Enclosure 1
Changes to PSAR Chapter 4
(Non-Proprietary)

The control elements are positioned via a counter-weighted winch system (Figure 4.2-8). The shutdown elements are also positioned by a counter-weighted winch, but they are typically only fully inserted or fully withdrawn. In the counter-weighted winch system, a wire-rope is connected to the element, and travels up around the sheave and down to a counter-weight. The counter-weight allows the wire-rope to wrap around the sheave without having to anchor the wire rope, similar to a capstan. The sheave, commonly known as a winch drum, is rotated by an electric motor. There is an electric clutch between the motor and the sheave. The motor allows small and controlled movements of the element. The maximum withdrawal and insertion time for the shutdown and control elements is 100 seconds over the full range of motion for motor-driven operations.

On a reactor trip, the electric clutch opens, which allows the sheave to rotate freely. With the sheave rotating freely, the shutdown and control elements are released from their drives and drop into the core and reflector, respectively, as a result of gravity. The control and shutdown elements reach ~~90 percent~~full insertion by gravity in no more than 10 seconds. Although both the control elements and the shutdown elements receive a reactor trip signal, the release of the clutch for the shutdown elements provides the primary safety-related reactor trip release mechanism.

Control and shutdown element position is monitored using two independent and diverse methods. The motor position is measured using an absolute encoder allowing the determination of the angle the sheave has swept from a known reference point, which directly correlates to the element position. The second position measurement device is a high-density reed switch array. Similar to existing reed switch position measurement designs, this instrument measures the position of the counterweight over its full range of motion. The reed switch array provides an analog signal, and the encoder provides a digital signal and the two used together provides the ability to determine the element position, while allowing real time functional checks.

The materials used in the RCSS are shown in Table 4.2-4. The primary materials are the B_4C absorber material and the stainless steel 316H cladding. The operating conditions are such that the control and shutdown elements are immersed in reactor coolant and experience temperatures up to 700°C during operation. The upper portions of the control and shutdown elements are exposed to reactor cover gas above the reactor coolant free surface. The control and shutdown drive mechanisms above the vessel are maintained at temperatures below their mechanical limits. The B_4C neutron absorber material is contained in pellets, which are stacked in SS 316H cylindrical tubes (pressurized with inert gas). The control and shutdown drive mechanisms are also made of stainless steel.

4.2.2.2 Design Basis

Consistent with PDC 2, the safety-related portion of the RCSS performs the shutdown function under design basis natural phenomena events.

Consistent with PDC 4, the safety-related portion of the RCSS accommodates the effects of the environmental conditions during normal plant operation as well as during postulated events as a result of equipment failures.

Consistent with PDC 23, the safety-related portion of the RCSS fails into a safe state in the event of adverse conditions or environments.

Consistent with PDC 26, the RCSS provides an independent and diverse means of controlling reactivity to assure that shutdown margin is maintained and that SARRDLs are not exceeded under conditions of normal operation. In addition, the RCSS provides a means of inserting negative reactivity at a sufficient rate to assure with appropriate margin for malfunctions and also provide a means to maintain the reactor shutdown for fuel loading, inspection and repair.

Consistent with PDC 28, the RCSS has appropriate limits on the potential amount and rate of reactivity increase to ensure the effects of postulated reactivity events can neither damage the safety-related elements of the reactor coolant boundary or disturb the core and internals such the ability to cool the core is impaired. The system allows only one element to move at a given time.

Consistent with PDC 29, the RCSS, in conjunction with reactor protection systems, assures an extremely high probability of accomplishing its safety-related functions.

4.2.2.3 System Evaluation

The RCSS meets the design bases as described below:

PDC 2

As noted in Section 4.2.2.1, the shutdown elements are inserted into guide structures in the upper reflector and then directly into the pebble bed. The guide structures and reflector blocks ensure the ability of the shutdown elements to insert under conditions of reflector block misalignment that could potentially occur in a design basis earthquake. The design basis earthquake is described in Section 3.4. This seismic analysis determines the maximum deflection of the insertion path. Insertion capability will be assessed in a one-time, out-of-pile, at scale test prior to initial operation, with and without maximum deflection of~~that deflects~~ the shutdown element guide structures consistent with the maximum misalignment caused by such an event and accounts for the expected changes in pebble bed packing fraction and concurrent insertion of all three shutdown elements into the pebble bed. The three shutdown element insertion times and insertion depths ~~is~~are measured and compared to the insertion time testing performed with no deflection of the upper reflector guide structures. The testing is performed to confirm that the element insertion time is within the insertion time assumed in the postulated event analysis in Chapter 13 under the condition of maximum expected misalignment of the upper reflector guide structures from a design basis earthquake. The tests will also confirm that the shutdown elements fully insert to the depth assumed in the shutdown margin calculations in Table 4.5-5. Additionally, the reflector blocks maintain the element insertion pathway as described in Section 4.3. These shutdown element design features provide conformance to PDC 2.

PDC 4

The safety-related portions of the RCSS are compatible with the environmental conditions that they will be subjected to during normal operation, maintenance, testing, and postulated events.

The RCSS shutdown elements are made with stainless steel cladding. Wear rates due to flow induced vibration are expected to be low in comparison to those of typical operating reactors with stainless steel cladding given the lower core flow rates (<0.13 meter/second) in the design. The neutron absorbing material is enclosed in two stainless steel barriers to mitigate the loss of neutron absorbing material in the shutdown elements. The shutdown elements are qualification tested out of pile prior to operation and a conservative wear limit is established to ensure that wear during shutdown element movement is acceptable. The shutdown elements can be removed for inspection or replaced if necessary. In addition, the shutdown elements are not adversely affected by neutron and gamma heating.

Analysis is performed on the shutdown elements to determine the internal gas release and swelling of the B_4C during normal operation over their design lifetime. The resulting increase in gas pressure is analyzed to ensure that stresses on the shutdown element tubes are within allowable stress limits for SS 316H. In addition, the effects of irradiation on SS 316H and clad wear are accounted for in the stress analysis.

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

4.2.2.4 Testing and Inspection

The 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 shutdown element cladding failure.

RCSS shutdown 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 excore 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 and optimally located relative to an excore source range detector for best detectability of criticality. 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

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2. Kairos Power, LLC, “Fuel Qualification Methodology for the Kairos Power Fluoride Salt-Cooled High Temperature Reactor (KP-FHR),”KP-TR-011-P, Revision 2. July 2022.
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6. Pitner, A.L., & Russcher, G. E., “Irradiation of Boron Carbide Pellets and Powders in Hanford Thermal Reactors,” 1970.
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