Guide 1.87 for 316H. If the time and temperature for both normal operations and postulated accident conditions change for the KP-FHR designs, they must still be bounded by the NRC staff-endorsed ranges found in Table 2 of Regulatory Guide 1.87 for 316H, or an adequate justification must be provided for NRC staff review and approval as to why the values outside of the endorsed ranges are acceptable. (see Limitation and Condition 3.)

Since ER16-8-2 is not currently qualified to the higher temperature necessary to support accident scenarios of the KP-FHR designs, the NRC staff imposes a condition that ER16-8-2 must be qualified to a temperature of **[[**[redacted]**]]** in accordance with the requirements of ASME Code, Section III, Division 5, that bounds the postulated accident conditions. The qualification must also be approved by the NRC staff (see Limitation and Condition 4).

5.1.1 Design of the KP-FHR

Section 1.1 of the TR provides an overview of the key design features of the KP-FHR designs. The applicant stated that these features are not expected to change during the development of the KP-FHR designs. The applicant also stated that these features provide the basis for the safety review of the 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. Because the TR is requesting approval of certain characteristics of the reactor coolant boundary 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 action. Accordingly, the NRC staff added a condition and limitation to the TR contingent on the design features provided in Section 1 of the TR (see Limitation and Condition 5).

5.1.2 Environment to be Tested

The environments for both the non-power (test) reactor and the commercial power reactor are specified in Table 1 of the TR and are similar except that the non-power reactor lifetime is 5 years, as opposed to [[redacted]] for the commercial power reactor. The operating environment parameters for the KP-FHR designs concerning environmental degradation include the following:

- Flibe salt temperatures of 550°C-650°C
- An intermediate salt coolant loop for the commercial reactor
- A Primary Heat Transport System that rejects heat to the air in lieu of an intermediate coolant loop for the non-power test reactor
- Non-power test reactor lifetime of 5 years (1 year commissioning and 4 years operation) and commercial power reactor lifetime of [[redacted]]
- "Near-atmospheric" primary coolant pressures
- End of life irradiation of less than 0.1 displacement per atoms (dpa)

These are key operating environment parameters necessary to develop the qualification testing of 316H and ER16-8-2 for specific environmental degradation mechanisms. Therefore, the NRC staff is imposing a limitation and condition that KP-FHR designs referencing this TR must have the key operating environment parameters described above and, if changed, could necessitate the modification of, or addition to, the testing program. (see Limitation and Condition 6).

Table 11 of the TR provides the specific degradation mechanics of 316H and ER16-8-2 for the operating environment in the KP-FHR designs with the associated testing to determine the effects the operating environment has on these materials. The NRC staff finds that environmental effects testing at the normal operating temperatures to validate the degradation of 316H and ER16-8-2 material is acceptable since it duplicates the environment the material would experience during operation. Also, the additional testing using higher test temperatures [[redacted]] will allow the applicant to develop environmental degradation rates that may be experienced during postulated accident scenarios [[redacted]]. [[redacted]] The NRC staff finds that the test temperature of [[redacted]] can be used to quantify any increase in degradation of the material during a postulated accident scenario with a maximum temperature of [[redacted]] for use in future licensing applications, in part, to satisfy PDC 31. However, if the postulated accident scenarios [[redacted]], the test temperature and time for the associated material testing in Section 4 of the TR should be increased to [[redacted]] (see Limitation and Condition 7).

As stated in Section 4.2.3 of the TR, most of the testing will be conducted in "Nominal Flibe", i.e., Flibe which has been purified to minimize water and other oxidizing contaminants but not with excess beryllium metal to invoke redox control (i.e., Redox Controlled Flibe). The NRC staff finds that material testing in Nominal Flibe will bound the materials (316H and ER16-8-2) in Redox Controlled Flibe because Nominal Flibe has a higher oxidizing potential leading to increased degradation rates than in Redox Controlled Flibe. Redox Controlled Flibe uses [[redacted]] which reduces the concentration of tellurium and the oxidizing potential in Nominal Flibe, thereby leading to potentially lower degradation rates in Redox Controlled Flibe. Therefore, the NRC staff finds that the material testing in Redox Controlled Flibe can be used as a sensitivity study to [[redacted]] that can be used in future license applications for the KP-FHR designs. However, the use of [[redacted]] in Flibe has the potential to form intermetallic phases in 316H and ER16-8-2 as noted in Reference 7. This potential effect is addressed in Section 5.1.3.3.2 of this SE with associated Limitation and Condition 11, to determine the effects of [[redacted]] on the mechanical properties of 316H and associated weld filler metal ER16-8-2.

Section 4.2.3.3 of the TR describes two potential accident scenarios for the commercial power reactor (i.e., intermediate salt ingress for [[redacted]]) and air ingress for [[redacted]] into the Flibe salt) that would produce a specific concentration of these impurities that could affect the safety-related components. [[redacted]] Therefore, Tables 12 and 13 of the TR, as described in Section 4.2.3.3, provide the proposed impurity testing for both salt and air that will cover accident scenarios postulated in the transient safety analyses, and originally defined in the materials Phenomena Identification and Ranking Table (PIRT) review. In addition, the ingress of air impurities is also accounted for and tested in combination with the intermediate salt from the intermediate loop for the power reactor. The NRC staff finds this approach acceptable for developing the effect on corrosion rates that both air and the intermediate salt may have on 316H and ER16-8-2 because it will bound the accident conditions for the power reactor. The NRC staff also finds that performing corrosion testing of 316H and ER16-8-2 in Nominal Flibe with air (as an impurity) for up to [[redacted]] provides a reasonable method of developing corrosion rates in Nominal Flibe with impurities for the non-power test reactor. The NRC staff also notes that the details of the impurity testing (e.g., the concentration of contaminant) have not been determined, as stated in Table 13 of the TR. Therefore, the specific conditions of the impurities in Nominal Flibe, including contaminant chemistry, used in the impurity effects testing on 316H and ER16-8-2 shall bound the accident scenarios postulated in the transient analyses documented in the safety analysis reports for the KP-FHR designs (see Limitation and Condition 8).

