**Enclosure 2**
**Response to NRC Request for Additional Information 339**
**(Non-Proprietary)**

# NRC Request for Additional Information

## RAI Package 339, Question 399

*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 systems, structures, and components (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 principal design criteria for the Hermes test reactor. KP-FHR PDC 32, "Inspection of the reactor coolant boundary," describes requirements to inspect portions of the reactor coolant boundary. The basis for this PDC states that "…the potential for flow blockages/restriction from failed internals (such as graphite reflector blocks) is addressed as part of compliance with PDC 35, 36, and 37, including inspections if appropriate." This indicates that the requirements of PDCs 35, 36, and 37 are applicable to vessel internals as well as other components in the residual heat removal system. PDC 36 states that "[t]he passive residual heat removal system shall be designed to permit appropriate periodic inspection of important components to ensure integrity and capability of the system."*

*Hermes PSAR, Section 4.3, "Reactor Vessel System," describes SSCs which are needed to maintain the passive residual heat removal path. This pathway is essential to ensure adequate cooling during postulated events where the primary heat transport and primary heat rejection systems are not available. As such, it is vital that adequate measures be available to assure that the natural circulation flow path will be available if called upon in a postulated event. Section 4.3.3, "System Evaluation," of the PSAR describes how the components in the reactor vessel system meet specific PDCs. However, it does not describe how certain components meet PDC 36. Based on information discussed during the General Audit, the staff understands that the vessel head will have four inspection ports and that Kairos has proposed to confirm the capability of the flow path during operation by monitoring temperature and flow. The staff has the following questions:*

1. *Provide a detail drawing of the natural flow path in the regions above the core.*
2. *It appears that a potential failure of graphite reflector blocks (e.g., debris, geometry changes, etc.) could cause flow blockages or restrictions of the natural circulation flow path. Where can the flow path be inspected versus where would it need to be verified with flow and temperature monitoring? Can all of the natural circulation flow path that isn't part of forced circulation flow path be inspected?*
3. *Will flow and temperature monitoring be used to verify the functionality of the relatively stagnant natural circulation flow path during normal (pumped) operation? Will flow and temperature monitoring identify the cause of an off-normal condition and the location of potential issues with SSCs? If so, please describe how these will be accomplished.*
4. *Provide the number of fluidic diodes in the Hermes design. In the case of failure of one or more fluidic diodes, how many are needed for adequate passive heat removal?*

# Kairos Power Response

## NRC Question 399, Item 1

*Provide a detail drawing of the natural flow path in the regions above the core.*

Figure 1 (provided with this response) shows the natural circulation flow path in the graphite structures above the core.

## NRC Question 399, Item 2

*It appears that a potential failure of graphite reflector blocks (e.g., debris, geometry changes, etc.) could cause flow blockages or restrictions of the natural circulation flow path. Where can the flow path be inspected versus where would it need to be verified with flow and temperature monitoring? Can all of the natural circulation flow path that isn't part of forced circulation flow path be inspected?*

The physical geometry of the reactor coolant natural circulation flow path within the reactor vessel consists of the following: the downcomer, the vessel bottom plenum formed by the reflector support structure, graphite reflector blocks, and the fluidic diodes. The downcomer, reflector support structure, graphite reflector, and fluidic diode are designed to maintain their structural integrity during postulated events to maintain a natural circulation path and coolable core geometry to support removal of decay heat. Functional capability of the downcomer and graphite reflector is assured by design because the reactor vessel internals are qualified in accordance with Reference 1 and Reference 2. The vessel and internals are also designed to perform their function during seismic events per Reference 3.

The downcomer, as described in Section 4.3.1.2.2, is an annular coolant flow pathway between the vessel and the core barrel. Flow from the downcomer moves through the reflector support structure and into the reflector block coolant inlet channels. The graphite reflector block structures are machined to form a physical geometry for reactor coolant to pass through as described in Section 4.3.1.2.1 of the Preliminary Safety Analysis Report (PSAR). The physical geometry created within the graphite structures that form the reactor coolant natural circulation flow path includes the core, coolant channels, annular hot well, and diode pathway. This natural circulation flow path is clarified in Figure 1, as well as the attached changes to PSAR Section 4.3.1.2.1, Section 4.3.3, Figure 4.3-1 and Figure 4.6-1.

During normal (pumped) operation, a small amount of flow bypasses the pebble bed through the graphite reflector structures, diode pathway, and fluidic diode. Changes in bypass flow through the fluidic diode during normal operation are inferred by temperature monitoring. The temperature monitoring across the fluidic diode provides assurance that flow is not stagnant in this portion of the natural circulation flow path.

Failures of internal graphite components, including fuel pebbles, are not likely during normal plant operation or postulated events. The pebble handling and storage system (PHSS), described in Section 9.3.1.5 of the PSAR, is designed to inspect pebbles to prevent damaged pebbles from entering the reactor. The PHSS is also designed to remove buoyant debris and filter debris-carrying coolant as described in Section 9.3.1.2 of the PSAR. As stated above, the graphite reflectors are qualified in accordance with Reference 1, therefore gross structural damage to the reflector blocks is precluded by design. Fuel pebbles are qualified in accordance with Reference 4, therefore gross failure of pebbles that will result in large debris, is precluded by design. The only graphite debris present in the system would be a result of normal wear (e.g., graphite dust).

Most of the natural circulation flow path is the same as the normal flow path and significant flow obstructions would be noticeable during normal (pumped) operations. Portions of the pathway that are unique to natural circulation include the fluidic diode pathway and fluidic diode. The fluidic diode may be visually inspected using inspection ports on the reactor vessel head. Although the diode pathway cannot be visually inspected, reactor coolant temperature is monitored. Reactor coolant temperature monitoring provides an indication of flow through the flow pathway during normal operation and provides assurance that the natural circulation flow pathway is available. Direct flow monitoring capability is not included in the design to assess the condition of the natural circulation flow path. PSAR Section 4.3.1, 4.3.2, Section 4.3.3, Table 4.3-1, Figure 4.3-1, and Figure 4.3-2 have been updated to reflect the capability for fluidic diode pathway monitoring and fluidic diode inspections.

