Enclosure 2

Response to NRC Request for Additional Information 350

(Non-Proprietary)

NRC Request for Additional Information

RAI Package 350, Question 410

Section 50.34 of Title 10 of the Code of Federal Regulations (10 CFR 50.34), "Contents of applications; technical information," provides requirements for information to be provided in a Construction Permit (CP). 10 CFR 50.34(a)(4) states that a CP shall contain a preliminary analysis and evaluation of SSCs provided for mitigation of the consequences of accidents to determine margins of safety during normal operations and transient conditions during the life of the facility.

Section 3.1.1, "Design Criteria," of the Kairos Power (KP) Hermes Preliminary Safety Analysis Report (PSAR) references document KP-TR-003-NP-A, "Principal Design Criteria [PDC] for the Kairos Power Fluoride-Salt Cooled, High Temperature Reactor," Revision 1, to provide the PDC for the Hermes test reactor. KP-FHR PDC 14, "Reactor coolant boundary," states that safety significant elements of the reactor coolant boundary shall have an extremely low probability of abnormal leakage, rapidly propagating failure, and gross rupture. KP-FHR PDC 31, "Fracture prevention of the reactor coolant boundary," states that the reactor coolant boundary shall be designed to consider service degradation of material properties including effects of contaminants. KP-FHR PDC 35, "Passive residual heat removal," states that a system shall be provided to remove residual heat during and after postulated accidents. KP-FHR PDC 74, "Reactor vessel and reactor system structural design basis," states that the vessel and reactor system shall be designed to ensure integrity is maintained during postulated accidents to ensure the geometry for passive heat removal and allow for insertion of reactivity control elements.

Section 4.3 of the PSAR, "Reactor Vessel System," describes the components that form the natural circulation flow path needed to provide residual heat removal during and following postulated events. These include portions of the graphite reflector as well as metallic components such as the core barrel, reactor vessel, and fluidic diode. This section of the PSAR describes how these components are needed to meet PDCs 14, 31, 35, and 74.

Section 5.1.3 of the PSAR, "System Evaluation," states that "significant" air ingress into the primary heat transport system (PHTS) is excluded by design basis. In an event with postulated air ingress into the PHTS, the components that comprise the natural circulation flow path will need to perform their safety functions (i.e., maintain the natural circulation flow path) to meet the PDC listed above. The staff notes that air ingress into the PHTS can cause oxidation of the graphite reflector as well as corrosion of metallic components in the primary system, and such degradation could potentially challenge natural circulation flow. In order to evaluate effects of air ingress, the staff needs to understand the amount of air ingress that will be allowed and how the limitation of ingress will be achieved.

Therefore, the NRC staff requests the following information:

1. *Define what constitutes "significant" air ingress into the PHTS and the basis for determining what is "significant."*
2. *Describe how component integrity is ensured if the duration of an air ingress event is longer than the duration covered by the materials qualification testing.*
3. *In an event such as a salt spill or heat radiator tube rupture, how is further air ingress prevented after a heat rejection blower trip?*

Kairos Power Response

NRC Question 410, Item 1

Define what constitutes "significant" air ingress into the PHTS and the basis for determining what is "significant."

The discussion in Preliminary Safety Analysis Report (PSAR) Section 5.1.3 is referring to limiting the amount of air ingress that is forced into the Flibe, not limiting the amount of air ingress to the reactor system as a whole. As cited in PSAR Section 5.1.3, the design evaluation of limiting significant air ingress demonstrates compliance with Principal Design Criteria (PDC) 33 and PDC 70. PDC 33 and PDC 70 are focused on details of the Flibe, not the gas space above the free surface of Flibe. This distinction is important to recognize for the responses provided to this RAI. The response to Item 2 below includes the consideration of oxidation effects for non-Flibe-wetted graphite above the free surface of Flibe.

As described in PSAR Section 5.1.3, “significant” air ingress into the Primary Heat Transport System (PHTS) refers to two scenarios:

- Significant air being entrained in the coolant during normal operation (to meet PDC 33)
- Forced air ingress occurring during postulated system leakage events (to meet PDC 70)

If air is entrained in the coolant during normal operation, operational controls are expected to monitor the quantity of air within the PHTS to prevent accumulating significant quantities with a technical specification, as discussed in PSAR Section 13.1.10.5. The limit for “significant” air ingress will prevent void accumulation and limit the total corrosion of Flibe-wetted components, as described in PSAR Table 14.1-1. Consistent with 10 CFR 50.34(a)(5), the PSAR identifies the variable expected to be subject to technical specification control, and PSAR Section 14.1 commits to providing the parameter limits with the application for an Operating License Application, consistent with 10 CFR 50.34(b)(6)(vi).

For the scenarios where significant forced air ingress is prevented during postulated events involving a breach or break in the PHTS, “significant” refers to amounts of air that could be forced into the Flibe by the driving forces associated with the heat rejection blower or the primary salt pump. As described in PSAR Section 7.3.1, there are safety-related trips on the heat rejection blower and primary salt pump, which remove the mechanisms that could force air into the Flibe during a system leakage event to prevent significant forced air ingress.

