From:	Michael Orenak
To:	Darrell Gardner; Drew Peebles
Cc:	Pravin Sawant; Matthew Hiser; Edward Helvenston; William Jessup; Candace de Messieres
Subject:	Hermes 2 Audit questions 2.5-2, 2.5-3, 4.3-2, 4.3-3, 4.5-1, 5.1-1, 5.1-2, 5.1-3, 5.2-2, 5.2-3, 5.2-4, 5.2-5, 6.3-1, 9.1-1, 9.1-2, 9.6-1, 13.1-7 through 10, TR-1, TR-2, TR-3
Date:	Tuesday, January 2, 2024 3:46:00 PM

Darrell and Drew,

Below is the sixth set of audit questions for the Hermes 2 General Audit. The NRC staff would like to have a discussion regarding these questions when Kairos is ready. Kairos is welcome to post answers to these questions on the Kairos electronic reading room, but no written answers are requested by the NRC staff at this time.

PSAR Section	Request Number	Request/Question
2.5, "Geology, Seismology, and Geotechnical Engineering"	2.5-2	Section 2.5.5.2, "Plant Layout and Foundation Interface," of the Hermes 2 PSAR states that the reactors will be located near Borings B-3 and B-6. In addition, Section 2.5.5.2 states that the foundation mat will be placed "directly over sound rock or over thin concrete fill." Figure 2.5-11, "Location of the Facility at K-33," indicates that the reactor foundation level may be in the Pond Spring Formation, which is thin-to-medium bedded limestone, but also shows the Murfreesboro Limestone at the far southeastern corner of the Hermes 2 reactors. Figure 2.5-22, "Foundation Interface," shows that the proposed foundation will be approximately at 745 ft. elevation and does not show the contact between the Murfreesboro Limestone and Pond Spring Formation in the subsurface or at the foundation level. a. Clarify the specific lithology of the foundation level rock, stating if the foundation level for both units is entirely within the Pond Spring Formation or if the far southeastern portion of the foundation will be underlain by the Murfreesboro Limestone. b. Discuss whether Figure 2.5-22 needs to be updated to account for these foundation rock variations.
2.5, "Geology, Seismology, and Geotechnical Engineering"	2.5-3	Borings B-3 and B-6 are the closest borings to the proposed Hermes 2 foundations that are at ~745 ft. elevation and ~20 ft. deep (ground level is at ~765 ft. elevation). The Due Diligence Report shows the multiple formations in those borings. B-3 terminated at 14.1 ft. deep where weathered rock was encountered; however, the formation is not documented in the borehole log. Boring B-6 is ~35 ft. deep. The borehole log of B-6 indicates moderately weathered and highly fractured rock at elevation 746 to 746.4 ft. (sample RC-3). Additionally, a clay-filled solution feature was

		observed at elevation 742.7 to 744 ft. Sample RC-5 at elevation 731 to 733 ft. indicates slightly weathered rock with clay-filled fractures. a. Section 2.5.5.2 of the Hermes 2 PSAR states, "The bearing system for the safety-related structures is a foundation mat resting directly over sound rock [*emphasis added*] or over a thin concrete fill. It is anticipated that sound bedrock [*emphasis added*] will be very close to the elevation of the bottom of the basemat." Additionally, in the supplement regarding boring B-6 posted to the Kairos electronic reading room on December 21, 2023, Kairos characterized the material encountered at a depth of 25 ft in B-6 (elevation ~741 ft) as "adequate for foundation purposes." However, taking account for the dip of the rock units at the site, this section of suitable rock may not be continuous at this depth and elevation throughout the excavation footprint. Discuss whether the observations from borings B-3 and B-6 are considered "sound rock" as described in Section 2.5.5.2 and whether this "sound rock" is expected to occur continuously at the foundation elevation throughout the entire excavation. b. Discuss the plan, if any, to characterize the weathered rock and clay-filled solution features and fractures observed at and below the proposed foundation level of the Hermes 2 reactors, including their spatial extents and mitigation of their effects on the reactor foundation stability. c. The description of sample RC-4 is the exact same as RC-5, despite being different elevations. However, the boring logs note that RC-4 has a recovery of 100% and RQD of 90% while RC-5 has a recovery of 96% and RQD of 68%. Clarify which sample (RC-4 or RC-5) is associated with the description given in the borehole log of B-6 and provide a description for the other. Also, clarify whether the lower RQD at RC-5 will affect the stability of the proposed foundation level closer to the elevation of RC-4.
4.3, "Reactor Vessel System"	4.3-2	Since the Hermes design contains graphite components that can oxidize during an air ingress event, discuss whether Kairos plans to assess potential combustible

