Enclosure 2
Changes to Non-Proprietary Portions of KP-TR-017-P, Revision 0
(Non-Proprietary)

2 CORE PHYSICS AND DESIGN

The core design and analysis methodology aligns very closely with the physical behavior of a KP-FHR core. The following section describes the reactor core physics of the KP-FHR and will serve as reference for the description of the modeling tools and capabilities used in core design.

2.1 DESCRIPTION

The KP-FHR core contains thousands of randomly packed buoyant fuel pebbles that slowly ascend through the reactor core. Pebbles are continuously inserted at the bottom of the reactor and extracted from the top. The dynamics of the reactor core is characterized by the transition from a startup core to an equilibrium core over time. The fuel pebbles may contain natural uranium all the way up to 19.55 wt% U-235 to reduce effective enrichment and core reactivity in early startup core operations. Depending on the chosen startup and operational schemes, the core will also contain a fraction of graphite-only moderator pebbles to maintain the desired carbon to heavy metal atom ratio. Similar to the water to fuel volume ratio in light water reactors, the carbon to heavy metal atom ratio is used in FHRs to define the neutron moderation conditions (over-moderated or under-moderated) and the mixing of different pebble types facilitates maintaining the core in under-moderated conditions.

When defining the desired carbon to heavy metal ratio, it is also important to recognize the role of the reactor coolant. Flibe is a moderator but also an absorber due mainly to lithium-6, a natural isotope of lithium (7.59% abundance) with a large thermal absorption cross section. Enriching lithium in Li-7 is required for acceptable core performance (i.e., fuel utilization) but also to ensure negative coolant temperature feedbacks.

An increase in temperature of Flibe leads to a decrease of its density with two competing reactivity feedbacks: a positive feedback due to reduced absorption and a negative feedback due to reduced moderation by Flibe. The latter effect is a function of the carbon to heavy metal ratio; therefore, the combined reactivity feedback can be designed to be negative by controlling the carbon to heavy metal ratio. After some period of operation, Li-6 is consumed and its concentration is lower than in fresh Flibe. Nevertheless, lithium-6 in Flibe is also produced by (n,α) reactions on Be-9 leading eventually to an equilibrium concentration.. Salt impurities present in fresh Flibe are also parasitic absorbers in addition to the accumulation of other corrosion material, each of which have an impact on the coolant reactivity coefficients. The properties and specifications for the reactor coolant are described in "Reactor Coolant for the Kairos Power Fluoride Salt-Cooled, High Temperature Reactor" topical report (Reference 18).

The ability to control the mixture of pebble types in the core allows excess reactivity to be minimized during startup and operation. Core reactivity is also controlled by the movement of the control elements. Shutdown elements are also available for insertion for ~~maintaining~~ safe shutdown at all core states. The KP-FHR thermal energy transfer phenomena in the core are described in Figure 2-1. During normal operating conditions, thermal power generated within the fuel is transferred by conduction to the pebble surface. The thermal energy is mainly transferred via convection from the pebble surface by the coolant that flows through the randomly packed bed. At the same time a smaller portion of the thermal energy is transferred by a mixed regime of conduction and thermal radiation. Specifically, pebble to pebble heat conduction through a stagnant fluid, pebble to pebble conduction, and pebble to pebble radiation. Figure 2-1 shows these heat transfer modes and those outside the reactor core as well. Bypass flow, core barrel,

reactor core, is also designed to be a low power producing region where pebbles have adequate amount of time to allow for the decay of short-lived fission products. The decay heat generation is then low enough for the pebble handling system to operate within designed temperature limits to accept the extracted pebble.

Coolant inlet and outlet channels located in the bottom and top reflector, respectively, are designed to reduce pressure losses while achieving acceptable flow distribution and flow rates through the core. The block-type reflector design is characterized by the presence of radial and axial spoke gaps between blocks and at the interface with the vessel core barrel. This geometry causes a portion of the mass flow rate to bypass the core region. Engineered channels in the graphite blocks allow for the movement of reactivity control elements placed ex-core and any additional channels required to reduce temperature in the reflector.

The reactivity control and shutdown system consist of control elements that insert directly into the reflector (near the periphery of the core) and shutdown elements that directly insert into the pebble bed. The control elements are ~~used~~ credited only for all planned power maneuvers of the KP-FHR reactor. To achieve short-term hot shutdown (i.e. not considering delayed impact from xenon), only the control elements are needed. To achieve ~~long-term~~ safe shutdown conditions, ~~to~~ the ~~safe~~ shutdown elements are used ~~temperature during which~~assuming the highest worth shutdown element is ~~assumed~~ fully withdrawn (stuck)~~, the shutdown elements are also required.~~ .The design of the reactivity control and shutdown system must satisfy PDC 25 and PDC 26 (Reference 2).

2.4 OPERATIONAL REGIMES

There are four main periods of core operation in the life of the KP-FHR reactor with respect to criticality and composition: startup, power ascension, approach to equilibrium core, and equilibrium core. An illustration of these stages can be observed in Figure 2-4.

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While still subcritical, source range control element worth testing is performed by measuring changes in neutron multiplication from a start-up source. The distribution of flux is also monitored and assessed against predicted calculations during this stage. Once criticality is achieved and at zero power, isothermal reactivity coefficient testing is performed and compared against predicted calculations.

Once all zero-power physics testing is completed, the ascension to the power phase begins. The primary salt pump runs at reduced speed to provide forced circulation. As the power level increases from zero power, negative reactivity feedbacks arise from temperature increases, the buildup of xenon, and the depletion of fuel. To compensate for these effects, the reactivity control elements can be partially

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5.2.4 Control Worth and Shutdown Margin

Consistent with PDC 26, the design of the Reactivity Control and Shutdown System (RCSS) provides sufficient reactivity for the KP-FHR core to shut down, and remain shut down with margin. The RCSS design also provides adequate worth to compensate for the positive reactivity inserted from the decay of full-power xenon, the change in temperature from full-power conditions to safe shutdown temperature (i.e., power defect), delayed neutrons, the maximum operational excess reactivity, the highest worth stuck element (i.e., fully withdrawn), and uncertainties (informed from Table 6-1) . [[

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Shutdown margin is also maintained at all core states. The control elements in the RCSS are responsible for all planned, normal power maneuvers. The worth requirements depend on the KP-FHR design of interest.

Control worth is calculated using Equation 5-2 where $k_{eff,out}$ is the withdrawn position and $k_{eff,in}$ is the inserted position of interest. Differential control worth is calculated using Equation 5-3, where $k_{eff,i}$ is the neutron multiplication factor of the core for step i position of interest, $k_{eff,i+1}$ is the neutron multiplication factor of the core for step $i+1$ position of interest, z_i is the axial position of the control rod(s) for step i position of interest, and z_{i+1} is the axial position of the control rod(s) for step $i+1$ position of interest.

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5.2.5 Kinetics Parameters

In addition to reactivity coefficients, kinetics parameters such as delayed neutron fraction and their associated decay constant(s), neutron mean generation time, and neutron mean lifetime are also calculated. As discussed in Section 3.4, kinetics parameters are used for modeling time-dependent