Enclosure 1

Changes to Hermes PSAR Chapters 3, 4, and 6

(Non-Proprietary)

Table 3.6-2: Design and Construction Codes and Standards for Fluid Systems

Components	**Safety-Related** (Note 1)	**Non-Safety Related, Containing Radioactive Materials** (Note 2)	**Non-Safety Related, Not Containing Radioactive Materials** (Note 3)
Pressure Vessels ~~(>15 psig)~~	ASME Code, Section III, Division 5, Class A or B (Reference 4) (Note 6)	ASME Code, Section VIII, Division 1 or ASME Code, Section VIII, Division 2 (Reference 5)	Local Building Code
Piping and Valves	ASME Code, Section III, Division 5, Class A or B (Reference 4) (Note 6)~~N/A~~	ANSI/ASME B31.1/B31.3 (References 6 and 7) (Note 4 and Note 5)	
Pumps	N/A	Manufacturers' standards or API-610, API-674, API-675 (References 8, 9, and 10)	
Atmospheric Storage Tanks	N/A	API-650 (Reference 11)	
Storage Tanks ~~(0-15 psig)~~	ASME Code, Section III, Division 5, Class A or B (Reference 4) (Note 6)~~N/A~~	API-620 (Reference 12)	
Core Support Structures	ASME Code, Section III, Division 5, Subsection HG/HH (Reference 4) (Note 6)	N/A	N/A

Notes:

1. The only safety-related fluid containing components in the KP-FHR ~~is~~ are the reactor vessel, including the upper and lower heads, nozzles and primary salt pump well, and Decay Heat Removal System components, including the storage tanks, thermosyphon thimbles, and thimble feedwater lines.
2. Only applicable to SSCs whose failure has the potential to exceed 100 mrem TEDE at the site boundary.
3. This column includes non-safety related systems that contain no radioactive material or non-safety related systems that do not contain enough radioactive material to have a potential to exceed 100 mrem TEDE at the site boundary.
4. Piping Systems are to be designed as category "M" systems if the system processes radioactive material in excess of the A2 quantities given in Appendix A to 10 CFR Part 71.

5. ASME BPVC Section II applied only to pressure retaining components.

~~5.~~6. Components will be designed and fabricated using the technical guidance in ASME Code, Section III, Division 5, with departures. Specifically, Hermes will implement an ANSI/ANS 15.8 Quality Assurance Program, as described in Section 12.9 rather than the NQA-1 standard specified in the ASME code. Therefore, the components will not meet ASME Code, Section III, Division 5 requirements that are dependent on or tied specifically to an NQA-1 program. Appropriate departures will be taken to the quality assurance related guidance of the ASME Code requirements for Hermes components, including stamping and certification requirements in the Code that are dependent on implementation of an NQA-1 program. Departures from other ASME Code requirements are also anticipated and will be identified with the Operating License Application. Such departures will still meet the intent of the code technical guidance and provide reasonable assurance of component performance.

There is extensive experience (References 5, 6, and 7) with B_4C under irradiation. In addition, the B_4C melting temperature is more than 1000˚C above the Hermes operating temperatures.

The control and shutdown elements and drive mechanisms are also analyzed to meet ASME Section III, Division ~~V~~ 5 (Reference 8) loads due to operational stepping, reactor trip, stuck element, fatigue, and shipping and handling. All stresses in the components of the reactivity elements are within limits.

Materials utilized in the RCSS elements are qualified for their operating environment. Materials are chosen to ensure reactor coolant induced diffusion bonding does not occur at interfaces where movement or separation is necessary.

The control and shutdown elements are tested to ensure that wear during control and shutdown element movement is acceptable.

These evaluations demonstrate conformance with PDC 4.

PDC 23

The safety-related reactor trip function of the RCSS is initiated by the reactor protection system through the reactor trip system (RTS) and is based on redundant trip determination signals to automatically open the reactor trip breakers. Removal of power from the electromagnetic clutch in the RCSS allows the control and shutdown elements to fall into the core by gravity. Normally open relays are utilized for this system such that during operation they are energized allowing the system to operate. When the RTS actuates, the energy holding the relays closed is removed and this loss of supply power initiates a reactor trip. The RCSS accomplishes safe shutdown (i.e., reactor trip) via gravity insertion of the control and shutdown elements on a reactor trip signal; or on a loss of normal electrical power after a short time delay to mitigate spurious trips. The electrical system design is described in Chapter 8. The reactor control and reactor protection system architecture are described in Chapter 7. These features, in conjunction with Chapter 7, demonstrate conformance to PDC 23.

PDC 26

The control and shutdown elements meet the requirements of PDC 26. The compliance with the requirements in PDC 26 is discussed in Section 4.5.

PDC 28

The control elements traverse their full range of movement in 100 seconds. This maximum design speed is analyzed in Chapter 13 to ensure that the rate of reactivity addition does not impact the safety significant portions of the reactor coolant boundary and also does not disturb the core and internals and impair cooling of the core.