5.1.3 Degradation Mechanisms

The TR provides the necessary material testing to determine the rate of degradation of 316H and ER16-8-2 in the environment of the KP-FHR designs using Flibe. The test results will be used to confirm that safety-related reactor coolant boundary material under operating and postulated accident conditions have an extremely low probability of abnormal leakage, rapidly propagating failure, or gross rupture, which partially satisfies the criteria in PDC 14 and 31. The material testing of 316H and ER16-8-2 in Flibe will be conducted for the following degradation mechanisms:

- Corrosion (including general corrosion, crevice corrosion, thermal aging, erosion/wear and cold leg occlusion)
- Environmentally assisted cracking (including stress corrosion cracking, environmental creep, and corrosion fatigue)
- Effects on metallurgical properties (including stress relaxation cracking, phase formation embrittlement, and thermal cycling)
- Irradiation effects (including irradiation-affected corrosion, irradiation-assisted stress corrosion cracking, and irradiation-induced embrittlement)

References 11 and 12 to the SE describe various degradation mechanisms, whether they occur in molten salt environments, and where additional information may be needed. These references identify corrosion, environmentally assisted cracking, and the effects of irradiation on materials as subjects where knowledge gaps may exist and require additional study. Reference 11 identifies that more data is needed for corrosion in molten salt including the effects of impurities and redox control on corrosion rates, and that there is a knowledge gap for environmentally assisted cracking in molten salts. This reference also notes that irradiation may affect degradation of material in molten salts, but that little data is currently available. Reference 12 identifies the potential for formation of intermetallic phases and the corresponding reduction in material strength. Therefore, the NRC staff finds that the above environmental degradation mechanisms are pertinent to 316H and ER16-8-2 in Flibe and are consistent with information needs identified in currently available research data and testing described above and in the TR.

Therefore, the NRC staff finds that the TR can be used in future licensing actions for the above degradation mechanisms described in Section 4 of the TR for the KP-FHR designs to partially satisfy PDCs 14 and 31, subject to the Limitations and Conditions found in Section 6.0 of the NRC staff's SE. The specific evaluation for the testing of each degradation mechanism is provided below. The NRC staff notes that additional information and research on different degradation mechanisms may become available in the future. These different degradation mechanisms would require additional testing and would be evaluated in future licensing actions.

5.1.3.1 Corrosion

Section 4.2.3 of the TR provides an overview of the proposed corrosion testing that will be used to develop quantitative corrosion models for 316H stainless steel in a Flibe environment. The NRC staff did not make a finding with regards to the overview of the proposed corrosion testing in Section 4.2.3.

5.1.3.1.1 Corrosion Test Systems

Section 4.2.3.1 of the TR describes the systems that were developed to perform corrosion tests. Kairos stated that the [[redacted]

[redacted]].

The NRC staff finds the proposed test systems acceptable because they will be able to [[redacted]] Therefore, test systems that incorporate these features are acceptable because they ensure that the degradation phenomena described in Section 4.2.3.3, "Corrosion Testing," of the TR can be accounted for.

5.1.3.1.2 Compositional Analysis and Electrochemical Potential (ECP)

Section 4.2.3.2 of the TR stated that for [[redacted]]. The TR also stated that Electrochemical Potential (ECP) monitoring and compositional analysis will be employed to [[redacted]].

The NRC staff evaluated the proposed use of compositional analysis to monitor the redox conditions of Flibe and finds it acceptable because it will quantify the impact that the Flibe composition has on the corrosion rates of the 316H and ER16-8-2 materials. An applicant referencing this TR for KP-FHR designs will need to demonstrate the Nominal Flibe composition for the coolant is consistent with the Nominal Flibe composition(s) used in this qualification test program (see Limitation and Condition 9). Additionally, the NRC staff finds the proposed use of ECP monitoring during testing acceptable because it will allow Kairos to measure the ingress of oxidizing impurities into the Flibe. The NRC staff also notes that the use of ECP during testing is acceptable because Kairos will also [[redacted]] The NRC staff will evaluate the method to monitor Flibe impurities during the review of future license applications.

5.1.3.1.3 <u>Corrosion Testing (General Corrosion, Crevice Corrosion, Erosion/Wear, Thermal Aging and Cold Leg Occlusion)</u>

Section 4.2.3.3 of the TR describes the proposed corrosion testing for 316H and ER16-8-2 exposed to Flibe. The proposed testing will use coupons of these materials in conditions described in Tables 12 and 13 of the TR. Tests will be performed under different conditions and will also include tests in off-nominal conditions to assess the impacts of specific corrosion degradation mechanisms. This includes tests to determine the effects of temperature, microstructure, salt composition, geometry, erosion-corrosion, thermal aging, graphite contact, and difference in solubility of corrosion products on the corrosion rate of 316H and ER16-8-2.