## NRC Question 399, Item 3

*Will flow and temperature monitoring be used to verify the functionality of the relatively stagnant natural circulation flow path during normal (pumped) operation? Will flow and temperature monitoring identify the cause of an off-normal condition and the location of potential issues with SSCs? If so, please describe how these will be accomplished.*

Much of the natural circulation flow path is the same as the normal circulation flow path and flow is not considered "relatively stagnant." As discussed in the response to Item 2, the bypass flow through the fluidic diode pathway, fluidic diode, and graphite structures provides assurance that flow is not stagnant in the natural circulation flow path. Although flow monitoring will not be used to verify functionality of the natural circulation flow path during normal (pumped) operation, temperature monitoring is used to confirm flow is occurring in these areas and demonstrates the functional capability of the natural circulation flow path during normal (pumped) operation as described in the response to Item 2.

Temperature monitoring will not identify the potential causes of an off-normal condition. However, temperature monitoring can be used to identify the location of potential issues by detecting unexpected changes in plant parameters as compared to expected values.

## NRC Question 399, Item 4

*Provide the number of fluidic diodes in the Hermes design. In the case of failure of one or more fluidic diodes, how many are needed for adequate passive heat removal?*

The Hermes design includes four fluidic diodes. Preliminary analyses have been performed and show that the Hermes design contains adequate heat removal with at least 25% reduction in total diode flow path area, which would indicate that the failure of one diode would still allow adequate flow for heat removal with margin. Section 4.3.1.2.1 of the PSAR has been updated to reflect the number of fluidic diodes in the Hermes design as shown in the attached markup.

## References:

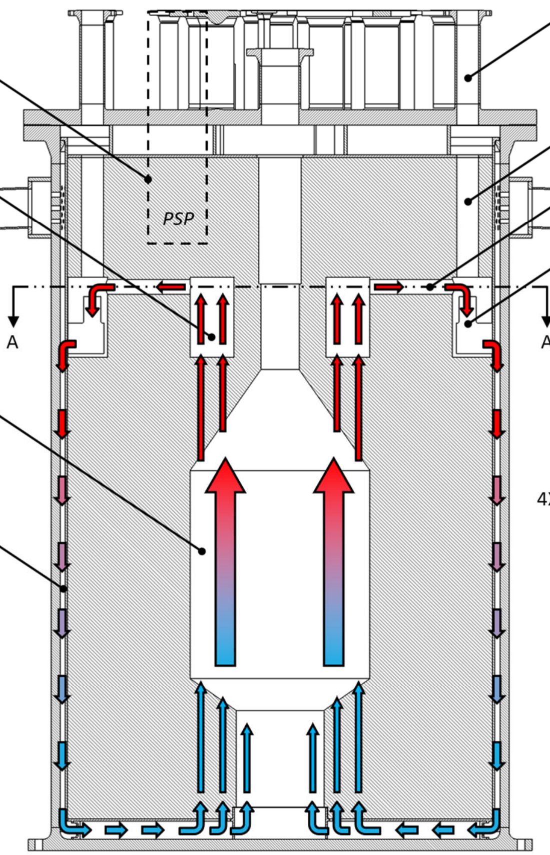
1. Kairos Power LLC, "Graphite Material Qualification for the Kairos Power Fluoride Salt-Cooled High-Temperature Reactor," KP-TR-014-P, Revision 3.

2. Kairos Power LLC, "Metallic Materials Qualification for the Kairos Power Fluoride Salt-Cooled High-Temperature Reactor," KP-TR-013-P, Revision 3
3. ASCE 43-19, "Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities."
4. Kairos Power LLC, "Fuel Qualification Methodology for the Kairos Power Fluoride Salt-Cooled High Temperature Reactor (KP-FHR)," KP-TR-011-P, Revision 2

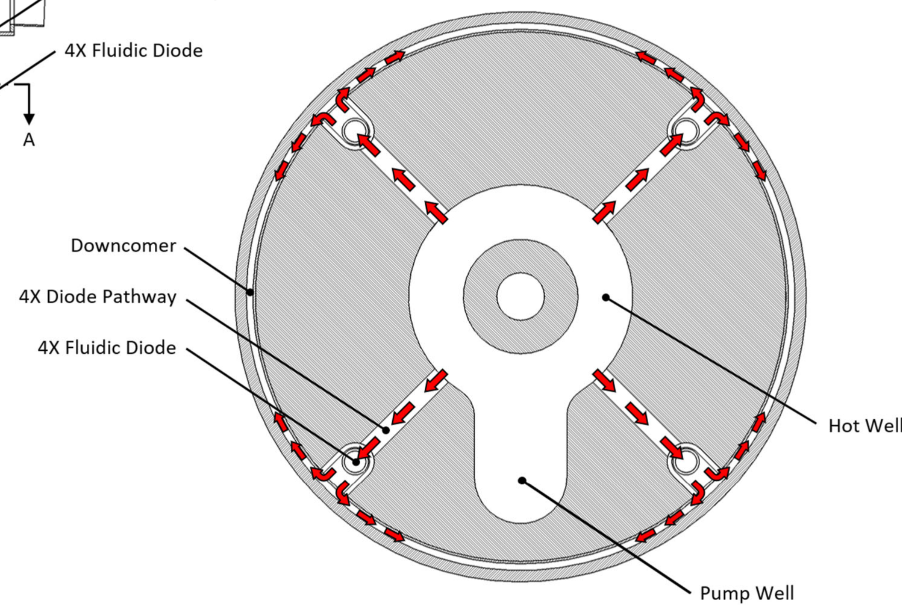

## Impact on Licensing Document:

This response impacts Sections 4.3.1, 4.3.1.1.1, 4.3.1.2.1, 4.3.2, 4.3.3, 4.3.5, 4.6.1.2, 4.6.3, Table 4.3-1, Figure 4.3-1, Figure 4.3-2, and Figure 4.6-1 of the Kairos Power Preliminary Safety Analysis Report. A markup of the affected sections is provided with this response.