PSAR Sections 5.1.3, and 13.1.10.5 have been updated to clarify that forced air ingress into the PHTS is precluded by design.

NRC Question 410, Item 2

Describe how component integrity is ensured if the duration of an air ingress event is longer than the duration covered by the materials qualification testing.

By maintaining the quantity of air within the technical specification limit during normal operation and removing the mechanisms to force air into the Flibe described in Item 1 of this RAI, the structural integrity of metallic and graphite components that remain Flibe-wetted is ensured to remain within conditions bounded by the materials qualification testing programs (References 1 and 2) for air ingress events up to seven days. The metallic materials qualification topical report includes [[ ]]

(Reference 1). The graphite material qualification topical report describes the assessment plan for the effects of air contamination in Flibe on ET-10 graphite (Reference 2).

During normal operation, the argon in the gas space will be monitored for potential air ingress as described in the Kairos Power response to RCI-02 (ML22231B230).

The graphite reflector blocks that are located above the free surface of the Flibe are subject to potential oxidation effects during a postulated air ingress event. Since the shutdown elements insert at the beginning of the event, this exposed graphite structure is not credited after insertion to perform a “long term” structural integrity safety function when oxidation could begin to affect the structural integrity. Additionally, if significant oxidation were to result in a loss of structural integrity of the exposed graphite, there is a layer of submerged (Flibe-wetted) graphite that mitigates debris from the exposed graphite from entering the natural circulation flow path.

As shown in Figure 1, the secondary hold-down structure is installed within the upper layers of the graphite reflector and extends below the minimum Flibe level for a PHTS break event. If significant oxidation were to result in a loss of structural integrity of the graphite above the minimum Flibe level, the secondary hold-down structure will transfer loads from the submerged graphite to the top head, keeping the remaining reflector structure in place and submerged in Flibe. The effects of non-forced air ingress on the integrity of components below the surface of Flibe will be bounded by the materials qualification testing programs for at least seven days following the initiation of the event. Beyond seven days, defense in depth features include: implementing repairs on damaged SSCs, replenishing argon supply, or removal of fuel from the vessel. This ensures that the geometry of the core and the natural circulation flow paths are maintained. PSAR Section 4.3 has been updated to remove the statement the reactor vessel is designed to preclude air ingress and to reflect the secondary hold-down structure design details described above. PSAR Section 13.1.10.5 has been updated to describe defense in depth features of the design available after the initial seven day period of a postulated air ingress event. A markup of changes to the graphite qualification topical report providing additional details of the of the assessment of air ingress on the integrity of components below the surface of Flibe is being provided with this response. A revision to the graphite qualification topical report will be submitted by separate letter.

NRC Question 410, Item 3

In an event such as a salt spill or heat radiator tube rupture, how is further air ingress prevented after a heat rejection blower trip?

As described in Item 1, safety-related trips on the heat rejection blower and primary salt pump remove the mechanisms that could force air into the Flibe during a system leakage event. The Hermes design does not credit any means of limiting further non-forced air ingress into the PHTS in the event of a salt spill or radiator tube rupture. See response to Item 2 for discussion of the impacts of non-forced air ingress on vessel internals.

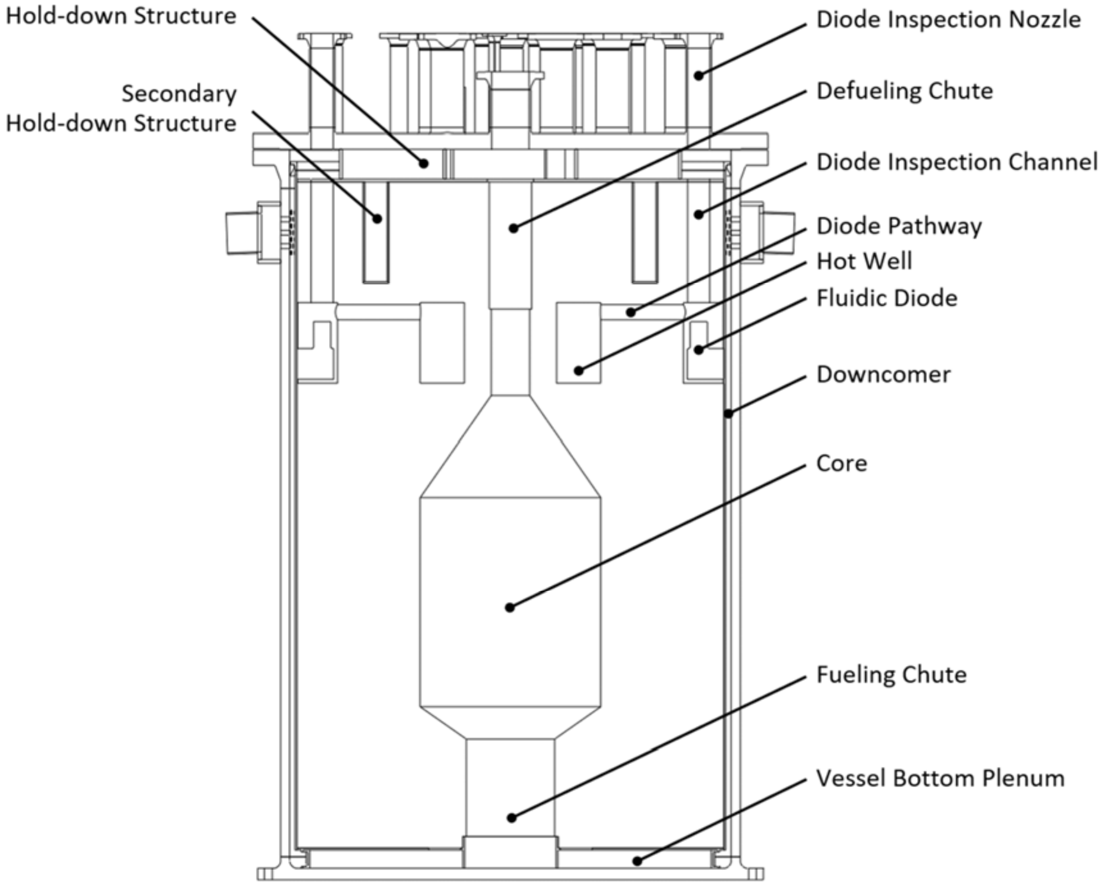
References:

1. Kairos Power LLC, “Metallic Materials Qualification for the Kairos Power Fluoride Salt-Cooled High-Temperature Reactor,” KP-TR-013-P, Revision 3.
2. Kairos Power LLC, “Graphite Material Qualification for the Kairos Power Fluoride Salt-Cooled High-Temperature Reactor,” KP-TR-014-P, Revision 3.

Impact on Licensing Document:

This response impacts Sections 4.3, 5.1.3, and 13.1.10.5 of the Kairos Power Preliminary Safety Analysis Report and Section 5.3 of “Graphite Materials Qualification for the Kairos Power Fluoride Salt-Cooled High-Temperature Reactor.” Markups of the affected sections are provided with this response.

Figure 1


Hold-down Structure
Secondary Hold-down Structure
Diode Inspection Nozzle
Defueling Chute
Diode Inspection Channel
Diode Pathway
Hot Well
Fluidic Diode
Downcomer
Core
Fueling Chute
Vessel Bottom Plenum

coolant level. The design of the reactor vessel allows for online monitoring, in-service inspection, and maintenance.

4.3.1.1.1 Vessel Top Head

The reactor vessel top head (see Figure 4.3-2) is a flat 316H SS disc bolted and flanged to the vessel shell. This interface is designed for leak-tightness but is not credited as being leak tight in safety analyses. The vessel top head controls the radial and circumferential positions of the reflector blocks to ensure a stable core configuration for all conditions (e.g., reactor trip and core motion). The top head contains penetrations, as shown in Figure 4.3-2 and Table 4.3-1, into and out of the vessel and provides for the attachment of supporting equipment and components (e.g., reactivity control elements, pebble handling and storage system components, material sampling port, neutron detectors, thermocouples, etc.). The top head supports the vessel material surveillance system (MSS) which provides a remote means to insert and remove material and fuel test specimens into and from the reactor to support testing. A hold-down structure sub-assembly is welded underneath the vessel top head. This structure contacts with the top surface of the graphite reflector and provides structural support against upward loads during normal operation and most postulated events. A secondary hold-down structure is installed through the upper graphite layers, extending from the reflector top into submerged graphite layers to transfer upward loads from submerged graphite to the vessel top head during postulated air ingress events. The secondary hold down structure extends to below the minimum reactor vessel coolant level that could result from postulated salt spill events.

4.3.1.1.2 Vessel Shell

The reactor vessel is a 316H SS cylindrical shell that, along with the vessel bottom head, serves to form the safety-related reactor coolant boundary within the reactor vessel. It contains and maintains the inventory of reactor coolant inside the vessel. The shell provides the geometry for coolant inlet and vessel surface for the DHRS which transfers heat from the reactor vessel during postulated events. The inside of the shell uses 316H SS tabs to maintain the core barrel in a cylindrical geometry and has a welded connection at the top of the core barrel.

4.3.1.1.3 Vessel Bottom Head

The reactor vessel bottom head is a flat 316H SS disc that is welded to the vessel shell. It contains and maintains the inventory of the reactor coolant inside the vessel, supports the vessel internals, maintains the reactor coolant boundary and provides flow geometry for low pressure reactor coolant inlet to the core. Hydrostatic, seismic and gravity loads on the vessel and vessel internals are transferred to the bottom head and are transferred to the RVSS.