The NRC staff evaluated the planned corrosion testing for the KP-FHR designs that is summarized in Section 4.2.3.3, and Tables 12 and 13 of the TR. The staff also evaluated the proposed method to determine corrosion kinetics and the steady state corrosion rate, which are described in Section 4.2.3.3 and Appendix C of the TR. The NRC staff finds the proposed corrosion testing acceptable because these tests will determine the impact of temperature, microstructure, salt composition, geometry, erosion-corrosion, thermal aging, presence of graphite, redox control, and difference in corrosion product solubility (i.e., cold leg occlusion) on the corrosion rates and corrosion kinetics of 316H and ER16-8-2. In addition, these tests are acceptable because they are consistent with the expected corrosion mechanisms for 316H and ER16-8-2 in a molten salt environment (Raiman 2021) and a portion of the tests will be conducted with flowing Flibe, which is necessary to simulate the flowing salt in a reactor.

The NRC staff finds the tests to determine the effect of temperature on corrosion rates acceptable because corrosion is evaluated over a range of temperatures consistent with the operating temperatures of the KP-FHR designs including bounding postulated accident conditions which satisfies PDCs 14 and 31, in part. In addition, the NRC staff finds the test durations will provide sufficient data to determine corrosion kinetics.

The NRC staff also finds the tests to evaluate the microstructural effects on corrosion rates acceptable because, as described in Table 12 of the TR, these include tests to examine effects of **[[**[redacted]**]]** which are known to increase corrosion rates.

The NRC staff finds that the tests using both the Nominal Flibe composition, as well as those tests with a reducing agent added, are acceptable because these tests will determine the effects of the Flibe composition, including how oxidizing contaminants, as well as redox control, affect the corrosion rate. These tests will provide data necessary to determine design margins for corrosion, allowable levels of impurities in the salt, and the potential benefit from adding a redox control agent. An applicant referencing this TR must demonstrate that the salt compositions (with reducing agent additions and impurities from postulated accident scenarios) tested in this program bound any potential salt compositions for the KP-FHR designs (see Limitation and Condition 10).

With regard to occluded geometry effects on corrosion rates, the NRC staff finds the proposed tests acceptable because these tests will determine whether crevice corrosion is a concern for 316H and ER16-8-2 in Flibe, and the potential effect on the corrosion rate.

The NRC staff finds the proposed tests to determine the effect of erosion-corrosion acceptable because the tests will utilize graphite particulate to determine the effect of these particles on corrosion rates, as well as **[[**[redacted]**]]**. This is necessary because the KP-FHR designs will utilize graphite pebbles, as well as a graphite reflector, which will introduce graphite dust into the Flibe. Additionally, it is appropriate to determine the effect of graphite on corrosion because the presence of graphite can accelerate corrosion of 316H and ER16-8-2 when in the same system as the fluoride salt (Flibe).

The NRC staff finds the tests to determine the impact of cold leg occlusion acceptable because the proposed tests have a temperature differential between the hot and cold legs consistent with the KP-FHR designs. This temperature differential is necessary because corrosion products are more soluble in the hot leg and will precipitate out in the cold leg. This creates a concentration gradient that will accelerate corrosion as a function of the temperature differential between the hot and cold legs and will be simulated in the tests.

5.1.3.1.4 Corrosion Modeling

Section 4.2.3.3 of the TR stated that testing will be used to analyze the depth of Chromium loss over time to establish the corrosion kinetics and to determine the steady state corrosion rate. The depth of Cr loss and other metallurgical changes will be analyzed using electron microscopy. Appendix C, "Data Analysis", of the TR stated that this will allow for more sensitive measurements than analyzing the weight change of the test coupons. This is because measuring weight change can be complicated due to factors such as carbon pickup or difficulties in removing dried salt from the coupons. Electron microscopy will instead allow Kairos to analyze coupon cross sections to assess corrosion and other compositional changes.

Appendix C of the TR also stated that baseline corrosion models will be developed and separate effects tests will assess key variables that may impact corrosion rates. Kairos also stated that it will perform statistical analysis on the data and will utilize prediction bands to ensure appropriate and conservative extrapolation to the KP-FHR operational times and temperatures. For test data of certain degradation mechanisms (e.g., stress corrosion cracking) that may not be amenable to statistical analysis, Kairos stated that testing will be performed to detect if the phenomenon occurs, and whether variables that impact stress corrosion cracking can be quantified in order to perform a statistical analysis on the data. In scenarios such as this, Kairos stated that other practices (e.g., periodic inspections) may be used to address such phenomena, if the test data is not amenable to performing a statistical analysis.

The NRC staff evaluated the proposed corrosion modelling by Kairos in order to determine if the proposed qualification program for the KP-FHR designs will be adequate to determine performance of 316H and ER16-8-2 when exposed to the molten Flibe reactor coolant. The staff finds it acceptable to model corrosion behavior as a function of Cr loss from the 316H and ER16-8-2 because Cr is the alloying element in 316H that is most thermodynamically favored to corrode (i.e., least noble) and therefore will likely corrode prior to other elements of 316H and ER16-8-2 (DeVan, 1962, Raiman 2021). The staff also finds it acceptable to analyze the corrosion data as described in Appendix C because statistical analysis of the data will provide reasonable assurance that significant contributors to corrosion can be identified and that uncertainties resulting from the test data can be conservatively incorporated into corrosion predictions. Additionally, the staff finds use of electron microscopy acceptable because this will allow Kairos to assess the depth of Cr loss as well as other compositional changes in the material to mitigate complicating factors from the corrosion tests such as carbon pickup or difficulty removing dried salt from the material. This will provide data that can be corroborated against the observations from the electron microscopy. Use of electron microscopy is also acceptable because, as stated in Section 4.2.3.3 of the TR, weight change for each corrosion coupon will also be measured. The staff finds it acceptable to perform separate effects testing, in addition to baseline corrosion testing, because it will allow different variables to be assessed for their impacts on the corrosion rate. The staff finds it acceptable to perform some tests primarily to detect whether a specific phenomenon occurs, if the test data of a degradation mechanism is not amenable to statistical analysis, because after assessing whether a phenomenon occurs, it can be quantified and mitigated via multiple measures (e.g., inspections).