Figure 1




*Natural Circulation Path*




*Section A-A*

| Principal Design Criteria | SAR Section |
|---|---|
| PDC 26, Reactivity control systems | 4.2.2<br>4.5 |
| PDC 28, Reactivity limits | 4.2.2, 7.3 |
| PDC 29, Protection against anticipated operation occurrences | 4.2.2, 7.3, 7.5 |
| PDC 30, Quality of reactor coolant boundary | 4.3 |
| PDC 31, Fracture prevention of reactor coolant boundary | 4.3 |
| PDC 32, Inspection of reactor coolant boundary | 4.3 |
| PDC 33, Reactor coolant inventory maintenance | 9.1.4 |
| PDC 34, Residual heat removal | 4.3, 4.6, 6.3 |
| PDC 35, Passive residual heat removal | 4.3, 4.6, 6.3 |
| PDC 36, Inspection of passive residual heat removal system | 4.3, 6.3 |
| PDC 37, Testing of passive residual heat removal system | 4.3, 6.3 |
| PDC 44, Structural and equipment cooling | 9.1.5, 9.7 |
| PDC 45, Inspection of structural and equipment cooling systems | 9.1.5, 9.7 |
| PDC 46, Testing of structural and equipment cooling systems | 9.1.5, 9.7 |
| PDC 60, Control of releases of radioactive materials to the environment | 5.1, 9.1.3, 9.2, 11.2 |
| PDC 61, Fuel storage and handling and radioactivity control | 9.3 |
| PDC 62, Prevention of criticality in fuel storage and handling | 9.3 |
| PDC 63, Monitoring fuel and waste storage | 9.3, 11.2 |
| PDC 64, Monitoring radioactivity releases | 9.1.2, 9.1.3, 9.2 |
| PDC 70, Reactor coolant purity control | 9.1.1 |
| PDC 71, Reactor coolant heating systems | 9.1.5 |
| PDC 73, Reactor coolant system interfaces | 5.2 |

## 4.3 REACTOR VESSEL SYSTEM

### 4.3.1 Description

This section provides an overview of the reactor vessel system (see Figure 4.3-1) which includes the reactor vessel and the reactor vessel internals. The reactor vessel forms a major element of the reactor coolant boundary and the inert gas boundary. The reactor vessel and vessel internals define the flow path for reactor coolant and fuel into the core. The reactor vessel system contains the reactor core and provides for circulation of reactor coolant and pebbles as well as insertion of the reactivity control and shutdown elements through the reactor core.

The reactor vessel system provides a flow path for reactor coolant to transfer heat from the reactor core to the primary heat transport system (PHTS) during normal operations. The reactor coolant enters the reactor vessel through two side inlet nozzles and flows downward through a downcomer annulus formed between the metallic core barrel and the reactor vessel shell. Coolant flow moves through the vessel bottom plenum formed by the reflector support structure and is distributed into the core by the design of the reflector blocks. Upon exiting the core, the coolant leaves the reactor vessel via the primary salt pump (PSP) (see Section 5.1.1) which draws suction directly from a pool of reactor coolant above the core and inside the vessel. An anti-siphon feature is provided to limit loss of vessel inventory in the event of a break in the PHTS.

The reactor vessel system also provides a flow path for pebbles to allow online refueling and defueling of the reactor core by the pebble handling and storage system (PHSS) (Section 9.3) during normal operation. The PHSS inserts pebbles into the reactor vessel and delivers them to the fueling chute below the reactor core by the pebble insertion line (Section 9.3.1). The buoyant pebbles float upward, and pebbles inserted via the insertion line will join the packed pebble-bed in the reactor core. Upon circulating through the core, the pebbles accumulate in the de-fueling chute at the top of the reactor core. The pebble extraction machine (PEM) (Section 9.3.1) at the top of the reactor core removes pebbles from the reactor vessel (see Figure 4.3-2.)

During postulated events when the PHTS and the primary heat rejection system (PHRS) are not available, the reactor vessel provides an alternative flow path as discussed in Section 4.6.1 to allow natural circulation of the reactor coolant to remove heat from the reactor core. The reactor coolant leaving the core flows into the hot well, fluidic diode pathway, fluidic diode, through a core barrel penetration and back into the downcomer annulus~~-~~ as shown in Figure 4.3-1~~via fluidic diodes~~. The heat from the core is transferred to the reactor vessel shell which transfers the heat to the decay heat removal system (DHRS) (Section 6.3).

The reactor vessel system interfaces with fuel (Section 4.2.1), primary heat transport system (PHTS) (Section 5.1), reactivity control and shutdown system (RCSS) (Section 4.2.2), reactor vessel support system (RVSS) (Section 4.7), decay heat removal system (DHRS) (Section 6.3), pebble handling and storage system (PHSS) (Section 9.3), reactor thermal management system (RTMS) (Section 9.1.5), inert gas system (IGS) (Section 9.1.2), inventory management system (IMS) (Section 9.1.4), and instrumentation and controls (Chapter 7).

#### 4.3.1.1 Reactor Vessel

The reactor vessel is a vertical cylinder design with flat top and bottom heads. The vessel houses the reactor vessel internals. The reactor vessel shell and bottom head provide a major element of the reactor coolant boundary. The vessel is constructed of 316H stainless steel (SS) with ER16-8-2 weld metal and is designed and fabricated per ASME BPVC Section III, Division 5 (Reference 1). It contains the inventory of reactor coolant such that the reactor core is covered by the coolant during normal operation and postulated event. There are no penetrations or attachments to the vessel below the 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.

##### 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 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, which includes the hot well, and the PSP pump well, 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 a~~n upper plenum and a~~ hot well and pathways to each of four fluidic diodes.~~, which~~ The fluidic diodes ~~is a~~are stainless-steel passive devices that connect~~s~~ the ~~upper plenum~~ hot well via the pathway to the top of the downcomer via a penetration in the core barrel 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~~hot well during normal plant operating conditions with forced (pumped) circulation. During natural circulation, t~~T~~he flow passes in the low-resistance direction of the diode from the ~~upper plenum~~hot well to the top of the downcomer~~ driven by natural circulation~~. Nozzles on the reactor vessel head and diode inspection channels in the upper reflector block structure are used to perform remote visual inspections of the fluidic diodes.

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.

Consistent with PDC 30, reactor vessel is fabricated, and tested to quality standards, and pre- and in-service inspections, as well as testing where practicable, will be used to detect and identify the location of coolant leakage.

Consistent with PDC 31, the reactor vessel has sufficient margin to withstand stresses under operating, maintenance, testing, and postulated events such that the reactor coolant boundary does not degrade due to the effects of neutron embrittlement, corrosion, material wear, fatigue, stress rupture, thermal loads, or failure due to stress rupture and fracture. The design shall account for residual, steady-state, and transient stresses and consider flaw size.

Consistent with PDC 32, the reactor vessel permits inspection, monitoring, or functional testing of important areas and features to assess structural integrity and leak-tightness of the safety-related portions of the reactor coolant boundary.

Consistent with PDC 34, the flow path established by the reactor vessel internals is designed to support the removal of decay heat during normal operation and postulated events, such that SARRDLs and the design conditions of the safety-related elements of the reactor coolant boundary are not exceeded.