4.3.1.2 Reactor Vessel Internals

The reactor vessel internal structures include the graphite reflector blocks, core barrel and reflector support structure. The vessel internal structures define the flow paths of the fuel and reactor coolant, provide a heat sink, a pathway for instrumentation insertion, control and shutdown element insertion, as well as provide neutron shielding and moderation surrounding the core. The design of the structures support inspection and maintenance activities as well as monitoring of the reactor vessel system.

4.3.1.2.1 Reflector Blocks

The reflector blocks are constructed of grade ETU-10 graphite. The reflector blocks provide a heat sink for the core and are restrained ensuring alignment of the penetrations to insert and withdraw control elements. The reflector blocks are buoyant in the reactor coolant. The top surface of the reflector blocks contacts the vessel top head hold-down structure sub-assembly which provides structural support against upward loads during normal operation and most postulated events. A secondary hold-down structure is installed through the upper reflector layers to transfer upward loads from submerged graphite to the vessel top head during postulated air ingress events. The bottom reflector blocks are machined with coolant inlet channels for distribution of coolant inlet flow into the core. The top reflector blocks are machined with coolant outlet channels to direct the coolant exiting from the core into the upper plenum, from which the PSP draws suction. The top reflector blocks also form a pebble defueling chute, as shown in Figure 4.3-1, to direct the pebbles from the core to the pebble extraction machine (PEM), allowing online defueling of the reactor (see Section 9.3). The reflector blocks also provide machined channels for insertion and withdrawal of the reactivity control and shutdown elements described in Section 4.2.2.

The reflector blocks form an upper plenum and a fluidic diode, which is a stainless-steel passive device that connects the upper plenum to the top of the downcomer as shown in Figure 4.3-1. The diode introduces a higher flow resistance in one direction, while having a lower flow resistance in the other direction. The diode restricts flow from the higher-pressure downcomer into the upper plenum during conditions with forced circulation. The flow passes in the low-resistance direction of the diode from the upper plenum to the top of the downcomer driven by natural circulation.

The graphite reflector blocks reflect neutrons back into the core, increasing the fuel utilization while protecting the reactor vessel from fluence based forms of degradation. Further discussion of the reflector’s neutronic characteristics are detailed in Section 4.5.

4.3.1.2.2 Core Barrel

The 316H SS core barrel creates an annular space between itself and the reactor vessel and defines the downcomer flow path for the coolant. The core barrel has a flanged top which is welded to the inner wall of the vessel shell. The barrel is kept concentric to the shell by radial tabs which allow for differential thermal expansion.

4.3.1.2.3 Reflector Support Structure

The 316H SS reflector support structure, as shown in Figure 4.3-1, defines the flow path from the downcomer annulus into the core as well as provides support to the graphite reflector blocks. The reflector support structure ensures a stable core configuration for all conditions (e.g., reactor trip and core motion) by controlling the radial and circumferential positions of the reflector blocks.

4.3.2 Design Basis

Consistent with PDC 1, the safety-related portions of the reactor vessel and reactor vessel internals are fabricated and tested in accordance with generally recognized codes and standards.

Consistent with PDC 2, the reactor vessel and reactor vessel internals perform their safety functions in the event of a safe-shutdown earthquake and other natural phenomena hazards.

Consistent with PDC 4, the reactor vessel and reactor vessel internals accommodate the environmental conditions associated with normal operation, maintenance, testing, and postulated events.

Consistent with PDC 10, the reactor vessel and internals maintain a geometry and coolant flow path to ensure that the specified acceptable system radionuclide release design limits (SARRDLs) will not be exceeded during normal operation including postulated events.

Consistent with PDC 14, the reactor vessel is fabricated and tested to have an extremely low probability of abnormal leakage or sudden failure of the reactor coolant boundary by gross rupture.

factors up to a temperature of 650°C for ER16-8-2 weld metal with 316H base metal. Testing provides stress rupture factors up to 816°C for weld material with 316H base metal (Reference 3). The plant control system will detect leakage from the reactor vessel and catch basins are used to detect leaks in nearby coolant-carrying systems. These features demonstrate compliance with PDC 30.