5.1.3.1.1.5 Effects of Operating Conditions on Corrosion

Section 4.2.3.4 of the TR describes how [[redacted]].

The NRC staff finds it acceptable to [[redacted]] The NRC staff will review the considerations discussed above to assess corrosion performance in a future submittal to determine whether the overall approach to assess and manage corrosion performance is acceptable.

5.1.3.2 Environmentally Assisted Cracking

5.1.3.2.1 Stress Corrosion Cracking and Corrosion Fatigue

Section 4.2.4 and Tables 14 and 15 of the TR provides the proposed material testing that will be performed to evaluate how the operating environment of the KP-FHR designs using Flibe affects the corrosion fatigue and stress corrosion cracking rates of 316H and ER16-8-2. Currently, there is little mechanical testing in molten salts due to the difficulty of conducting in-situ mechanical testing in highly reducing molten salt. There is also limited data of environmentally assisted cracking in stainless steels and nickel-based alloys in molten salts. Therefore, in-situ mechanical testing systems will be used to conduct slow strain rate testing (SSRT) for corrosion fatigue and stress corrosion cracking. Section 4.2.4.1 of the TR states that the SSRT tests will be conducted at temperatures [[redacted]] at various strain rates as described in Table 14 of the TR. The SSRT testing will be conducted in Nominal Flibe and Redox Controlled Flibe to assess if 316H, ER16-8-2, and the [[redacted]] of 316H are susceptible to environmentally assisted cracking in Flibe. Section 4.2.4.1 of the TR states that the SSRT testing will be conducted in accordance with American Society for Testing and Materials (ASTM) ASTM G129-00, "Standard Practice for Slow Strain Rate Testing to Evaluate the Susceptibility of Metallic Materials to Environmentally Assisted Cracking," 2000 Edition.

In addition to the SSRT testing, Section 4.2.4.2 of the TR states that fracture mechanics-based testing of pre-cracked compact tension type samples will be used to evaluate fatigue crack growth rates, stress corrosion cracking rates, and the fracture behavior of 316H and ER16-8-2 in the Flibe environment at temperatures [[redacted]] as described in Table 15 of the TR. The test samples will consist of [[redacted]] with a sharp flaw (i.e., the corrosion fatigue crack) placed in the appropriate locations (i.e., weld metal, [[redacted]] and base metal) and allows the crack to grow in the area to be tested. [[redacted]

[redacted]] These SSRT tests will include both a corrosion fatigue portion (high variable stress intensity factor to initiate and grow fatigue crack which will be used for subsequent stress corrosion testing) and stress corrosion cracking portion (a constant stress intensity factor to initiate stress corrosion under aggressive testing conditions and then transition to conditions that are representative of the KP-FHR designs).

The NRC staff finds that the samples to be tested are acceptable because they are representative of the material and weldments to be used in the KP-FHR designs. In particular, the use of **[**[redacted]] The NRC staff also finds that performing the testing for fatigue and stress corrosion cracking in air **[[**[redacted]**]]** and then comparing it to testing performed in both Nominal Flibe and Redox Controlled Flibe acceptable in simulating and determining the crack growth rates for fatigue and stress corrosion cracking relative to the environment in the KP-FHR designs. **[[**[redacted]**]]** The NRC staff also finds that SSRT and fracture mechanics-based testing (ASTM G129-00) of pre-cracked compact tension samples acceptable because these test methods are well-established, are an accepted methodology, and have been effective in other environmentally assisted cracking testing used by licensees and the NRC staff.

5.1.3.2.2 Environmental Creep

Section 4.2.4.3 of the TR describes the material testing that will be performed to assess the susceptibility of 316H and ER16-8-2 to environmental creep in **[[**[redacted]**]]** as described in Table 16 of the TR. The NRC staff finds that performing creep testing in both Normal Flibe using welded base metal samples to include the base metal, weld metal and heat affected zone of the base metal acceptable since it simulates the material to be used and the environment of the KP-FHR designs. In addition, the NRC staff finds it acceptable that **[[**[redacted]**]]** are not required to be performed unless significant degradation is noted compared to creep tests performed in air, such as failure times outside of the 90% confidence interval from creep tests performed in air, or a change in fracture mode because the creep tests in air would bound the results in Nominal Flibe in the temperature range of the KP-FHR designs. The NRC staff notes that the creep tests in Nominal Flibe are to determine if the Flibe contributes additional degradation beyond those determine from the creep tests performed in air. If the testing determines Flibe has an additional effect on degradation, additional testing would be required to quantify any increase in degradation contributing to Flibe, and the test results would be reviewed by the NRC staff in future licensing submittals by the applicant.