Consistent with PDC 35, the reactor vessel internals are designed to maintain structural integrity to ~~will~~ assure sufficient core cooling during postulated events and to support removal of~~e~~ ~~residual~~ decay heat. The safety function of the fluidic diode, reflector blocks, and downcomer is to ~~provide~~ maintain a flow path ~~via~~ that supports natural circulation ~~to~~ and transfer heat from the reactor core during and following postulated events ~~such that~~ to prevent fuel and reactor internal structure damage that could interfere with continued effective core cooling ~~is prevented~~.

Consistent with PDC 36 and PDC 37 the fluidic diodes are designed to permit periodic monitoring and inspection to provide assurance that the integrity of the natural circulation flow path for decay heat removal is maintained. The design of the decay heat removal natural circulation flow path provided by the downcomer, graphite reflector, hot well, diode pathway and fluidic diode, is also capable of being periodically confirmed to provide assurance that the integrity of the natural circulation flow path for decay heat removal is maintained.

Consistent with PDC 74, the design of the reactor vessel and reflector blocks shall be such that their integrity and geometry are maintained during postulated events to permit sufficient insertion of the control and shutdown elements providing for reactor shutdown.

### 4.3.3 System Evaluation

The 316H SS structures of the reactor vessel system are fabricated and tested in accordance with Reference 1 standards. The 316H SS vessel internals also satisfy the chemistry restrictions of the ASME Section III code in Division 5, Article HGB-2000. Per the ASME standard, ER16-8-2 weld metal will be used in fabrication of the 316H structures. Commensurate with the safety-related function of the reflector block in ensuring acceptable design limits and maintaining the reactor coolant flow path, quality related controls will be placed on the ETU-10 graphite. KP-FHR specifications and procurement documents incorporate and reference the applicable guidance and ASME standards. The quality assurance program is described in Section 12.9. These controls demonstrate conformance with PDC 1.

The reactor vessel system makes up a portion of the reactor coolant boundary. The reactor vessel and graphite reflector blocks are therefore designed to maintain geometry during a safe shutdown earthquake to ensure the vessel integrity, insertion of negative reactivity via the RCSS, and to maintain the flow path. The reactor vessel and vessel internals will have dynamic behaviors during a design basis earthquake. These include fluid-structure interaction within the vessel, oscillatory response of components mounted to the reactor top head, i.e., head-mounted oscillators, and relative movement of graphite reflector blocks with respect to one another within the coolant. These dynamic behaviors are accounted for in the design of the reactor and its internals, to ensure continued functionality during and after a design basis earthquake. Models are used to understand fluid migration tendencies considering the pebble bed, reflector blocks, core barrel, and other reactor vessel internal features. The insights gained from the analysis of these models are used to design the reactor to prevent damage to the vessel testing. The RVSS-reactor vessel bottom head interface is designed to allow access for weld inspections. The reactor vessel top head supports in-service inspection of attachments and penetrations.

The reactor vessel shell and bottom head maintain a coolant pathway for cooling the reactor core and ensure submergence of fuel pebbles in the core. The reactor vessel is fabricated, erected, and tested in accordance with Reference 1 as a Class A component to account for thermal and physical stresses during normal operation and postulated events. The vessel is fabricated from 316H SS base metal and ER16-8-2 weld metal using a gas tungsten arc welding process. Reference 1 provides for weldment stress 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.

The reactor vessel internals support decay heat removal during normal operations by establishing the physical geometry for the coolant flow path. During normal operations, the reactor vessel internal structures act in conjunction with forced flow in the PHTS to ensure the transfer and rejection of heat from the core via the coolant flow path. When passive decay heat removal is required in response to postulated events, the physical geometry and structure of the reactor vessel internals provides a pathway for continuous natural circulation of coolant via flow through the fluidic diodes. These features demonstrate conformance to PDC 34.

The downcomer, graphite reflector, hot well, fluidic diode pathway and f~~F~~luidic diodes are used to establish a flow path for continuous natural circulation of coolant in the core during postulated events to remove ~~residual~~ decay 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~~hot well through the diode pathway, the low flow resistance direction of the fluidic diode, to the cooler downcomer via natural circulation.~~,~~ ~~thereby cooling~~ T~~t~~he core is thereby cooled 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 features also limit~~s~~ 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. Additional functions performed by the DHRS to support passive decay heat removal are described in Section 6.3.

The downcomer, graphite reflector blocks, and fluidic diodes are passive components designed to maintain structural integrity during postulated events to maintain a natural circulation path and a coolable core geometry for removal of decay heat. The reactor vessel internals are qualified in accordance with Reference 3 and Reference 4 and are designed to perform their function during seismic events as noted above. Based on the design and qualification, there are no credible failure mechanisms within the design basis of the core barrel and the graphite structures that result in a loss of structural integrity. Therefore, degradation of the natural circulation flow path required to support decay heat removal is not expected during normal or postulated events and such failures would be beyond the design basis. However, graphite dust is expected to be present in small quantities in the system and could be postulated to accumulate in portions of the reactor coolant pathway. The functional capability of the normal flow path can be periodically confirmed during operation by monitoring temperature changes to the exit from the reactor vessel. Similarly, the portions of the reactor coolant flow path that are unique to natural circulation (diode pathway and fluidic diode) are capable of being confirmed during normal operations via temperature changes across the diode and across the pathway. Additionally, the fluidic diodes are designed to permit periodic remote inspections via penetrations on the vessel top head to ensure the pathway remains unobstructed. These features and capabilities demonstrate conformance to PDC 36 and PDC 37. Additional functions performed by the DHRS to support passive decay heat removal are described in Section 6.3.

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.

### 4.3.4 Testing and Inspection

The reactor vessel and internals will be included in an in-service inspection program which will be submitted at the time of the Operating License Application.