		gas generation due to oxidation of graphite as part of a future operating license application.
4.3, "Reactor Vessel System"	4.3-3	Although thermal aging is mentioned in the Kairos topical report KP-TR-013-P, "Metallic Material Qualification for the Kairos Power Fluoride Salt-Cooled High-Temperature Reactor," in the context of corrosion coupons, it is not clear how embrittlement due to thermal aging is incorporated into the Hermes 2 design as it is not explicitly discussed in PSAR Section 4.3, "Reactor Vessel System." Please discuss whether Kairos evaluated thermal embrittlement for an 11-year lifetime plant. If so, discuss whether it was judged to be a significant factor and describe how it may eventually be incorporated into design of metallic safety-related SSCs, which includes the effect on loss of tensile strength and embrittlement in welds from thermal aging.
4.5, "Nuclear Design"	4.5-1	The vessel irradiation discussion in PSAR Section 4.5.3.2, "Nuclear Design Analysis Inputs to Other Sections," remains unchanged from the Hermes 1 PSAR. State whether the preliminary best estimate dpa plus uncertainty for Hermes 2 is still within 30% of the low-level irradiation value taking into account the Hermes 2 vessel lifetime of 11 years (as opposed to 4 years for the Hermes 1 design).

5.1, "Primary Heat Transport System"	5.1-1	PSAR Section 5.1, "Primary Heat Transport System," states that the primary coolant (Flibe) in the primary heat transport system (PHTS) is maintained at a higher pressure than the intermediate coolant (BeNaF).
		a. In case of an intermediate heat exchanger (IHX) leak or break, please discuss if:
		    a. the consequences of not maintaining the pressure differential are limited only to the contamination of Flibe,
		    b. there are any nuclear safety concerns stemming from contamination of Flibe by BeNaF, and
		    c. Kairos has established an acceptable level of contamination of the Flibe by BeNaF.
		b. Provide the acceptable pressure differential between the primary and intermediate loops and the basis for this value.

5.1, "Primary Heat Transport System"	5.1-2	Paragraph 10 CFR 50.34(a)(3)(iii) requires, in part, that construction permit applicants provide information relative to materials of construction as part of the preliminary design information for a proposed facility. State the materials to be used to construct the PHTS and intermediate heat transport system (IHTS). Additionally, state whether the materials will be galvanically similar to each other and the reactor vessel