5.1.3.3 Metallurgical Effects

5.1.3.3.1 Stress Relaxation Cracking

Section 4.2.5 of the TR states that stress relaxation cracking in 316H will be addressed by using test results conducted in air up to temperatures of [[redacted]] as discussed in Section 3.2 of the TR, and by conducting future analysis and design refinements of the KP-FHR designs, such as weld designs in Figure 23 of the TR, and specific weld processes and parameters to minimize stress relaxation cracking as detailed in Section 3.3.1 of the TR to reduce the triaxial stresses. Section 3.3.2 of the TR provides [[redacted]]]. Current data and experience show that ER16-8-2 weld metals are not susceptible to stress relaxation cracking, while the heat affected zone of 316H base metal with high triaxial stresses is susceptible to stress relaxation cracking. In addition, Table 10 of the TR provides the specific, [[redacted]]]. Section 4.1 of the TR states that the stress relaxation cracking testing is summarized in Table 11 of the TR.

The NRC staff finds testing in air acceptable because these test results would be valid for 316H in Flibe for the KP-FHR designs since triaxial stresses are the major contributor to stress relaxation cracking. In addition, the NRC staff finds that comparing the susceptibility of 316H to that of 347 as discussed in Section 3.3.1 of the TR would allow a determination of the bounding triaxial stresses that could cause stress relaxation cracking in 316H. The NRC staff also finds the stress relaxation testing for the KP-FHR commercial power reactor and the non-power test reactor in Table 10 of the TR acceptable because the [[redacted]]] will provide reasonable data to assess the bounding triaxial stresses that could cause stress relaxation cracking in 316H. The NRC staff notes that in Section 3.3.2 of the TR Kairos states that it's developing the capability to model weld residual stresses using [[redacted]]] to better assess and limit the magnitude of the weld residual stresses induced during welding of 316H for the KP-FHR designs. The results of these analysis can be used in future licensing actions to address stress relaxation cracking of 316H in the KP-FHR designs.

5.1.3.3.2 Phase Formation Embrittlement

Section 4.2.5 of the TR discusses how the qualification program addresses phase formation embrittlement, and degradation from thermal cycling or thermal gradients. Kairos states that phase formation embrittlement may occur when 316H and ER16-8-2 picks up an element during its exposure to Flibe and forms a deleterious second phase. To address this, Kairos proposed to [[redacted]]].

The NRC staff reviewed the proposed method to address phase formation embrittlement. The NRC staff finds it acceptable because Kairos will [[redacted]]]. This testing will determine whether this degradation mechanism occurs for the KP-FHR designs. Additionally, this is subject to Limitations and Conditions 2 and

5 which states that the results of the qualification testing are only applicable to the KP-FHR designs that is bound by the test conditions. In this case, a design that utilizes [[redacted]]. Therefore, the NRC staff is imposing a limitation and condition that if intermetallic formation occurs, an applicant will need to perform testing to quantify the effects on the mechanical properties of 316H and associated weld filler metal ER16-8-2 (see Limitation and Condition 11).

5.1.3.3.3 Thermal Cycling/Stripping

Table 11 of the TR states that thermal cycling [[redacted]]. In addition, Section 4.2.5 of the TR states that degradation of 316H and ER16-8-2 by large thermal transients could lead to high stresses resulting in thermal fatigue degradation. Kairos will address the thermal cycling by conducting analysis to refine the design and operation of the KP-FHR designs to mitigate large thermal gradients. The NRC staff finds it acceptable that future analysis, in lieu of testing, will be used to mitigate thermal cycling because the thermal gradients will be minimized through the use of appropriate design and operating conditions of the KP-FHR (power and non-power test reactor), as informed by the analysis. However, since the design has not been finalized and no testing will be conducted as part of this material qualification program, the NRC staff is imposing a limitation and condition that an applicant implementing this TR will address thermal cycling/stripping in future licensing submittals by minimizing the thermal gradients via appropriate design and operating conditions of KP-FHR designs based on analysis (see Limitation and Condition 12).

5.1.3.4 Irradiation Effects

5.1.3.4.1 Irradiation-Induced Embrittlement

Section 4.2.6.1 of the TR states that existing data indicates that tensile properties and fracture toughness of austenitic stainless steels, when tested at high strain rates and temperatures from 550°C to 650°C, are relatively unaffected by irradiation levels <0.1 displacement per atoms (dpa) with a helium content of 10 atomic parts per million (appm) in current light water reactor environments. However, at low strain rates, data shows irradiation-induced embrittlement can affect material properties such as tensile strength and ductility and creep life due to the generation of helium. The applicant stated in Section 4.2.6.1 of the TR that existing data will be used to develop degradation factors, but that it will conduct irradiation tests on ER16-8-2, 316H, and the associated heat affected zone of 316H to quantify margins at irradiation levels for the non-power test reactor and the commercial power reactor which will be provided in future licensing actions. The NRC staff finds it acceptable to conduct testing for irradiation-induced embrittlement on ER16-8-2, 316H, and the associated heat affected zone of 316H, because the testing will be representative of the environment in the KP-FHR designs and this information will be submitted in future licensing actions. NRC staff is imposing a limitation and condition that the test environment shall bound the KP-FHR designs, including the expected irradiation damage (dpa) and helium content (see Limitation and Condition 13).

5.1.3.4.2 Irradiation-Affected Corrosion

Section 4.2.6.2 of the TR states that no immediate material testing of 316H and ER16-8-2 for irradiation effects on corrosion is proposed for the qualification of 316H and ER16-8-2 because the reactor vessel has a low irradiation dose level (<0.1 dpa) and existing data shows that irradiation may increase general corrosion rates but decrease intergranular corrosion rates. However, the applicant will implement a materials surveillance system program for the non-power test reactor and (at least the first) commercial power reactor systems to monitor irradiation-affected corrosion. In addition, an inspection and monitoring program that will assess the wall thickness of the reactor vessel will also be implemented. The initial plans for these programs are provided in Appendix B of the TR. The applicant has not finalized plans for these programs and will provide the detailed programs in future licensing actions.