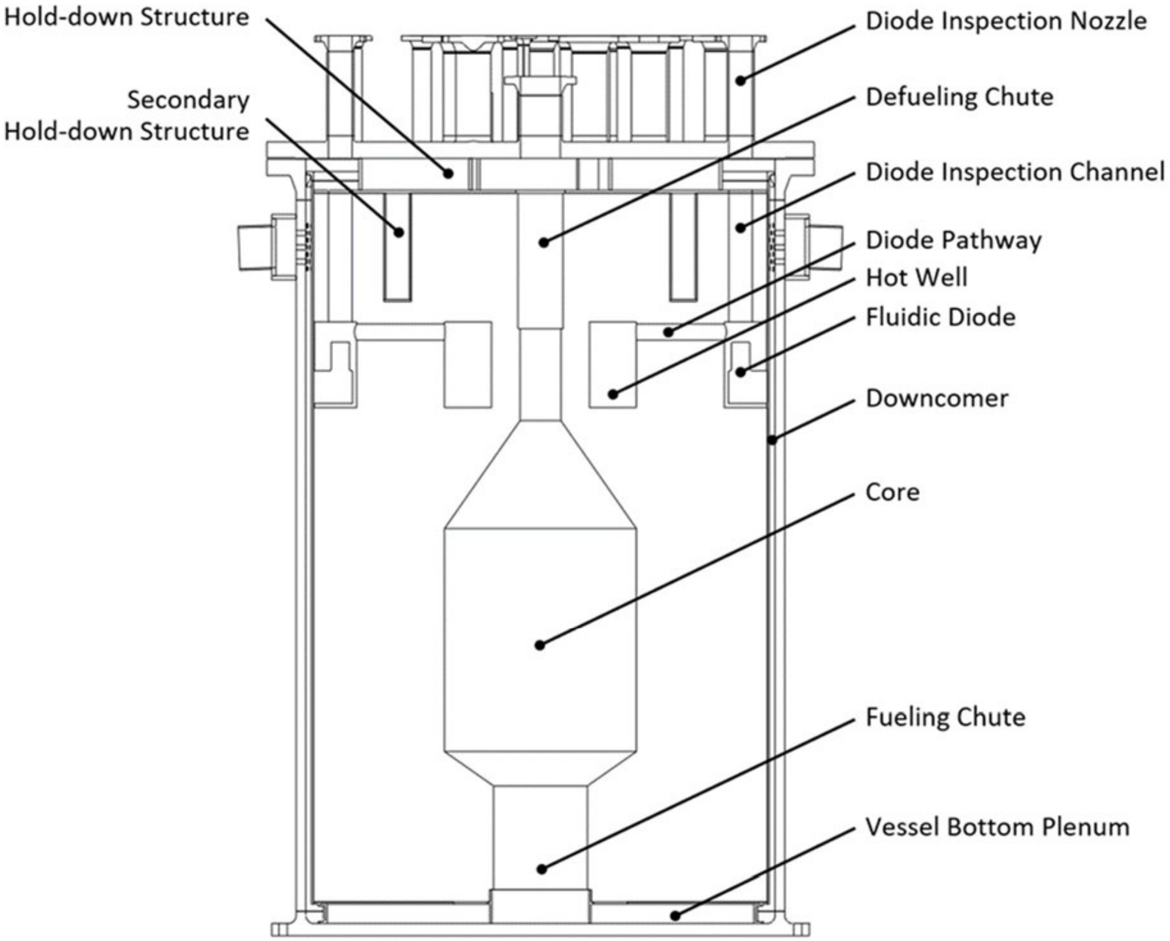
Reactor vessel stress rupture factors are determined up to 816°C to encompass transient conditions. The stress rupture factors are determined by a creep-rupture test on the vessel base material with weld metal under the gas tungsten arc welding process. The vessel precludes material creep, fatigue, thermal, mechanical, and hydraulic stresses. The leak tight design of the reactor vessel head minimizes air ingress into the cover gas and precludes corrosion of the internals. The high temperature, high carbon grade 316H SS of the core barrel and reflector support structure have high creep strength and are resistant to radiation damage, corrosion mechanisms, thermal aging, yielding, and excessive neutron absorption. Vessel fluence calculations, as described in Section 4.5, confirm adequate margin relative to the effects of irradiation. The fast neutron fluence received by the reactor vessel from the reactor core and pebble insertion and extraction lines is attenuated by the core barrel, the reflector, and the reactor coolant. Coolant purity design limits are also established in consideration of the effects of chemical attack and fouling of the reactor vessel. These features demonstrate conformance with PDC 31.

The MSS utilizes coupons and component monitoring to confirm that irradiation-affected corrosion is non-existent or manageable. The 316H SS reactor vessel and ER16-8-2 weld material, as a part of the reactor coolant boundary, will be inspected for structural integrity and leak-tightness. As detailed in Reference 3, fracture toughness is sufficiently high in 316H SS under reactor operating conditions that additional tensile or fracture toughness monitoring and testing programs are unnecessary. These features demonstrate conformance to PDC 32.

Fluidic diodes are used to establish a flow path for continuous natural circulation of coolant in the core during postulated events to remove residual heat from the reactor core to the vessel wall. During and following a postulated event, the hot coolant from the core flows from the upper plenum through the low flow resistance direction of the fluidic diode to the cooler downcomer via natural circulation, thereby cooling the core passively. Continuous coolant flow through the reactor core prevents potential damage to the vessel internals due to overheating thereby ensuring the coolable geometry of the core is maintained. The anti-siphon feature also limits the loss of reactor coolant inventory from inside the reactor vessel in the event of a PHTS breach. These features demonstrate compliance with PDC 35.