		system materials.
5.1, “Primary Heat Transport System”	5.1-3	PSAR Section 5.1 describes two heat removal systems: the heat rejection subsystem (HRS) and IHTS. a. Discuss the relationship between the HRS, IHTS, and the Power Generation System (PGS) (e.g., when plant operations transitions from the HRS to the PGS and back). b. Inadvertent actuation of the non-safety HRS could lead to overcooling. Discuss whether there are control system setpoints (e.g., minimum temperature) to avoid overcooling or freezing. c. Discuss how the HRS impacts decay heat removal system (DHRS) operation and threshold power.
5.2, “Intermediate Heat Transport System”	5.2-2	PSAR Section 5.2.1, “Description,” states that BeNaF is “thermodynamically stable, is compatible with structural materials, and has analogous properties to the primary Flibe coolant.” However, in PSAR Section 1.3.9, “Research and Development,” a new research and development activity, “Complete compatibility evaluation of the intermediate and reactor coolant chemical interaction (Section 5.1.3),” is listed. The NRC staff would like to understand the basis for the aforementioned statement in PSAR Section 5.2.1 and the research activity scope discussed in PSAR Section 1.3.9, including a high-level description of: a. the compatibility evaluation process and the parameters/characteristics that will be quantified (e.g., corrosivity, radionuclide solubilities, thermophysical properties), b. the interactions with structural materials (e.g., 316H SS, graphite) that will be characterized and quantified, and c. whether the ingress of the BeNaF into the primary loop would alter thermophysical properties of the Flibe (e.g., viscosity) or change solubilities of radionuclides or salt components.
5.2, “Intermediate Heat Transport System”	5.2-3	PSAR Section 5.2.1 states that the IHTS is equipped with safety-related rupture disks located in the intermediate inert gas system to prevent over-pressurization of the IHTS during a postulated superheater tube leak or rupture event. a. One of the stated functions of the intermediate inert gas system is to keep the intermediate coolant pressure in the heat exchangers lower than the pressure in the PHTS. Please discuss how the safety-related rupture disks, the non-

		safety-related intermediate inert gas system, and IHTS interact to maintain this pressure differential. b. State whether the IHTS rupture disk should be listed as a safety-related SSC in PSAR Table 3.6 1, “Structures, Systems, and Components.” c. State whether any preliminary calculations have been performed to size the safety-related rupture disks to maintain acceptable pressures within the IHTS. If so, please make these calculations available for NRC staff audit. d. From the discussion in PSAR Section 13.1.10.11, “IHX Failure Due to Superheater Tube Rupture or Leak,” it appears that preventing IHX failure is an important function of the safety-related rupture disks. However, this is not clear from the description of the design in PSAR Section 5.2. Please describe the safety functions of the rupture disks. e. Discuss the consequences of the IHTS rupture disks failing to burst. f. Discuss whether inadvertent operation of non-safety-related trace heating could lead to IHTS over-pressurization and rupture disk burst. g. Although PSAR Section 5.2.1 cites the need for safety-related rupture disks for overpressure protection, the remainder of the IHTS appears to be classified as non-safety related. State the consequences of IHTS failure from mechanisms besides overpressure (e.g., corrosion, creep rupture) and discuss whether Kairos has assessed the consequences of these alternate failure mechanisms.
5.2, “Intermediate Heat Transport System”	5.2-4	Provide the currently available thermophysical properties (e.g., thermal conductivity, viscosity, density, heat capacity) of BeNaF.
5.2, “Intermediate Heat Transport System”	5.2-5	Anhydrous hydrogen fluoride is used for tritium management in the IHTS. Since anhydrous hydrogen fluoride is known to increase the corrosivity of the salt, please discuss if there is any limit on the addition of hydrogen fluoride in the IHTS. Additionally, please provide information on when and how the salt will be sparged with hydrogen fluoride.
6.3, “Decay Heat Removal System”	6.3-1	PSAR Section 6.3, “Decay Heat Removal System,” states that the DHRS is credited in PSAR Chapter 13, “Accident Analysis,” for decay heat removal during postulated events that assume the PHTS is unavailable.