Since Appendix B of the TR is not a finalized program for assessing irradiation-affected corrosion, the NRC staff cannot provide a conclusion on the proposed initial planned programs. Notwithstanding, the NRC staff finds it acceptable to implement a materials surveillance program that will be submitted as part of future license applications for the non-power test reactor and the commercial power reactor because this program could provide sufficient information that can be used in determining any affects irradiation has on the corrosion rate of 316H and ER16-8-2 in the environment of the KP-FHR designs. However, the NRC staff notes that the materials surveillance program should not be limited to only the first commercial power reactor, because there is limited data on the effects of irradiation on corrosion rates in Flibe on 316H and ER16-8-2. Therefore, the materials surveillance program should apply to both the non-power test reactor and the commercial power reactors. In addition, the NRC staff finds it acceptable to use an inspection and monitoring program to assess any changes in the wall thickness of the reactor vessel because the program should be capable of detecting wall thinning that could prevent the reactor vessel from performing its safety function. Therefore, the NRC staff is imposing a limitation and condition that the materials surveillance program and the inspection and monitoring program will be submitted in future license applications for NRC staff review and approval to verify that these programs are sufficient to address irradiation-affected corrosion of the reactor vessel. (See Limitation and Condition 14.)

5.1.3.4.3 Irradiation-Assisted Stress Corrosion Cracking (IASCC)

Section 4.2.6.3 of the TR states that IASCC is not expected to be a degradation mechanism in the KP-FHR design due to the low irradiation level (<0.1 dpa) and that radiolysis of Flibe is not expected because of the rapid recombination of ions in the molten Flibe state. In addition, the chemistry control system will have the capability to adjust the redox potential of the salt and to correct Flibe chemistry changes induced by transmutation. The applicant also states that the test program specified in Section 4.2.4 will determine if stress corrosion cracking is a credible degradation mechanism for the environment of the KP-FHR designs. Therefore, the applicant does not propose additional material testing of 316H and ER16-8-2 for irradiation effects on stress corrosion cracking. However, a materials surveillance program and the inspection and monitoring program, as discussed in Appendix B of the TR, will be implemented and submitted in future license applications to address concerns for IASCC.

The NRC staff finds it acceptable to implement a materials surveillance program that will be submitted in future license applications for the non-power test reactor and the commercial power reactor because this program could provide sufficient information that can be used in determining any effects irradiation has on the stress corrosion cracking rate of 316H and ER16-8-2 in the KP-FHR environment. As stated in Section 5.1.3.4.2 of this SE, the NRC staff notes that the materials surveillance program should not be limited to only the first commercial power reactor, because there is limited data on the effects of irradiation on stress corrosion cracking rates in Flibe on 316H and ER16-8-2. Consistent with the discussion in Section 5.1.3.4.2 of this SE, above, this warrants implementation of a materials surveillance program for all commercial power reactors using the KP-FHR design. In addition, the NRC staff finds it acceptable to use an inspection and monitoring program to detect cracking of the reactor vessel because the program should be capable of detecting cracking that would prevent the reactor vessel from performing its safety function. Therefore, the NRC staff is imposing a limitation and condition that the materials surveillance program and the inspection and monitoring program will be submitted in future license applications for NRC staff review and approval to verify that these programs are sufficient to address irradiation-affected stress corrosion cracking of the reactor vessel (see Limitation and Condition 14).

5.1.4 Quality Assurance

Section 1 of the TR states that the non-power test reactor application is implementing a quality assurance program based on ANSI/ANS-15.8-1995, "Quality Assurance Program Requirements for Research Reactors," (ANSI/ANS-15.8), which is endorsed by NRC Regulatory Guide 2.5, "Quality Assurance Program Requirements for Research and Test Reactors." The NRC staff finds it acceptable to use ANSI/ANS-15.8-1995 for material testing that will only be used to support the non-power test reactor. The NRC staff notes that Revision 4 of the TR does not specify if material testing related to safety-related components will be conducted under a program that complies with the requirements of 10 CFR 50 Appendix B, as stated in previous revisions of the TR. The quality and accuracy of material testing results that could be used for the commercial power reactor must be confirmed when used to address potential materials reliability and environmental compatibility of safety-related components. Therefore, the NRC staff is imposing a limitation and condition that material testing will be conducted under a quality assurance program that complies with the requirements of 10 CFR 50 Appendix B to confirm the quality of the data obtained during the material testing that will be used for the commercial power reactor (see Limitation and Condition 15).

5.2 Evaluation Summary

The NRC staff finds that the material qualification methodology for 316H and ER16-8-2 materials in Section 4 of the TR satisfy, in part, the PDCs 14 and 31 for the KP-FHR designs and is acceptable, subject to the Limitations and Conditions found in Section 6.0 of the NRC staff's SE below. The NRC staff finds that testing at the normal operating and postulated accident temperatures, and in both Nominal Flibe and Redox Controlled Flibe, to validate the degradation of 316H and ER16-8-2 material, is acceptable since the testing duplicates the operating environment that the material will experience in the KP-FHR designs. The NRC staff also finds it acceptable that the material test samples will include not only the 316H base metal and associated ER16-8-2 weld metal, but the [[redacted]]. The NRC staff also finds that there is reasonable assurance that the degradation mechanisms to be tested as described in in Section 4 of the TR include the appropriate environmental degradation mechanisms for the KP-FHR designs based on the current research and testing information provided in the TR and in References 11 and 12 of this SE. These references discuss topics such as corrosion, environmentally assisted cracking, and the effects of irradiation on materials, and their applicability in molten salt environments.