PDC 29

The RCSS supports a high probability of accomplishing its design function, because the trip function is safety-related and the elements are inserted via gravity. There are two means of inserting negative reactivity and these two means contain sufficient negative reactivity such that the highest worth reactivity element can fail to insert, and the safety-related function can still be achieved. The first means of inserting reactivity would be to use the motor to lower the element into the core region. The second means is upon a reactor trip which releases the elements, allowing them to drop into the core by gravity.

The control and shutdown element insertion versus time will be provided in the application for an Operating License. A conservative control element drop time value is used in Chapter 13. These features demonstrate conformance to PDC 29 for the RCSS.

4.2.2.4 Testing and Inspection

The control and shutdown elements are periodically inspected to ensure that there is no unacceptable wear or other damage to the cladding that encapsulates the B_4C absorber material. In addition, the reactor coolant is periodically examined for an increase in boron from B_4C absorber material, which provides an indication of control and shutdown element cladding failure.

RCSS element insertion times and shutdown margin are periodically confirmed to be within safety analysis limits by surveillance requirements provided in the technical specifications (see Chapter 14).

4.2.3 Neutron Startup Source

A neutron startup source is used to provide an adequate neutron flux to the source range detectors during initial and subsequent plant startups. The startup neutron source allows monitoring of the change in neutron multiplication during the addition of fuel and the approach to criticality. The neutron startup source does not perform any safety-related functions.

The neutron source(s) will be located in the reflector region of the reactor near the outside edge of the core, in proximity to an ex-core source range detector. The source will have sufficient strength to provide a detectable count rate.

The source material is encased in a metal sheath. The neutron startup source is compatible with the chemical, thermal, and irradiation conditions expected in the reflector. The neutron startup source can be removed and replaced during the life of the plant, if needed.

4.2.4 References

1. Electric Power Research Institute, “Uranium Oxycarbide (UCO) Tristructural Isotropic (TRISO)-Coated Particle Fuel Performance,” Topical Report EPRI-AR(NP)-A, 3002019978, November 2020.
2. Kairos Power, LLC, “Fuel Qualification Methodology for the Kairos Power Fluoride Salt-Cooled High Temperature Reactor (KP-FHR),”KP-TR-011-P, June 2020.
3. Kairos Power, LLC, “KP-FHR Fuel Performance Methodology,” KP-TR-010-P, June 2021.
4. Nuclear Regulatory Commission, “Electric Power Research Institute – Safety Evaluation for Topical Report, Uranium Oxycarbide (UCO) Tristructural Isotropic (TRISO) Coated Particle Fuel Performance: Topical Report EPRI-AR-1(NP),” August 11, 2020.
5. Fryger, B., Gosset, D., & Escleine, J.M., “Irradiation Performances of the Superphenix Type Absorber Element, Absorber Materials, Control Rods and Design of Backup Reactivity-Shutdown Systems for Breakeven and Burner Cores for Reducing Plutonium Stockpiles,” 1995.
6. Pitner, A.L., & Russcher, G. E., “Irradiation of Boron Carbide Pellets and Powders in Hanford Thermal Reactors,” 1970.

7. Demars, R.V., Dideon, C.G., Thornton, T.A., Tulenko, J.S., Pavinich, W.A., & Pardue, E. B. S., “Irradiaton Behavior of Pressurized Water Reactor Control Materials, Nuclear Technology,” 62(1), 75-80, 1983.

~~7.~~8. American Society of Mechanical Engineers, ASME Boiler & Pressure Vessel Code, Section III, Division 5, “High Temperature Reactors.” 2017.

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 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 back into the downcomer annulus 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~~ using the technical guidance in ASME BPVC Section III, Division 5 (Reference 1) with departures as shown in Table 3.6-2. 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 reactor vessel internal structures are designed and fabricated using the technical guidance in ASME BPVC Section III, Division 5 (Reference 1) with departures as shown in Table 3.6-2. 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, 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

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 35, the reactor vessel internals will assure sufficient core cooling during postulated events and remove residual heat. The safety function of the fluidic diode is to provide a flow path via natural circulation to transfer heat from the reactor core during and following postulated events such that fuel and reactor internal structure damage that could interfere with continued effective core cooling is prevented.

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~~ to meet the intent of Reference 1 standards with departures as shown in Table 3.6-2. 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. The graphite reflector will be designed to meet the intent of Reference 1 standards with departures as shown in Table 3.6-2. 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 during a design basis earthquake. The reactor vessel, vessel internals, and vessel attachments such as the RCSS are classified as SDC-3 per ASCE 43-19 “Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities” (Reference 2). The reactor vessel will also be protected from the failure of nearby non-safety related SSCs during a design basis earthquake by seismically mounting, physically separating, or using a barrier to preclude adverse interaction, and from failure of attached non-safety related SSCs, such as attached piping (e.g., by design for preferential failure of the non-safety component is a way that does not impact the vessel). These features demonstrate compliance with PDC 2.