		Please state whether the DHRS is also credited during postulated events that assume the IHTS is unavailable.
9.1, “Reactor Coolant Auxiliary Systems”	9.1-1	PSAR Section 9.1.3, “Tritium Management System,” references the previously approved topical report KP-TR-012, “KP-FHR Mechanistic Source Term Methodology” (Agencywide Document Access and Management System Accession No. ML22088A228) to determine speciation of tritium between the salt and gas space. In Section 5.3.1, “Tritium Speciation,” of the referenced topical report, Kairos describes how the methodology relies on the redox potential and solubility of tritium in a Flibe salt. Discuss whether Kairos evaluated this portion of the methodology to determine whether use of a different (i.e., BeNaF) salt would impact tritium speciation in the IHTS.
9.1, “Reactor Coolant Auxiliary Systems”	9.1-2	PSAR Figure 5.1-1, “Heat Transport System and Intermediate Heat Transport System Process Flow Diagram,” shows the Heat Rejection Radiator (HRR) and the IHX as components of the reactor coolant system. PSAR Section 9.1.4.1.3, “PHTS Fill/Drain Tank,” states that, “the PHTS fill/drain tank is sized to hold the PHTS and the IHX reactor coolant inventory,” but does not mention the reactor coolant inventory for the HRR (which is a component of the HRS). State whether the Hermes 2 PHTS fill/drain tank is sized to also include the reactor coolant inventory of the HRS.
9.6, “Possession and Use of Byproduct, Source, and Special Nuclear Material”	9.6-1	By letter dated October 27, 2023 (ML23304A144), Kairos stated that its responses to Hermes audit questions were applicable to Hermes 2, with the exception of Hermes General Audit Questions 1.3.9-1 and 9.6-2. Regarding Hermes General Audit Question 9.6-2, Kairos stated that this question does not apply to Hermes 2 because the Hermes 2 design includes a secondary coolant loop, and therefore text regarding tritium in secondary coolant is included in the Hermes 2 PSAR. Hermes 2 PSAR Section 5.2 and Section 9.9, “Power Generation System,” discuss the expected presence of tritium in the IHTS and PGS, respectively, and also discuss how tritium in these systems will be controlled. However, Hermes 2 PSAR Section 9.6, “Possession and Use of Byproduct, Source, and Special Nuclear Material,” only appears to discuss tritium in the primary coolant system, fuel pebbles, pebble handling and storage system, and tritium management system. Clarify and discuss whether PSAR Section 9.6 should be updated to address the presence of tritium in additional systems that are included in Hermes 2.
Chapter 13, “Accident Analyses”	13.1-7	The language in PSAR Chapter 13 and topical report KP-TR-022, “Hermes 2 Postulated Event Methodology,” has several definitive statements regarding the

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<tr><td></td><td></td><td>bounding nature of certain limiting events. However, the staff understands based on previous discussions (e.g., November 2023 audit) with Kairos that the limiting nature of these events will be validated as part of developing the Hermes 2 final safety analysis report (FSAR) (see example below; emphasis added).

<table>
<tr><th>PSAR Section 13.1.2, “Insertion of Excess Reactivity”</th><th>Staff’s Understanding Based on Previous Discussions</th></tr>
<tr><td>“The limiting insertion of reactivity event is initiated by a control system error or an operator error that causes a continuous withdrawal of the highest worth control element at maximum control element drive speed…”

“This postulated insertion of excess reactivity bounds other insertion of reactivity events, including:…”</td><td>The limiting insertion of reactivity event is assumed to be initiated by a control system error…

