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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

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UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

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701ST MEETING

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

(ACRS)

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OPEN SESSION

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WEDNESDAY

NOVEMBER 30, 2022

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The Advisory Committee met via Video-Teleconference, at 8:30 a.m. EST, Joy L. Rempe, Chairman, presiding.

COMMITTEE MEMBERS:

JOY L. REMPE, Chairman
WALTER L. KIRCHNER, Vice Chairman
DAVID A. PETTI, Member-at-Large
RONALD G. BALLINGER, Member
VICKI M. BIER, Member
DENNIS BLEY, Member
CHARLES H. BROWN, JR. Member
VESNA B. DIMITRIJEVIC, Member
MATTHEW W. SUNSERI, Member

DESIGNATED FEDERAL OFFICIAL:

WEIDONG WANG

ALSO PRESENT:

SAMUEL CUADRADO de JESUS, NRR
BILL JESSUP, NRR
JORDAN HAGAMAN, Kairos Power
RACHEL HAIGH, Kairos Power
BRANDON HAUGH, Kairos Power
RYAN LATTA, Kairos Power
GUS MERWIN, Kairos Power
NADER SATVAT, Kairos Power
JIM TOMPKINS, Kairos Power
CHRIS VAN WERT, NRR

A-G-E-N-D-A

P R O C E E D I N G S

8:30 a.m.

CHAIR REMPE: Well, good morning. The meeting will now come to order. This is the second day of the 701st meeting of the Advisory Committee on Reactor Safeguards. I'm Joy Rempe, Chairman of the ACRS. Other members in attendance are Ron Ballinger Vicki Bier, Charles Brown, Vesna Dimitrijevic, Walt Kirchner, Dave Petti, and Matt Sunseri.

Member March-Leuba is excused for today, and Member Halnon is not present at this time, but he may be participating intermittently during this meeting. Nevertheless, we do have a quorum. And, similar to yesterday, the Committee is meeting in-person and virtually.

A communications channel has been opened to allow members of the public to monitor the Committee discussion. Mr. Weidong Wang is the designated federal officer for today's meeting.

During today's meeting, the Committee will consider the Kairos Fuel Qualification Methodology Topical Report. And portions of this meeting may be closed as stated in the agenda. After that we'll go back to working on some of our letters that were produced in this meeting.

The transcript of the open portions of the meeting is being kept, and it's requested that speakers identify themselves and speak with sufficient clarity and volume so they can be readily heard. Additionally, participants should mute themselves when not speaking.

At this time, I'll ask other members if they have any opening remarks, and if not, I'd like to ask Dave Petti to lead us to this topic today, please.

MEMBER PETTI: Okay, thank you. I've not received any information, so does NRC management want to say something before we get going?

Go ahead, Bill.

MR. JESSUP: Okay, thank you, Member Petti, and thank you Chairman Rempe, for the opportunity to present to the Committee this morning. My name is Bill Jessup. I'm chief of the Advanced Reactor Licensing, Branch 1, in the NRC's Office of Nuclear Reactor Regulation.

This morning the staff will be providing a brief overview of our review and the safety evaluation for Kairos Topical Report, KPTR 011, Fuel Qualification Methodology for the Kairos Power fluoride salt-cooled high temperature reactor, Revision 2. This will follow a presentation from

Kairos on this topical report.

The Kairos Report presents a series of tests, available data, and surveillance plans used to support qualification of reactor fuel pebbles utilizing TRISO fuel particles and Kairos non-power and power reactor designs.

The staff presented on this topic to the ACRS Kairos subcommittee on October 17th. And during that meeting, several important topics relative to the fuel qualification methodology were addressed.

The staff's slides today will provide an abbreviated version of the subcommittee presentation with a focus on some of the key issues raised during the subcommittee meeting, including irradiation testing and the potential impacts of salt impurities on the fuel.

As mentioned during the October subcommittee meeting, the HERMES test reactor construction permit review is well underway. The topical report we're discussing this morning, and two others that are going to come to the Committee early next year, are referenced in the Hermes application. And finalizing these topical reports will be necessary before the construction permit review can be completed.