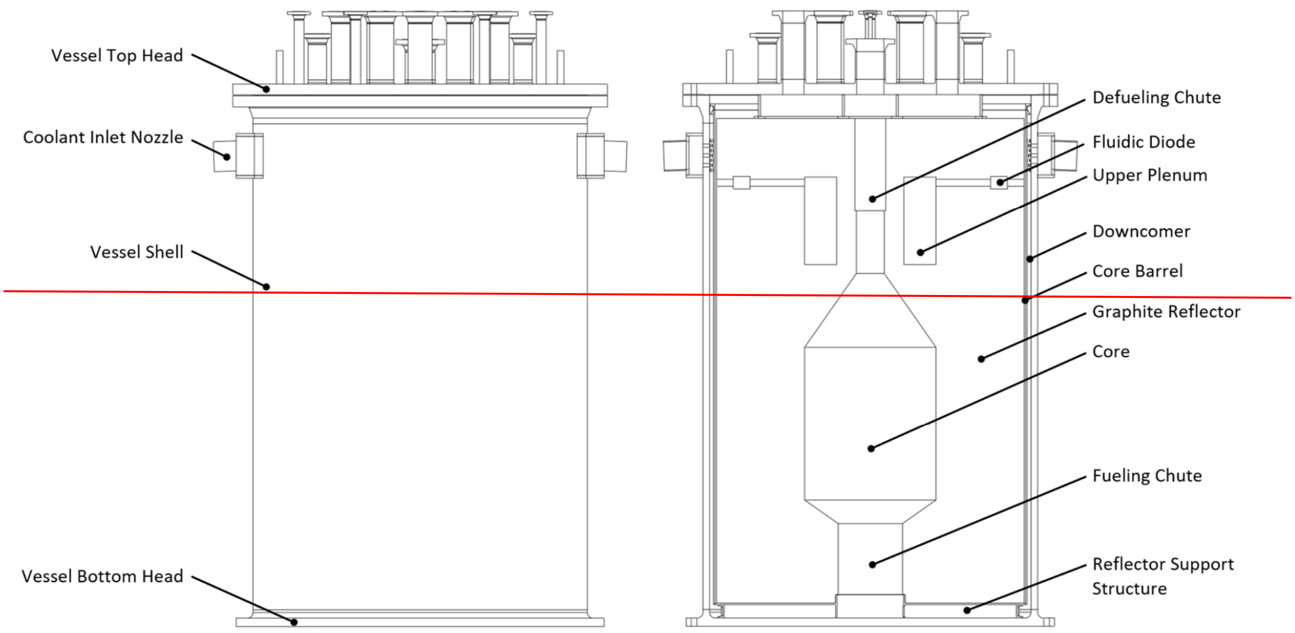
### 4.3.5 References

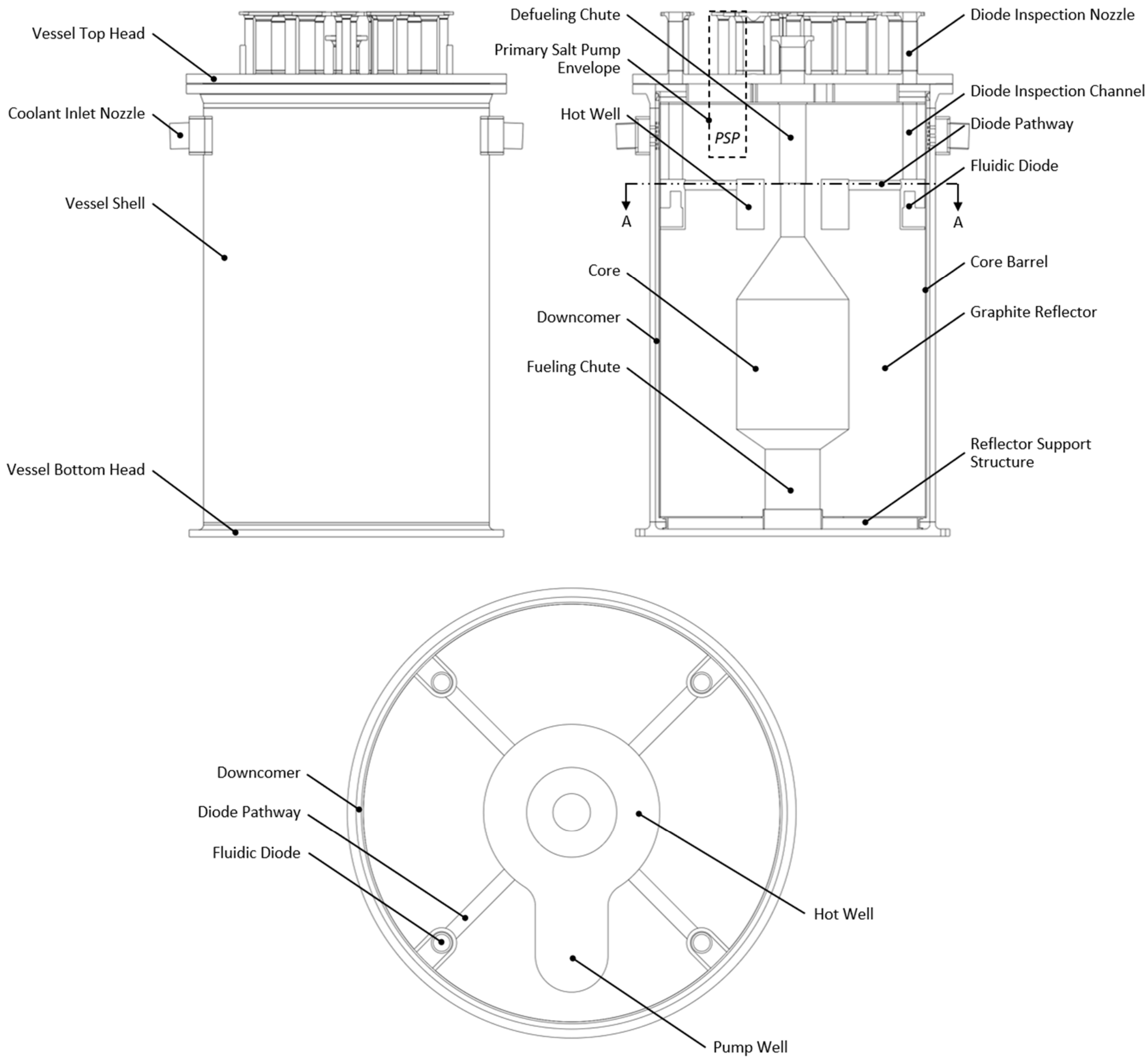
1. ASME Boiler & Pressure Vessel Code, Section III, Division 5 (2019)
2. ASCE 43-19, "Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities."
3. Kairos Power, LLC, "Metallic Materials Qualification for the Kairos Power Fluoride Salt-Cooled High-Temperature Reactor," KP-TR-013-P, Revision 3~~1~~.
4. Kairos Power, LLC, "Graphite Material Qualification for the Kairos Power Fluoride Salt-Cooled High-Temperature Reactor," KP-TR-014-P, Revision 3~~1~~.