Kairos will confirm in the application for an operating license that this postulated insertion of excess reactivity bounds other possible insertion of reactivity events, including:</td></tr>
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Clarify whether Kairos intends to update PSAR Chapter 13 and KP-TR-022 to reflect the preliminary nature of the Hermes 2 safety analyses.</td></tr>
<tr><td>13.1, “Initiating Events and Scenarios”</td><td>13.1-8</td><td>The language in PSAR Sections 13.1.2, “Insertion of Excess Reactivity,” through 13.1.9, “Internal and External Hazard Events,” does not appear consistent with the audit discussion held on November 6, 2023. Specifically, the PSAR definitively identifies the limiting event in each section (category). The absence of any changes to language in Chapter 13 of the Hermes 2 PSAR regarding limiting events, as compared to Chapter 13 of the Hermes 1 PSAR, suggests that the events evaluated for Hermes 1 facility are bounding for the Hermes 2 facility. However, Kairos stated during the audit discussion that calculations are not available to completely justify the assumed limiting event for each category. Rather, the limiting events in the Hermes 2 construction permit application were selected primarily using engineering judgment. Kairos’s stated intent was to capture all the events in each category to provide assurance that all events would be checked and the</td></tr>
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		limiting event confirmed at the FSAR stage when final design details are available and sensitivity studies can be performed. Paragraph 10 CFR 50.34(a)(4) requires, in part, that construction permit applicants include “[a] preliminary analysis and evaluation of the design and performance of [SSCs] of the facility with the objective of assessing the risk to public health and safety resulting from operation of the facility and including determination of the margins of safety during normal operations and transient conditions anticipated during the life of the facility, and the adequacy of [SSCs], provided for the prevention of accidents and the mitigation of the consequences of accidents…” Please clarify what analyses and evaluations have been performed in support of the Hermes 2 construction permit application, considering the addition of the IHTS and PGS, and provide a justification for how these analyses meet the relevant regulatory requirements. Further, discuss the analyses that Kairos expects to perform in support of a future Hermes 2 operating license application, considering the information in PSAR Chapter 13 and KP-TR-022 regarding limiting events and the November 6, 2023, audit discussion.
13.1, “Initiating Events and Scenarios”	13.1-9	PSAR Section 13.1.2 states that the consequences of increased heat removal events are bounded by a postulated insertion of excess reactivity event; this is also discussed in KP-TR-022 Section 3.2.2.3. However, limited information has been provided to-date regarding the potential consequences associated with a Flibe freezing event. With the introduction of the IHTS and PGS, the staff expects that the potential for overcooling due to increase of heat removal events may be higher in the Hermes 2 design than the Hermes 1 design. For example, new initiating events such as steam line break or spurious opening of a turbine bypass valve or steam safety valve may lead to overcooling and approach the freezing temperature of Flibe in the reactor vessel. Discuss whether the consequences of a Flibe freezing event are also bounded by the limiting reactivity insertion event.
13.1, “Initiating Events and Scenarios”	13.1-10	PSAR Figure 4.6-1, “Coolant Flow Path,” shows that there are flow paths for circulation of Flibe through the graphite bottom core support channels. Discuss whether a partial blockage of core channels is considered in the safety analysis or whether this event is bounded by other postulated events. Additionally, discuss if a partial core blockage or flow degradation could lead to over-heating of portions of the core.

KP-TR-022, "Hermes 2 Postulated Event Methodology"	TR-1	KP-TR-022 Section 3.2.2.7, "Intermediate Heat Exchanger Tube Break". a. KP-TR-022 Section 3.2.2.7 postulates that a complete break of one IHX tube is the limiting event. Discuss whether any other break scenarios were considered that could be more limiting (e.g., partial breaks of multiple tubes due to a common-mode degradation mechanism). b. KP-TR-022 Section 3.2.2.7 states, "A conservative amount of Flibe is assumed to flow into the intermediate loop to mix with the intermediate salt." Provide the basis for why the assumed Flibe flow rate is conservative. c. State which reactor protection systems signal(s) would lead to a reactor trip for an IHX tube break event. d. Discuss whether a break in the IHX tube(s) would lead to over-pressurization of the IHTS and safety-related rupture disk burst. If so, discuss whether the consequences of this event would still be bounded by the salt spill event.
KP-TR-022, "Hermes 2 Postulated Event Methodology"	TR-2	Please state whether the IHTS, IHX, and HRS are included in the plant KP-SAM model. If so, discuss how they are modeled.
KP-TR-022, "Hermes 2 Postulated Event Methodology"	TR-3	Given the addition of the IHTS and PGS relative to Hermes 1 design, discuss whether Kairos will consider initial IHTS and PGS conditions as input parameters with sensitivities similar to the parameters listed in KP-TR-022 Table 4-4, "Input Parameters Considered for Postulated Events."

If you have any questions or need clarifications on the questions before the discussion, please do not hesitate to contact me. This email will be added to ADAMS and will be made public.

Mike

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