We're looking forward to this morning's discussion, and are appreciative of the Committee's insights and comments on this very important topic. And with that, I'll turn it back over to you, Member Petti and Chairman Rempe.

MEMBER PETTI: Okay. With that, I think, Kairos, are you ready?

MR. TOMPKINS: We are ready. Can you hear me?

MEMBER PETTI: Not that great, actually, a little bit louder if possible.

MR. TOMPKINS: Okay, can you hear me?

CHAIR REMPE: Much better, it was a user here in the room.

PARTICIPANT: Thank you.

MEMBER PETTI: Thank you. Go ahead.

MR. TOMPKINS: All right, thanks, David. So my name's Jim Tompkins, Manager of Fuel Licensing at Kairos. With me here in Alameda we have Ryan Latta, who's the principal engineer for fuel qualification, Gus Merwin, who is manager of salt chemistry for Kairos, Nader Satvat, who is our manager of core design, Tim Drzewiecki who, I think, almost all of you know. He's in the room with us as well. He's in the Safety Analysis Group here at Kairos.

We're a little scattered today, so I'm going to kind of go through -- I think we have a number of folks calling in. So, Micah, are you on?

Sounds like no Micah. How about Brandon, are you on?

MR. HAUGH: Yes, I'm on, Jim.

MR. TOMPKINS: Okay. You want to just introduce yourself, and title, and everything?

MR. HAUGH: Sure. My name is Brandon Haugh. I'm the senior director of Modeling and Simulation at Kairos Power.

MR. TOMPKINS: Okay. And we also have Rachel Haigh. She's on in Charlotte. And is anyone else on from Kairos?

MR. HAGAMAN: Yeah, Jim, this is Jordan Hagaman, Director of Reliability Engineering and Quality Assurance at Kairos.

MR. TOMPKINS: Thanks, Jordan. Anyone else? All right, well, that's the group. I think we can go ahead and get started. So Rachel, you want to, can you go to the first slide?

So some of this material we presented. What we've put together is an abbreviated presentation that summarizes the overall methodology. And then we've got some slides discussing a couple of what we

thought were the key issues from the subcommittee meeting.

So I'm going to start with this first slide and just go over the definition that we're working to which is qualified fuel is fuel for which there's a reasonable assurance that exists that the fuel fabricated per the specification will perform consistent with the safety analysis. And so I think there's an important consideration there that it is tied to the facility you're putting it into.

Fuel qualification methodology is applicable to both test and power reactors. So we tried to write this generally. The qualification is subject to the conditions and limitations described in the topical report and some conditions added by the NRC in their SER. Some of the conditions apply to the power reactor only. And so I just wanted to point that out.

We intend to demonstrate qualification met this. The topical is the methodology for qualification. It's not the actual qualification. So we're actively initiating and starting to perform some of our lab testing. The demonstration that the fuel is officially qualified for Hermes, which will obviously come first, will be documented in safety

analysis report documents as part of the licensing, which we're doing initially under Part 50.

So with that, I'm going to turn it over to Ryan, and he's going to walk through the -- give you a high level of the methodology and then respond to some of our questions.

MR. LATTA: Okay. Ryan Latta speaking for Kairos Power, Fuel Qualification Engineer. I'm first going to give a couple slides that go point by point through sections of the methodology, and then we'll follow that up with a few more slides on some specific questions that were raised in the subcommittee meeting.

Okay. So starting with the first section of the report, we discussed the U.S. and international experience with TRISO fuels. There's a wide range of experiences in multiple countries in the use and development of TRISO fuel and different fuel forms. And then there's subsequent use in gas reactors that were their test reactors or demonstration commercial type reactors.

This kind of culminates in the U.S. in the initiation of the AGR Program in the early 2000s. We ran the AGR Program to develop a particle design and perform the radiation and safety testing to qualify

that fuel system. The AGR 1 and AGR 2 tests were written up into a topical report written by EPRI. And that was reviewed by the NRC and issued an SER.