The staff has reasonable assurance the qualification program meets the requirements listed in Section 4.1 described above, as they relate to the qualification of 316H and ER16-8-2 in the

Flibe environment, because the TR describes the use of generally accepted engineering standards, unique safety features, novel design features, and the relation of facility design to the PDC.

6.0 LIMITATIONS AND CONDITIONS

An applicant may reference the TR only if the applicant demonstrates compliance with the following limitations and conditions:

1. (**Section 1.0**) As stated by Kairos in the TR, NRC staff review and approval of only Section 4 of the TR was requested. Therefore, KP-FHR designs referencing this TR may only use this TR for purposes related to the information on 316H and ER16-8-2 material found in Section 4 of the TR, subject to the specific limitations and conditions found in the NRC staff SE below. All other information related to the 316H and ER16-8-2 material will be evaluated in separate documents and licensing actions.

2. **(Sections 1.1.3.2 and 5.1**) The environmental effects qualification testing for the KP-FHR designs in this TR can only be used for other components with environments that are bounded by the environment the reactor vessel would experience and are used in this TR. For example, other components that would have Flibe on one side of the metallic material and another salt on the other side of the metallic material, or higher irradiation levels than those specified in the TR, etc. would not be bounded by this TR.

3. If the time and temperature for both normal operations and postulated accident conditions change for the KP-FHR designs, they must still be bounded by the NRC staff-endorsed ranges found in Table 2 of Regulatory Guide 1.87 for 316H, or an adequate justification must be provided for NRC staff review and approval for why the values outside of the endorsed ranges are acceptable.

4. (**Section 4.2.1**) ER16-8-2 material must be qualified to a temperature of **[[**[redacted]**]]** in accordance with the requirements of ASME Code, Section III, Division 5, and for a time that bounds the postulated accident conditions and be approved by the NRC staff.

5. (**Section 1.1**) Because there is information that has not yet been developed and/or reviewed as part of this TR, KP-FHR designs referencing this TR must provide information that completely and accurately describes the design of the reactor coolant boundary (and associated systems) and any associated functions it is credited to perform for NRC staff review and approval. As stated in the TR, if key design features of the KP-FHR designs 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, KP-FHR designs referencing this TR must demonstrate that all regulatory and safety requirements related to the characteristics of the metallic materials are met when considering the final design of the KP-FHR.

6. (**Section 4.1**) As presented in the TR, there are key design parameters without which the proposed reactor coolant boundary design and associated properties may not be supported. Therefore, KP-FHR designs referencing this TR must have the following:

- Flibe Salt temperatures of 550°C-650°C
- An intermediate salt coolant loop for the commercial reactor
- A Primary Heat Transport System that rejects heat to the air in lieu of an intermediate coolant loop for the non-power test reactor
- Non-power test reactor lifetime of a maximum of 5 years (1 year commissioning + 4 years operation) and commercial power reactor lifetime of a maximum of **[[**[redacted]**]]**
- “Near-atmospheric” primary coolant pressures
- End of life irradiation of less than 0.1 dpa

These key design parameters of the KP-FHR designs, if changed, could necessitate the modification of, or addition to, the testing program.

7. (**Tables 12, 13, 14, 15 and 16**) If the postulated accident conditions **[[**[redacted]**]]**, the test temperature and time for the associated material testing in Section 4 of the TR must be increased to **[[**[redacted]**]]**.

8. **(Section 4.2.3.3 and Table 13)** The impurity effects testing on 316H and ER16-8-2 must include the potential loss of Flibe chemistry control from both air ingress and intermediate salt loop ingress based on the safety analysis reports. An applicant referencing this TR must demonstrate that any potential impurity ingress (including postulated accidents) in the KP-FHR designs is bound by the testing performed as part of this TR.

9. (**Section 4.2.3.2, Tables 13 and 14)** An applicant referencing this TR must demonstrate that the Nominal Flibe salt composition used in the KP-FHR designs is consistent with the Nominal Flibe salt composition used in these tests including initial impurities in the salt.

10. **Section 4.2.3.2, Tables 13 and 14)** An applicant referencing this topical report must demonstrate that the salt compositions (with reducing agent additions and impurities from postulated accident scenarios) tested in this program bound any potential salt compositions for the KP-FHR reactor designs.

11. **(Section 4.2.5)** In order to address phase formation embrittlement for the KP-FHR designs an applicant must show that testing bounds potential design conditions [redacted]**]]** and that if a secondary phase is detected during testing, the effects on mechanical properties of 316H and ER16-8-2 must be quantified via testing and approved by the NRC staff.

12. **(Section 4.2.5 and Table 11)** The applicant will assess thermal cycling/striping in future licensing submittals by minimizing the thermal gradients via appropriate design and operating conditions of the KP-FHR designs based on analysis.

13. (**Section 4.2.6.1**) Testing for irradiation-induced embrittlement of ER16-8-2, 316H, and the associated heat affected zone of 316H must be performed that bounds the environment representative of the KP-FHR designs, including the expected irradiation

damage (dpa) and helium content. The program describing this testing must be submitted in future license applications for NRC staff review and approval to verify this testing program is sufficient to address irradiation-induced embrittlement of the reactor vessel.