The reactor vessel can accommodate internal and external static and dynamic loads. The thermal expansion of the reactor vessel shell and bottom head is supported by the reactor vessel support system (RVSS) (see Section 4.7) during reactor startup, normal operation, and postulated events. Mechanical loadings from static weight, seismic load, and forces from the pebble bed, coolant, and core

4.7 REACTOR VESSEL SUPPORT SYSTEM

4.7.1 Description

The reactor vessel support system (RVSS) provides structural support to the reactor vessel support the full weight of the reactor vessel with fuel and coolant, vessel internals, and all head-mounted components. The system transmits pressure, seismic, and thermal loads to the cavity structures during normal operation and design basis earthquakes. The RVSS provides adequate thermal management to support the vessel's thermal expansion while transitioning from room temperature at assembly to nominal operating temperature for primary coolant fill. The RVSS also supports the vessel's thermal expansion during postulated events.

The RVSS interfaces with the reactor vessel (see Section 4.3), the reactor thermal management system (RTMS) (See Section 9.1.5), and the safety-related portion of the Reactor Building (see Section 3.5). The safety-related portion of the Reactor Building is seismically isolated to reduce seismic loads (see Section 3.5.3).

The bottom support consists of a support tray, ledge, support columns, support pads, base plate, vessel connector, and anchoring connector as shown in Figure 4.7-1. All the components are made of 316H stainless steel. The reactor vessel bottom head sits directly on top of the tray and is connected to the tray by the vessel connector to prevent uplift and shear. The ledge around the edge of the tray contains spilled Flibe in case of leakage. The tray is reinforced by 316H SS support colum[illegible] spaced appropriately to provide structural support for the total weight of the ve[illegible] head components, coolant, and fuel. The support columns are welded onto the [illegible] allows relative sliding with the underlying base plate to accommodate thermal expansion. The support pads have slotted holes to allow relative sliding with the anchoring connectors. The anchoring connectors prevent the reactor vessel and RVSS from uplift and shear. The RVSS is designed and fabricated ~~per~~ using the technical guidance in ASME BPVC Section III, Division 5 (2017~~9~~) (Reference 1) as shown in Table 3.6-2.

Highlighted text was previously changed. Submitted on 6-30-22 (ML22181B158).

The RTMS provides thermal management for the bottom support with a load bearing metallic insulation material which acts as a thermal break that reduces heat loss and cooling load for the RVSS support columns. The bottom insulation of the RTMS, as shown in Figure 4.7-1, protects the reactor building cavity concrete from thermal effects. The RVSS is also vertically anchored to the foundation through the bottom insulation. The bottom support insulation interface accommodates relative thermal expansion between the support columns and the insulation material.

There are no lateral seismic restraints for the reactor vessel and the head-mounted components. The RVSS is designed to keep the reactor vessel from uplift and shear during seismic events. The design also leverages seismic isolation of the Reactor Building to reduce seismic effects on the reactor vessel, RVSS, and the head-mounted components (see Section 4.3).

4.7.2 Design Basis

Consistent with PDC 2, the RVSS can withstand the effects of natural phenomena and to perform its safety function in the event of a design basis earthquake.

Consistent with PDC 4, the RVSS accommodates the environmental conditions associated with normal operation, maintenance, testing, and postulated events.

Consistent with PDC 74, the design of the reactor structural support system ensures the integrity of the reactor vessel during postulated events to support the geometry for passive removal of residual heat

Table 6.3-4: Applicable Design Codes and Standards for the DHRS

Code	Title	Applicability
ASME Sec. III Div. 5 Class B (Reference 1)	ASME Boiler and Pressure Vessel Code – High Temperature Reactors	~~M~~The DHRS metallic pressure boundary and supports will be designed and fabricated using the technical guidance in ASME, Section III, Division 5, with departures as shown in Table 3.6-2. ~~In general, low temperature service corresponds to the requirements of ASME Sec. III Div. 1 subsection NC. This applies to most DHRS components. The risers are an exception and must follow rules for high-temperature service. These provide additional modifications to Div. 1 rules.~~
ASME Sec. XI Div. 1 and 2 (Reference 2)	Rules for Inservice Inspection of Nuclear Power Plant Components	Provides rules and guidelines for testing and inspection of DHRS pressure boundary and structural components.
ASCE 43-19 (Reference 3)	Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities	Provides design criteria for seismic analysis of reactor components (including DHRS).
ASCE 4-16 (Reference 4)	Seismic Analysis of Safety-Related Nuclear Structures	Provides additional design criteria for safety-related systems (including DHRS) that expand upon ASCE 43-19.
ACI 349-13 (Reference 5)	Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary	Applicable to cavity support structures for DHRS panels and potentially the condenser pool construction.