And Kairos leverages this AGR particle design and the data used in the AGR 1 and 2 in this issued SER and TR, topical report, for our application in an FHR, okay.

That section of the report is the Kairos Power fuel element PIRT. And so Kairos Power performed a fuel PIRT exercise with the goal of looking at the figure of merit where the figure of merit was fission product transport and release from the fuel under different conditions of normal operation and accidents in our application to an AP-FHR.

In doing this, we identified over 200 phenomena related to fuel performance and then identified the high importance phenomenon for further investigation. These were high importance levels and low -- medium to low mileage levels. And that kind of forms a lot of the basis of the qualification methodology, and specifically the pebble laboratory test section that I'll talk about later.

Okay. Next section is on the fuel specification, manufacturing, and quality control

through inspection. So as I previously said, Kairos leverages the AGR particle design. We have a fuel specification that's equivalent to what was used in the AGR Program.

Currently we're developing TRISO manufacturing and annular fuel pebble development in an in-house program to produce a quality commercial product. Product that is produced goes through a quality control process where inspection is used to ensure that the fuel specification is met. The fuel indeed does meet the product specification equivalent to the AGR Program. And in forming that characterization, we demonstrate that quality is maintained.

Okay, next section is the fuel qualification envelope. So as I previously said we're leveraging the AGR Program, and this defines our fuel qualification envelope. Specifically in this case, we're leveraging AGR 2 that was documented in the EPRI TRISO topical report. And so the fuel qualification envelope considers irradiation test conditions and transient conditions.

There are four key parameters for normal operation. These are power, temperature, burn-up, and fluence. And the initial reactor has to operate

within this envelope for steady state conditions and without needing additional irradiation test data outside of that -- if you're going to operate outside of that test data within the commercial reactor, then you need additional irradiation testing to meet the new envelope.

Additionally, there are temperature limits for transient conditions, and also noting that there are significant margins in the temperature regime which AGR was tested. Tests were conducted versus the KB-FHR designs for both the test and power reactor.

Next slide, please. Okay, the next section of the report is on pebble laboratory testing. And so this test program came out of the findings of the PIRT. The high priority items identified were to be investigated in this test program with the goal of demonstrating that the pebbles and particles meet function requirements, that there's no physical damage or interaction of particles with FLiBe.

And so there are two categories of testing that are being worked on. The first category is mechanical test of the pebble. The second category is material compatibility testing of the pebble.

The prescribed mechanical tests are pebble compression, pebble impact, tribology, which is wear

behavior, and then molten salt infiltration behavior. The material compatibility tests are interactions of the pebble with FLiBe or with air. And then for each of these specific tests, acceptance criterias were defined within the topical report.

The next section, fuel irradiation qualification testing, so if you, as I previously described, if you are outside of the fuel qualification envelope, it requires a fuel irradiation test. The test that's proposed is very similar to the AGR type of irradiation tests that were performed in the AGR.

We would use our TRISO fuel particles, a statistically significant number of them in our annular fuel pebble design. And then we would perform an irradiation test at the bounds of the commercial reactor to extend the bounds of the qualification envelope.

Fission product gas monitoring would be performed during the test to understand the failure fraction of fuel in the test. And then after the test, there would be PIE performed to confirm the failure fraction and the behavior of the fuel.

MEMBER KIRCHNER: This is Walt Kirchner, just a clarification. So you're just talking about

fuel particles, not fuel particles in a pebble?

MR. LATTA: No, these would be fuel particles in our annular fuel pebble design, so it would be in our annular pebble, the Kairos pebble. So they would be inside the pebble.

MEMBER KIRCHNER: Okay, thank you.

MEMBER PETTI: And, Walt, because this is for the bigger reactor.

MEMBER KIRCHNER: Yeah.

(Simultaneous speaking.)

MEMBER PETTI: Not for Hermes, right?

MR. LATTA: Yes, that's correct. Okay, that section is on fuel performance modeling. This section, for information, right, the description of models related to fuel that Kairos is using, the main focus is on KP-BISON which is the subject of a previous topical report where an SER was -- where the topical report is reviewed and an SER issued.