Table 4.3-1: Reactor Vessel Top Head Penetrations

| Name of Penetration | Number of Penetrations | System |
|---|---|---|
| Pebble Extraction Machine (PEM) | 1 | PHSS |
| Pebble Insertion | 2 | PHSS |
| Reactivity Shutdown Element | 3 | RCSS |
| Reactivity Control Element | 4 | RCSS |
| Primary Salt Pump (PSP) | 1 | PHTS |
| Coolant Fill/Drain Line | 2 | IMS |
| Inert Gas Line | 2 | IGS |
| Material Surveillance System | 1 | MSS |
| Neutron Source | 1 | RSS |
| Source Range Neutron Detector | 3 | RSS |
| Reserve Instrumentation | 3 | I&C |
| Reactor Coolant Level Sensor | 4 | I&C |
| Reactor Coolant Thermocouple | 3 | I&C |
| Graphite Thermocouple | 2 | I&C |
| Fluidic Diode Inspection Nozzle | 4 | I&C |

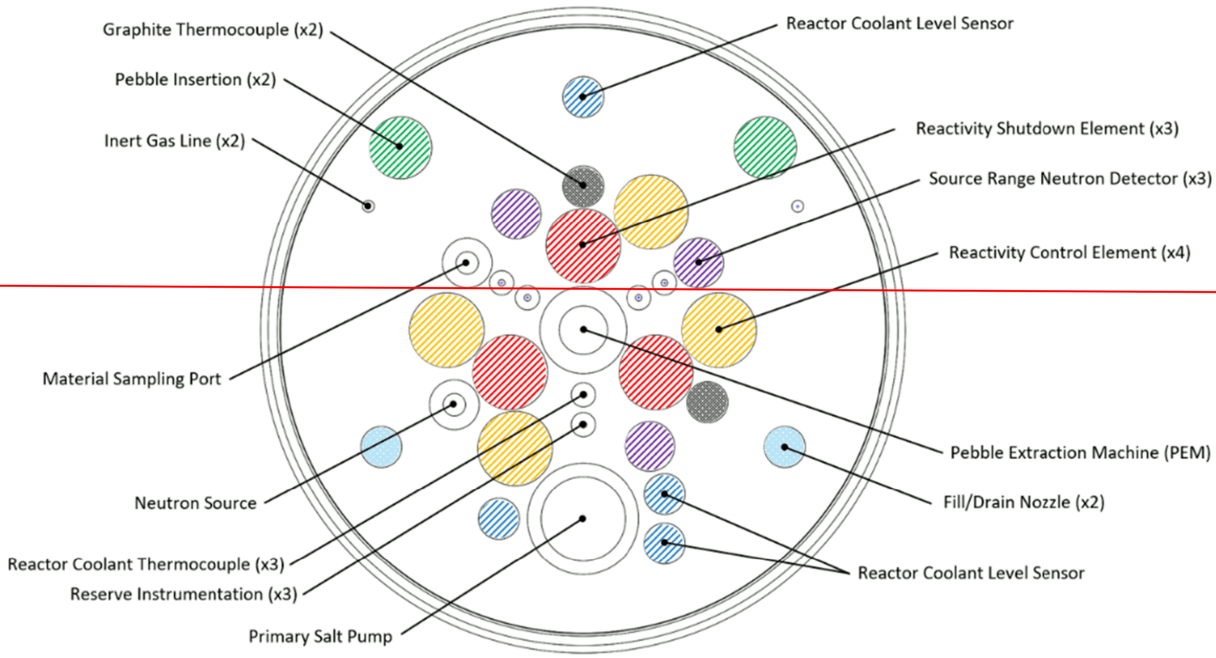
Figure 4.3-1: The Reactor Vessel System

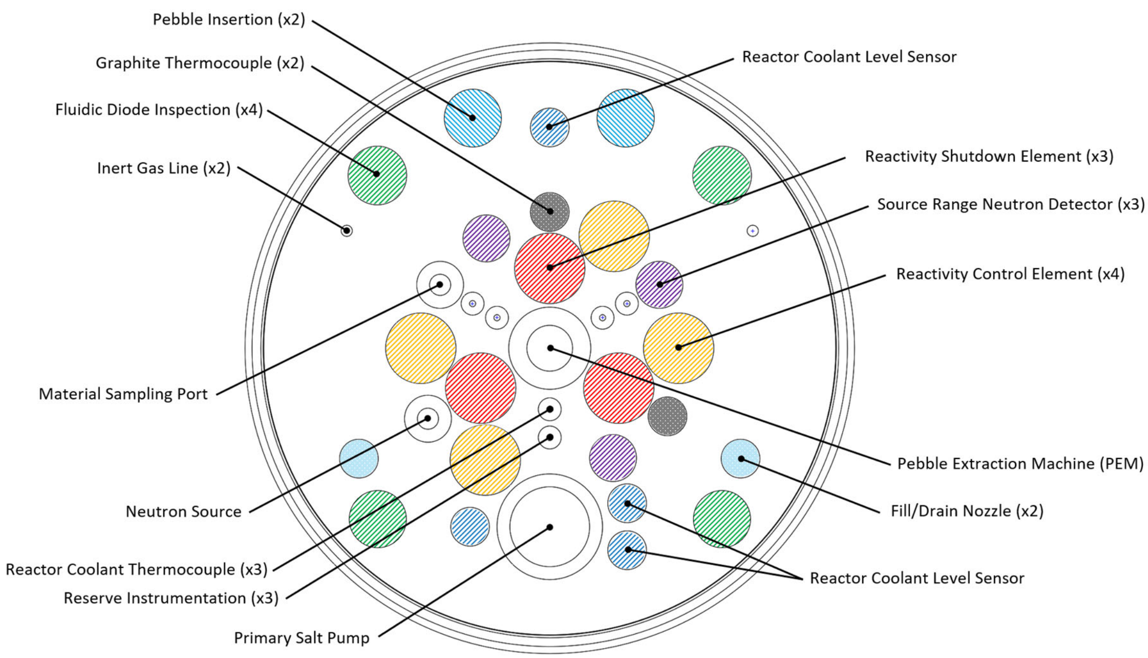



Vessel Top Head
Coolant Inlet Nozzle
Vessel Shell
Vessel Bottom Head
Defueling Chute
Primary Salt Pump Envelope
Hot Well
PSP
A
A
Core
Downcomer
Fueling Chute
Diode Inspection Nozzle
Diode Inspection Channel
Diode Pathway
Fluidic Diode
Core Barrel
Graphite Reflector
Reflector Support Structure
Downcomer
Diode Pathway
Fluidic Diode
Hot Well
Pump Well

***Section A-A***

**Figure 4.3-2: Reactor Vessel Top Head Design**



## 4.6 THERMAL-HYDRAULIC DESIGN

### 4.6.1 Description

The thermal hydraulic design of the reactor is a combination of design features that enable effective heat transport from the fuel pebble to the reactor coolant and eventually to the heat rejection system of the reactor, considering the effects of bypass flow and flow non-uniformity. The design features that play a key role in the thermal-hydraulic design of the reactor system include the fuel pebble (see Section 4.2.1), reactor coolant (see Section 5.1), reactor vessel and reactor vessel internal structures (see Section 4.3), the primary heat transport system (PHTS) (see Section 5.1), and the primary heat rejection system (PHRS) (see Section 5.2).