The reactor vessel reflector blocks permit insertion of the reactivity control and shutdown elements. The ETU-10 grade graphite of the reflector blocks is compatible with the reactor coolant chemistry and will not degrade due to mechanical wear, thermal stresses and irradiation impacts during the reflector block lifetime. The graphite reflector material is qualified as described in the Kairos Power topical report “Graphite Material Qualification for the Kairos Power Fluoride Salt-Cooled High-Temperature Reactor,” KP-TR-014 (Reference 4). To preclude damage to the reflector due to entrained moisture in the graphite, the reflector blocks are “baked” (i.e., heated uniformly) prior to coming into contact with coolant~~ and the reactor vessel is design to preclude air ingress~~. The reflectors, which act as a heat sink in the core, are spaced to accommodate thermal expansion and hydraulic forces during normal operation and postulated events. The gaps between the graphite blocks also allow for coolant to provide cooling to the reflector blocks. The reactor vessel permits the insertion of the reactivity control and shutdown elements as well. The vessel is classified as SDC-3 per ASCE 43-19 and will maintain its geometry to ensure the RCSS elements can be inserted during postulated events including a design basis earthquake. These features demonstrate compliance with PDC 74.

Figure 4.3-3: The Reactor Vessel System Secondary Hold-Down Structure



5.1.3 System Evaluation

The design of the nonsafety-related PHTS is such that a failure of components of the PHTS does not affect the performance of safety-related SSCs due to a design basis earthquake. In addition to protective barriers, the PHTS pipe connections to the reactor vessel nozzles have sufficiently small wall thickness, such that if loaded beyond elastic limits, inelastic response occurs in the PHTS piping which is nonsafety-related. These features, along with the seismic design described in Section 3.5, demonstrate conformance with the requirements in PDC 2 for the PHTS.

While the PHTS is a closed system, there are conceivable scenarios that may result in the release of radioactive effluents. The fuel design locates the fuel particles near the periphery of the fuel pebble, enhancing the ability of the fuel to transfer heat to the coolant. The thermal hydraulic analysis of the core (see Section 4.6) ensures that adequate coolant flow is maintained to ensure that SARRDLs, as discussed in Section 6.2, are not exceeded. These features demonstrate conformance with the requirements in PDC 10.

The design of the reactor coolant, in part, ensures that power oscillations cannot result in conditions exceeding SARRDLs. The reactor is kept near ambient pressure and the reactor coolant in the PHTS does not experience two phase flow. The coolant has a high thermal inertia making the reactor resilient to thermal-hydraulic instability events. These features, in part, demonstrate conformance with the requirements in PDC 12.

The functional containment is described in Section 6.2. The design relies primarily on the multiple barriers within the TRISO fuel particles to ensure that the radiological dose at the exclusion area boundary as a consequence of postulated events meets regulatory limits. However, the reactor coolant also serves as a distinct physical barrier for fuel submerged in Flibe by providing retention of fission products that escape the fuel. The design of the reactor coolant composition provides, in part, a means to control the accidental release of radioactive materials during normal reactor operation and postulated events (PDC 60), and supports, in part, demonstration of the functional containment aspects. The design aspects of the reactor coolant are discussed in Reference 5.1.5-1. The Flibe also accumulates radionuclides from fission products, and transmutation products from the Flibe and Flibe impurities. The retention properties of the Flibe are credited in the safety analysis as a barrier to release of radionuclides accumulated in the coolant, and radionuclide cor specifications. The transport of radionuclides through Flibe is b justified in the application for an Operating License. These feat requirements in PDC 16.

Highlighted text was previously changed. Submitted 2-18-22 (ML22049B556)

Significant forced air ingress into the PHTS is excluded by design basis. Air ingress could affect the inventory of reactor coolant in the reactor vessel as well as affect the purity of the reactor coolant. Design features of the heat rejection subsystem and the reactor trip system will limit the quantities of air ingress during system leakage events by tripping the heat rejection blowers and tripping the PSP. These design features satisfy PDC 33 and PDC 70. The effects of non-forced air ingress into the PHTS on safety-related Hermes components are bounded by the results of materials qualification programs as described in Section 4.3.

The design of the PHTS controls the release of radioactive materials in gaseous and liquid effluents in the event the PHTS working fluid is inadvertently released to the atmosphere via leaks in the piping system. The PHTS SSCs that are part of the reactor coolant boundary are designed to the ASME B31.3 Code (for the piping) and Section VIII (for the PHX) such that leaks are unlikely. Means are provided for detecting and, to the extent practical, identifying the location of the source of reactor coolant leakage in the PHTS SSCs. A postulated event in the PHTS would be a PHX tube failure. This event would cause Flibe ensure there is no recriticality after the RCSS has initiated shutdown, as described in Section 4.5. Additionally, the graphite reflector blocks are designed to maintain structural integrity and ensure misalignments do not prevent the insertion path of the shutdown elements, as discussed in Section 4.3.