The KP-BISON would be validated to IAEA, and AGR data, and eventually to Kairos-produced irradiation test data. And this tool has been used for core design and source term analysis.

There's additional description of DEM and FEM models that are used to understand the flow behavior of pebbles to the core, wear, behavior, and

loads in the core, and along with mechanical behavior of the pebble.

Next section of the report is the in-service surveillance program --

MEMBER PETTI: Just to go back a question on the performance model.

MR. LATTA: Yes.

MEMBER PETTI: You plan on running the test predictions of this irradiation that's in the second bullet and then also sort of a post-test --

MR. LATTA: Yeah, yeah.

MEMBER PETTI: -- sort of thing?

MR. LATTA: Yeah, you know, for designing an irradiation test, we'll certainly be modeling it before we conduct the test. Yeah.

MEMBER PETTI: Thank you.

MR. LATTA: Okay. Speaking to Field Surveillance program, so once there's a test reactor, a commercial reactor, in those reactors there would be a surveillance program for the fuel to confirm fuel performance in the operating environment.

In this case, the surveillance program has three parts. The first part is fission product monitoring in the cover gas and FLiBe coolant for radioactivity. There's a circulating limit that's

allowable for the reactors.

Next part is the pebble inspection. So pebbles traverse the core and are reinserted into the core. As you saw, the pebbles exit the core, they are inspected for physical damage along with the burn-up being measured over their lifetime.

The third part of fuel surveillance is destructive PIE. And so pebbles that have reached their equilibrium would be extracted from the core through the pebble handling system. And they'd be sent to hot cells where PIE would be performed on test reactor pebbles and pebbles from the initial power reactor. And the objective there is to confirm fuel performance of the fuel in its application.

MEMBER PETTI: Just a question for clarification. I didn't think, based on previous discussions that we've had, that you'd actually ever get to equilibrium in Hermes in a pebble. So, that would only be pebbles in the power KB-FHR?

MR. LATTA: The maximum burnup would be much slower in the Hermes.

MEMBER PETTI: Right. So you can't monitor your PIE on a pebble that had reached equilibrium burn-up until you're downstream in with the --

MR. LATTA: It would be the --

MR. SATVAT: Yeah, this is Nader for core design. Basically, the maximum burn-up that is achievable in Hermes, based on the full lifetime of Hermes, there is a possibility of achieving equilibrium. But because of capacity factors, it might not happen.

MR. LATTA: So it would be the maximum burn-up in Hermes which may or may not be the equilibrium for Hermes.

MEMBER PETTI: Right, okay. Thanks, that helps.

MR. LATTA: Yes, thank you.

Okay, next slide, please. So that was a summary of the fuel qualification methodology. The next few slides go in to address a few questions, specific questions from the previous subcommittee meeting.

These two questions, the first was related to the presence of transition metals in FLiBe and their effect on the sodium carbide layer. Second question was related to pebble irradiation program and irradiation testing for the Hermes test reactor. So in the next couple of slides, I'll go through those, address these questions in some more detail.

Okay, first slide here says relates to the presence of transition metals in FLiBe. So we're conducting laboratory testing of the pebbles in FLiBe at temperature and pressure, and looking at pressure thresholds for infiltration of FLiBe, and we're precluding infiltration by design in the fuel so that FLiBe will not reach the fuel region of the pebble.

For any kind of mechanism to occur here, the FLiBe would have to infiltrate into the fuel region, and this would have to bring the transition metal fluorides in contact with the TRISO particle.

Additionally, the OPIC layer separates the SiC layer from the free surface of the OPIC. So you have to go through the OPIC, the metal fluorides would have to transmit through the OPIC. So you would have to have a failed OPIC contact between the salt and the sodium carbide.

The previous meeting, I brought up about AGR-567 where Capsule 1 had a significant amount of failures due to nickel ingressing into the fuel and damaging the particles. That's performed at a significantly higher temperature than KB-FHR fuel operates at. It's at least 500 degrees temperature difference or more higher in the AGR test.