#### 4.6.1.1 Core Geometry

The core geometry is maintained in part by the reactor vessel internals including the reflector blocks which keep the pebbles in a general cylindrical core shape. Coolant inlet channels in the graphite reflector blocks are employed to limit the core pressure drop. The use of pebbles in a packed bed configuration also creates local velocity fields that enhance pebble-to-coolant heat transfer. The reactor thermal hydraulic design uses the following heat transfer mechanisms to extract the fission heat.

- Pebble-to-coolant convective heat transfer
- Pebble radiative heat transfer
- Pebble-to-pebble heat transfer by pebble contact conduction
- Pebble-to-pebble heat transfer by conduction through the reactor coolant
- Heat transfer to the graphite reflector by modes of conduction, convection, and radiation.

#### 4.6.1.2 Coolant Flow Path

During normal operation, reactor coolant at approximately 550°C enters the reactor vessel from two PHTS cold leg nozzles and flows through a downcomer formed between the metallic core barrel and the reactor vessel shell as shown in the normal, pumped flow pathway on Figure 4.6-1, part (a). The coolant is distributed along the vessel bottom head through the reflector support structure, up through coolant inlet channels in the reflector blocks and the fueling chute and into the core with a portion of the coolant bypassing the core via gaps between the reflector blocks, the fluidic diode pathway and the fluidic diode. The coolant transfers heat from fuel pebbles which are buoyant in the coolant and provides cooling to the reflector blocks and the control elements via engineered bypass flow. Coolant travels out of the active core through the upper plenum via the coolant outlet channels and exits the reactor vessel via the PHTS outlet. The ~~maximum vessel exit~~ nominal core outlet temperature is ~~620°C and~~ dependent on the amount of corresponding bypass flow ~~through the reflector blocks~~.

During postulated events where the normal heat removal path through the PHTS is no longer available, including when the PHTS is drained, a fluidic diode (see Section 4.3), is used to create an alternate, natural circulation flow path. During such events, forced flow from the primary salt pump (PSP) is also not available. The fluidic diode then directs flow from the hot well and~~to the downcomer~~ diode pathway through the core barrel and into the downcomer as shown in the natural circulation flow pathway on Figure 4.6-1, part (b). This opens the path for continuous flow via natural circulation. During normal operation, while the PSP is in operation, the fluidic diode minimizes reverse flow.

### 4.6.2 Design Basis

Consistent with PDC 10, the thermal-hydraulic design provides adequate transfer of heat from the fuel to the coolant to ensure that the specified acceptable system radionuclide release design limits (SARRDLs) will not be exceeded during normal operation and unplanned transients.

Consistent with PDC 12, the thermal hydraulic design of the reactor system ensures that power oscillations that can result in conditions exceeding SARRDLs are not possible or can be reliably and readily detected and suppressed.

Consistent with PDC 34, the thermal hydraulic design removes residual heat during normal operation and anticipated transients, such that SARRDLs and the design conditions of the safety-related elements of the reactor coolant boundary are not exceeded.

Consistent with PDC 35, the reactor transfers heat from the reactor core during anticipated transients such that fuel and reactor internal structure damage that could interfere with continued effective core cooling is prevented.

### 4.6.3 System Evaluation

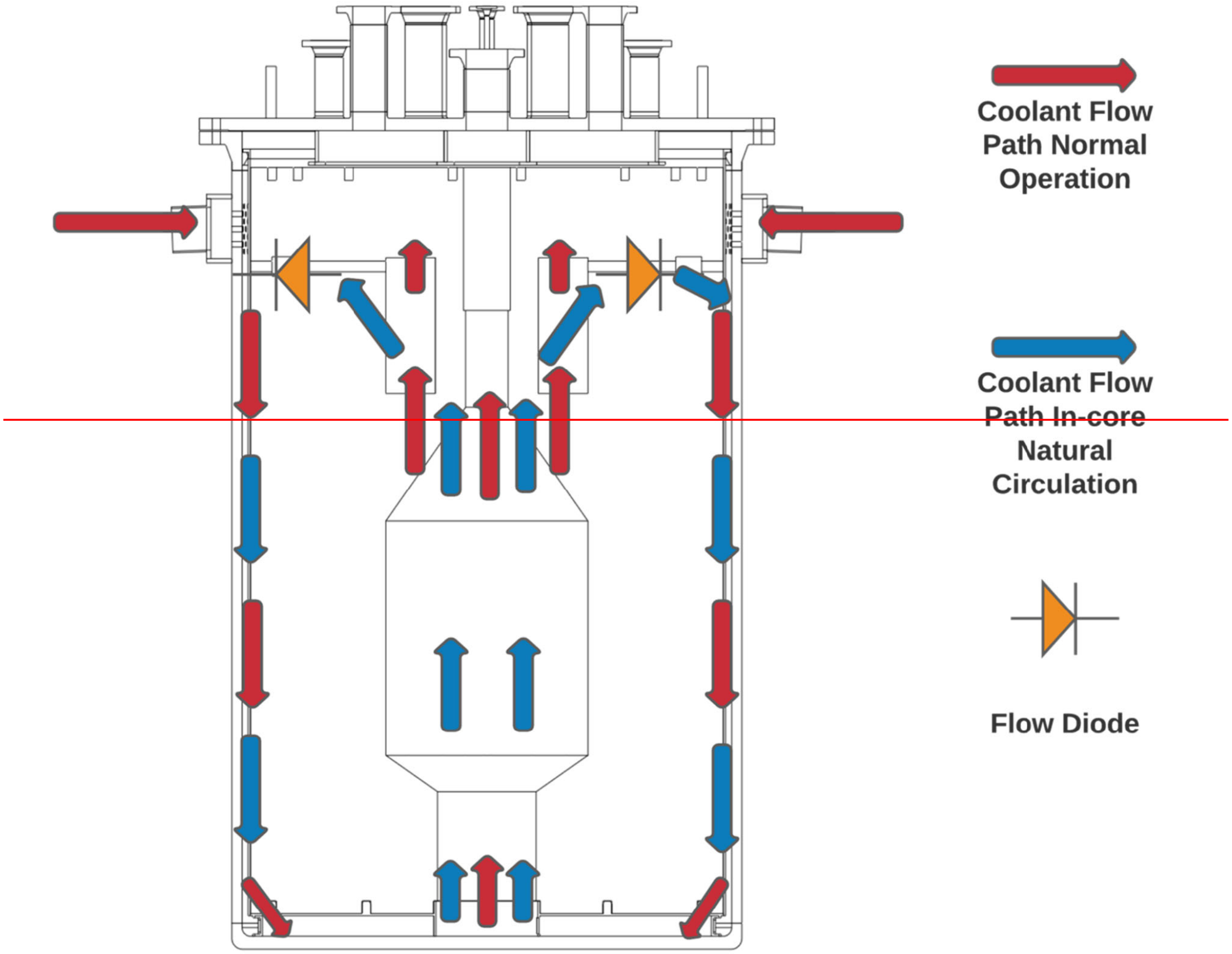
The reactor core and heat removal systems associated with the thermal hydraulic design of the reactor system have appropriate margin to ensure that SARRDLs are not exceeded during any condition. The height of the core (e.g., height of the downcomer) and the axial decay heat profile (e.g., the temperature difference between the hot leg and the cold leg) ensure there is sufficient driving force to enable natural circulation in the event of a loss of forced circulation. Pressure losses are also minimized by design to ensure that heat is transferred from the coolant in the downcomer below the fluidic diode to the vessel shell during a loss of forced circulation event. Due to buoyancy forces, hot fluid coming out from the fluidic diode path into the downcomer will flow downward as a plume, which enhances heat removal from the vessel shell above the elevation of the fluidic diode. A summary of pertinent thermal-hydraulic parameters is provided in Table 4.6-1. These features and analyses demonstrate conformance to PDC 10 with respect to thermal hydraulic design.