13.1.10.2 Degraded Heat Removal or Uncooled Events

In postulated events where the normal heat rejection is not available, natural circulation in the reactor vessel and the heat removal function of the DHRS are relied upon to remove heat from the reactor core. Degraded heat removal or uncooled events are excluded from the design basis. The initiation of natural circulation is completely passive, and the design features, including the structural integrity of the reactor vessel internals, that ensure a continued natural circulation flow path are discussed in Section 4.6. The DHRS is aligned and operating when the reactor power is above a threshold power and remains in this state as described in Section 6.3, precluding the need for an actuation to occur for the DHRS to remove heat during a postulated event. The DHRS design includes sufficient redundancy to perform its safety function assuming the loss of a single train, as discussed in Section 6.3.

13.1.10.3 Flibe Spill Beyond Maximum Volume Assumed in Postulated Salt Spills

In the salt spill postulated event category, an upper bound volume of Flibe is assumed to spill out of the PHTS onto the floor. A volume of Flibe spilling out of the system beyond the amount assumed in the bounding salt spill event is excluded from the design basis. There are several design features ensuring the amount of Flibe available to spill is limited to an upper bound value. The reactor vessel is designed with anti-siphon features discussed in Section 4.3. These features are designed to passively break the siphon in the event of a break. The PSP also trips to allow the primary system to depressurize. The reliability of the RPS, which trips the PSP and ISP in the event of a salt spill, is discussed in Section 7.3. The reactor vessel shell also maintains integrity in postulated events to ensure the fuel in the core remains covered with Flibe. The reactor vessel shell design features that prevent leakage are discussed in Section 4.3.

13.1.10.4 In-Service TRISO Failure Rates and Burnups Above Assumptions in Postulated Events

The in-service fuel failure rates and the burnup of pebbles assumed in the postulated events are based on the fuel qualification specifications in Section 4.2.1. In-service TRISO failure rates above the rate assumed in postulated events are excluded from the design basis. The insertion of pebbles with a burnup higher than the fuel qualification envelope is excluded from the design basis. As described in Section 7.3, the RPS includes a function to stop the pebble insertion and extraction functions to ensure pebbles are not damaged in faults occurring after an event initiation. The fuel qualification program includes testing, inspection, and surveillance to ensure the fuel operating envelope is within the fuel qualification envelope. Inspection and surveillance of the fuel in service is performed in the PHSS as discussed in Section 9.3.

Highlighted text was previously changed. Submitted 2-18-22 (ML22049B556)

13.1.10.5 Significant ~~Intermediate Coolant~~ Air Ingress Into PHTS

Events where significant quantities of air are entrained in the PHTS coolant during normal operation are excluded from the design basis. Operational controls are expected to monitor the quantity of air within the PHTS to prevent accumulating significant quantities. Chapter 14 discusses the expected coolant systems technical specifications that monitor significant air ingress.

Events where significant quantities of forced air enter the PHTS following postulated HRR tube break events are also excluded from the design basis. Chapter 5 discusses the design features of the HRR that

Highlighted text was previously changed. Submitted 2-18-22 (ML22049B556)

limits the quantities of forced air ingress during salt spill transients.~~The pos~~ ~~positive pressure differential between the primary and intermediate coolant systems. Events where significant quantities of intermediate coolant enter the PHTS are excluded from the design basis. Chapter 5 discusses the design features of the PHTS and PHRS that maintain a positive pressure differential.~~

The effects of non-forced air ingress on reactor vessel and vessel internal components will remain bounded by the materials qualification testing programs for at least seven days during air ingress events as described in Section 4.3. Beyond seven days, defense in depth strategies include: implementing repairs on damaged SSCs, replenishing the argon supply, and removal of fuel from the vessel (fuel core offload capability discussed in Section 9.3.1.8.3).

13.1.10.6 DHRS Reactor Cavity Flooding

The DHRS is a water-based system that removes heat from the reactor vessel shell. Events where the water from the DHRS leaks into the reactor cavity in quantities significant enough to wet the reactor vessel are excluded from the design basis. Leak prevention, including double walled components and leak detection, for the DHRS is described in Section 6.3.

13.1.10.7 Insertion of Excess Reactivity Beyond Rate Assumed in Postulated Events

The insertion of excess reactivity postulated event category includes a limiting reactivity insertion rate based on the maximum control element drive withdrawal rate. Multiple control elements moving simultaneously is excluded from the design basis. Control element movement is limited to one element at a time, as described in Section 7.2. A control element withdrawing faster than the limit is excluded from the design basis. The maximum drive withdrawal speed is limited by the drive hardware, as described in Section 4.2.2. A rapid control element ejection is excluded from the design basis because the reactor operates at low pressures.

The insertion of reactivity due to an overcooling event is also bounded by the limiting reactivity insertion rate. Core cooling due to pump overspeed from the PSP, ISP, or PHRS blower are limited to a maximum limit within the programmed normal operating range discussed in Section 7.2.

13.1.10.8 Criticality Occurrence External to Reactor Core

Pebbles outside of the reactor core are contained in the PHSS. The PHSS includes pebbles in transit during handling, in storage, and in a transport configuration. The PHSS is designed to preclude criticality assuming postulated event conditions using design features that maintain a non-critical geometry of pebbles in each of these areas. The design features of PHSS preventing criticality are described in Section 9.3.