14. **(Sections 4.2.6.2 and 4.2.6.3)** As described in Sections 4.6.2.2 and 4.2.6.3 of the TR, a materials surveillance program and an inspection and monitoring program must be implemented for all non-power test reactors and commercial power reactors using KP-FHR designs to assess and monitor both irradiation-affected corrosion rates and irradiation-affected stress corrosion cracking rates of 316H and ER16-8-2 in the environment of KP-FHR designs. The materials surveillance program and the inspection and monitoring program must be submitted in future license applications for NRC staff review and approval to verify these programs are sufficient to address both irradiation-affected corrosion and irradiation-affected stress corrosion cracking of the reactor vessel.

15. **(Section 1.0)** Material testing for the commercial power reactor must be conducted under quality assurance program that meets the requirements of 10 CFR Part 50 Appendix B to confirm the quality of the data obtained during the material testing that will be used for the commercial power reactor.

7.0 CONCLUSION

Based on the evaluation above, the NRC staff concludes that Kairos has provided reasonable assurance that the information in Section 4 of the TR will satisfy, in part, KP-FHR PDCs 14 and 31 as described above, for the KP-FHR designs subject to the Limitations and Conditions in Section 6.0 of this SE. The NRC staff also concludes that the qualification program proposed by Kairos will satisfy, in part, the requirements of 10 CFR 50 and 52, as described in Section 4.1 above, with respect to contents of applications, subject to the limitations and conditions discussed above. The information provided in Section 4 of the TR establishes the material qualification methodology for environmental effects of Flibe on the 316H and ER16-8-2 structural materials to be used as a basis in future licensing actions to address potential materials reliability and environmental compatibility issues of the reactor vessel using the KP-FHR designs. The results of the planned tests, along with a description of the design, operation, inspection, and surveillance programs to manage the materials performance must be provided as part of future license application submittals.

8.0 REFERENCES

1. Kairos Power LLC letter No. KP-NRC-2006-004, dated June 30, 2020 (ADAMS Accession No. ML20182A800) submitting Kairos Power LLC, “Metallic Materials Qualification for the Kairos Power Fluoride Salt-Cooled High-Temperature Reactor,” KP-TR-013, Revision 0, June 30, 2020 (ADAMS Accession No. ML20182A800)

2. Email, Nuclear Regulatory Commission Richard Rivera to John Price, “Preliminary Questions on Kairos Metallic Materials Qualification Topical Report,” November 25, 2020 (ML20332A076).

3. Kairos Power LLC letter No. KP-NRC-2106-007, “KP-FHR High Temperature Metallic Materials Topical Report,” KPTR-013, Revision 1, June 30, 2021 (ML21181A386)

submitting "KP-FHR High-Temperature Metallic Materials Topical Report," KPTR-013, Revision 1, June 30, 2021 (ML21181A387)

4. Email, Nuclear Regulatory Commission Richard Rivera to Darrell Gardner and John Price, "Preliminary Questions on Revision 1 of Kairos Metallic Materials Qualification Topical Report," October 13, 2021 (ML20332A076)

5. Kairos letter No. KP-NRC-2204-003, "KP-FHR High Temperature Metallic Materials Topical Report," KPTR-013, Revision 2, dated April 26, 2022, (ML22116A247) submitting "Metallic Materials Qualification for the Kairos Power Fluoride Salt-Cooled High-Temperature Reactor," KPTR-013, Revision 2, April 2022 (ML22116A249)

6. Kairos letter No. KP-NRC-2208-001, "KP-FHR High Temperature Metallic Materials Topical Report," KPTR-013, Revision 3, dated August 19, 2022, (ML22231B222) submitting "Metallic Materials Qualification for the Kairos Power Fluoride Salt-Cooled, High Temperature Reactor," KPTR-013, Revision 3, April 2022 (ML22231B224)

7. Kairos letter No. KP-NRC-2209-005, "KP-FHR High Temperature Metallic Materials Topical Report," KP-TR-013, Revision 2, dated September 20, 2022, (ML22263A457) submitting "Metallic Materials Qualification for the Kairos Power Fluoride Salt-Cooled, High Temperature Reactor," KP-TR-013, Revision 4, September 2022 (ML22263A459)

8. Kairos Power LLC, letter KP-NRC-1907-006, P. Hastings, Vice President, Regulatory Affairs and Quality, to USNRC document control desk, re: "Principal Design Criteria for the Kairos Power Fluoride Salt-Cooled, High Temperature Reactor (Revision 1)," July 31, 2019 (ADAMS Accession No. ML19212A756).

9. US NRC, NUREG-2245, "Technical Review of the 2017 Edition of ASME Code, Section III, Division 5, "High Temperature Reactors", dated January 2023 (ML23030B636).

10. US NRC, Regulatory Guide 1.87, "Acceptability of ASME Section III, Division 5, High Temperature Reactors," Revision 2, dated January 2023 (ML22101A263).

11. Stephen S. Raiman, et. al., Oak Ridge National Laboratory, TLR-RES/DE/CIB-CMB-2021-03, "Technical Assessment of Materials Compatibility in Molten Salt Reactors," March 2021 (ADAMS Accession No. ML21084A039).

12. J. R. Keiser, P. M. Singh. M.J Lance et. al., "Interaction of Beryllium with 316H Stainless Steel in Molten Li_2BeF_4 (Flibe)," Published in Journal of Nuclear Materials, Volume 565, July 2022.