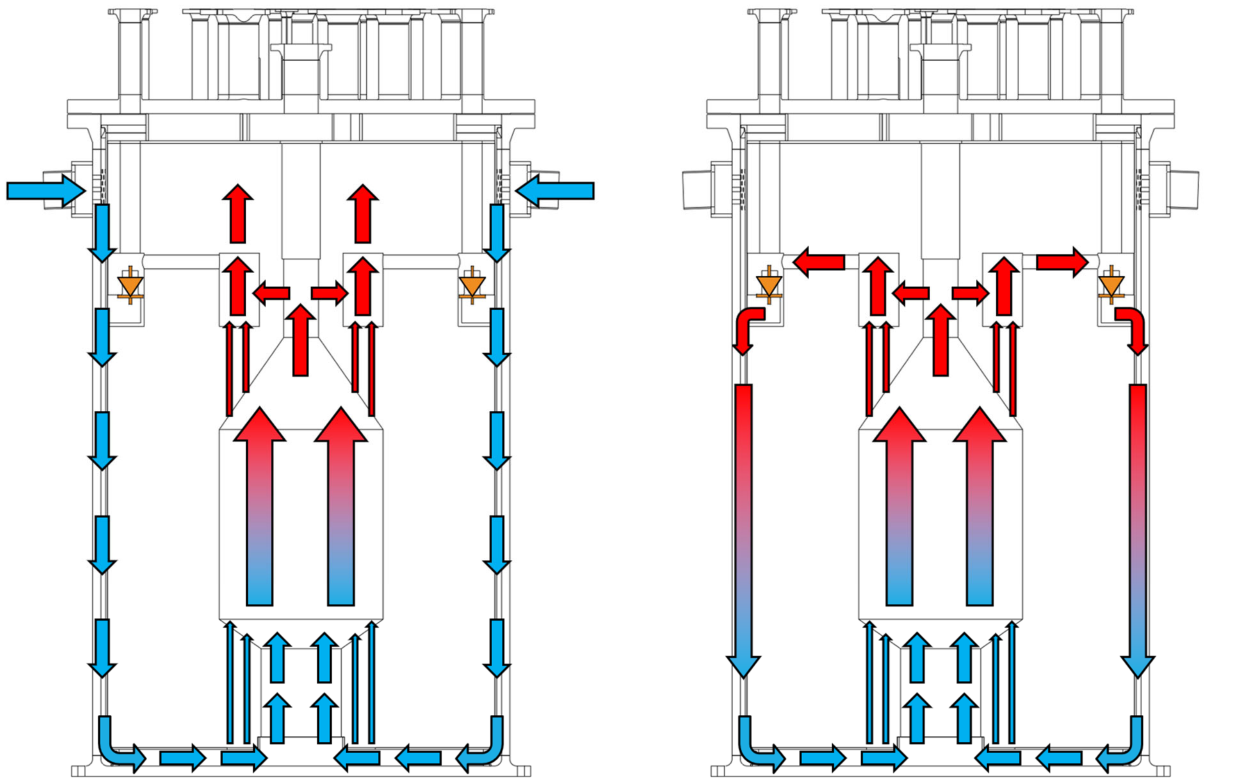
The thermal hydraulic design of the reactor system inherently prohibits instability phenomena that could exceed SARRDLs. The reactor is kept at atmospheric pressure; the coolant in the core does not experience two phase flow and has a high thermal inertia making the reactor restrictive to core-wide thermal-hydraulic instability events. This demonstrates compliance with PDC 12 with respect to the thermal hydraulic design. The results of analyses supporting the inherent stability of the reactor will be provided with the application for an Operating License.

The thermal hydraulic design of the reactor system provides residual heat removal during normal operations, including startup and shutdown. During normal operations, the thermal hydraulic design of the reactor in conjunction with forced flow in the PHTS and PHRS ensures the transfer and rejection of heat from the core via the coolant flow path as described in Section 4.6.1.2. The relationship between power and flow of the thermal hydraulic system as well as the thermal inertia of the coolant ensures that heat transfer can be achieved at a rate that maintains the design conditions of the core. These features demonstrate conformance to PDC 34 with respect to thermal hydraulic design.

The thermal hydraulic design of the reactor supports passive residual heat removal following postulated events. The design of the reactor ~~hot well,~~ downcomer, reflector blocks and the fluidic diode provide a path for continuous flow to ensure decay heat is transferred via natural circulation from the core to the reactor vessel shell, as described in Section 4.6.1.2. These features, in part, demonstrate compliance with PDC 35. Residual heat is removed from the vessel wall by the DHRS as described in Section 6.3.

Figure 4.6-1: Coolant Flow Paths





(a) Normal Operation Coolant Flow Path

(b) Natural Circulation Coolant Flow Path