13.1.10.9 Excessive Radionuclide Release from Flibe

The postulated events assume a release of radionuclides from the free surfaces of Flibe. The assumed release of radionuclides from Flibe could be affected by the characteristics of the cover gas such as a higher pressure affecting the cover gas flow or the purity of the cover gas affecting the radionuclides available for release. The cover gas is maintained by the inert gas system, described in Section 9.1.2.

13.1.10.10 Internal or External Events Interfering with SSCs

SSCs that perform safety functions are located in a portion of the reactor building designed to preclude damage from both internal and external hazards that could interfere with those functions. Additionally, SSCs containing Flibe are protected from internal floods to preclude the potential for Flibe – water interactions. The failure of safety functions due to internal or external hazards is excluded from the

5.3 OXIDATION OF GRAPHITE

In a KP-FHR, most of the structural graphite components are immersed in Flibe molten salt,~~ where air oxidation does not occur~~. The top reflector above the molten salt is protected by the Argon cover gas, as discussed in Section 1.1.3. The density of Argon gas is ~25% higher than that of oxygen (Ar, 0.492 kg/m^3, O_2, 0.393 kg/m^3, at 700°C, 1 bar). In normal operating conditions, Ar gas naturally acts as a protection layer above the top reflector in the event that trace amounts of air enters the Ar gas. Therefore, oxidation in normal operating conditions is not expected.

In the event that air leaks into the cover gas, oxidation may occur at the top of the reflector that is not immersed in Flibe molten salt. In addition, oxidation may also occur in the graphite reflector materials that are immersed in Flibe. [[

]].

The main concern with the graphite oxidation is a potential loss of the strength. Kairos Power will conduct a design-specific analysis to demonstrate that the weight loss due to oxidation does not challenge a design limit for the reflector structure. The results of the analysis would be provided in an application for an operating license.

The assessment of the effect of oxidation on graphite strength will be conducted separately in the safety analysis program. For exposed graphite not submerged in Flibe, this ~~which~~ involves two major tasks: (1) determine the weight loss of graphite under the postulated event conditions; (2) determine the strength reduction due to the oxidation. The ~~major tasks included~~ steps to accomplish these tasks are highlighted below.

1. Determine basic oxidation characteristics of ET-10, e.g., rate of oxidation per ASTM D7542.
2. Determine the effective gas diffusivity of ET-10.
3. The parameters obtained from Task #1 and #2 will be fed into a newly developed model by INL to generate the oxidation depth profile and weight-loss profile.
4. As confirmation and model validation, the weight loss value will be obtained experimentally. The oxidation temperature and duration will bound the conditions determined by the safety analysis. Kairos Power's early estimate is that testing will start by using a temperature of 750°C and a duration of 3 days. The safety analysis scenario definition will account for cover gas supply.
5. Determine strength reduction based on the relationship between strength and weight-loss, which will be established for ET-10 grade graphite through the testing program. The planned temperature range is 550 – 750°C (Kinetic regime).

For the assessment of graphite submerged in Flibe, where there is air ingress in the cover gas under postulated event conditions, the two major tasks are: (1) determine if there is oxidation by observing porosity or density change; (2) if there is significant oxidation by porosity or density change, as compared to air oxidation experiments, then determine the strength reduction due to oxidation. The steps to accomplish these tasks are highlighted below.

1. Determine the changes in porosity or density due to oxidation of graphite submerged in Flibe.
2. If oxidation is significant, then demonstrate the structural integrity bounds the effects of oxidation.

To assess the structural integrity of the ~~top~~ reflector due to the oxidation, stress levels experienced by the top reflector blocks will be compared to the material's strength values and, if applicable, relevant ASME allowable stress limits. The elastic modulus of unoxidized graphite will be used to predict internal stresses. This is conservative because the elastic modulus will decrease due to the oxidation, which means that using the elastic modulus value corresponding to unoxidized graphite will lead to higher predicted stress levels in modeling.

Thermal conductivity will also decrease as a result of oxidation. However, KP-FHR does not rely on the top reflector for heat dissipation (to cover gas). The design is based on an adiabatic thermal boundary condition between top reflector and cover gas, where oxidation may occur in the event of air ingress. Therefore, the decrease of thermal conductivity of graphite at the top reflector is not a factor impacting its safety function. Thermal conductivity is not expected to be significantly affected due to oxidation in the submerged graphite. Kairos Power will not measure the thermal conductivity of the oxidized graphite in the qualification program.

In summary, for normal operation, oxidation is not expected for the structural graphite ET-10 because the material is in an inert environment. This can be confirmed in future license applications which will contain design details for the Cover Gas System. In postulated event conditions safety analysis will characterize the potential and quantity of air ingress. ~~Air ingress would only affect the oxidation of the top portion of the reflector.~~ Testing will quantify the reduction in strength in postulated event conditions for the ~~top of the~~ reflector based on the inputs from the safety analysis and the data from INL correlating graphite strength change with weight loss.