Additionally, there was an overwhelming

amount of nickel in the AGR irradiation. There was an Inconel nickel-based alloy sheath covered a niobium sleeve where it is believed that the two components, nickel and niobium, formed a low melting point eutectic. And this helped to transport nickel through the system resulting in failures. Whereas in our case we have transition metal fluorides in salt.

So because of these low temperatures and difference in the system, due to these detrimental effects were active, we expect them to progress very slowly. And in the instance of TRISO failures, we are monitoring fission gas products in the gas space and the coolant spaces of the reactor. And there's a circulating activity limit that's a technical specification for the reactor. And this really ensures the safety of the system.

MEMBER PETTI: So let me -- there's a lot on the exhibit I don't understand. We have a different understanding of the system. I'm not worried about transition metal fluorides. If you're doing redox control you will have elemental transition metal because of the redox state. Those metals, even though it doesn't fully wet a pebble, they will be in contact and can get into the pebble.

It doesn't have to get into the TRISO

particle, it just has to get into the matrix. There's old data from General Atomics where they introduced iron from their furnace that fell into their compacting equipment. And a little bit of iron got in and attacked.

Second, you've seen the letter, the draft letter. There are references to show that transition metals will react with silicon carbide much more quickly. There's 500 degrees C lower. That's irrelevant. There's data out there from diffusion experiments to show that if you can get the material to the silicon carbide layer, even at lower temperatures, that you will start to get the corrosion to occur.

Now, so the question is, can you get it there? That's the big issue.

MR. LATTA: Right.

MEMBER PETTI: And I would argue that there's so little experience in this new first of a kind system that that's an issue that should be thought about.

MR. TOMPKINS: Let me just respond, first by saying that, yeah, we agree that the, you know, even at lower temperatures it's still going to be a problem. But our understanding is that it would be

slower. But the real protection is making sure the salt doesn't get there in the first place. That's really what we're trying to design out of the system. And I don't know --

MEMBER PETTI: So again, I have this mental problem, because I read a topical report that said that the tritium is going to get all into the graphite. We're going to mass transport all the tritium that's produced in the FLiBe and get into the graphite. But we're not going to get any of these metallic elements that are in the salt to the surface of the graphite.

They're going to pretty much get there by the same mechanism which is mass transport in the liquid. So again, I'm having trouble with the physics in trying to put the whole picture together.

MR. MERWIN: This is Gus Merwin from salt chemistry. I'll take maybe two small points. If redox control is implemented, it'll be implemented in the chemistry control system which is separate from the reactor core as well as the primary heat transport system. And so the making of metallic particles would be physically separated from the fuel region of the core. And then that --

MEMBER PETTI: What does that mean? I

don't understand what you're talking about. If you set the redox, you set the equilibrium condition in the entire coolant system. You agreed to do it, that's fine that you're doing it outside the core, that's an easy place to do it. It makes sense. But whatever you do, you set that chemical equilibrium across the entire system. Otherwise, it wouldn't work.

MR. MERWIN: I agree. The goal of redox's potential is it's going to keep those transition metals in a metallic form which would not bring them into the reactor coolant. They would stay in the element.

MEMBER PETTI: But they're coming in off the walls, all the surfaces.

MR. MERWIN: Which would make them fluorides. They'd be in an oxidation process.

MEMBER PETTI: And then they would be reduced to elemental because of the redox condition.

MR. MERWIN: I don't believe that they would first oxidize and then reduce in the salt. If the system's at equilibrium, there would be either a driving force to oxidize them or a driving force to reduce them. Having both of them in parallel doesn't make sense to me.

MEMBER BALLINGER: Have you folks produced what amounts to a PORV diagram for this system.

MR. MERWIN: Yes, but we are not crediting that in this fuel performance topical.

MEMBER BALLINGER: That's where they would find a few and be able to define the conditions, the electrochemical conditions, so potentially the system. And you could -- that's where they map the various species.

MEMBER BALLINGER: Correct --

MEMBER PETTI: There will always be an equilibrium between the oxide and the metal. And if you're doing redox control, the oxide should be very low, right?

MEMBER BALLINGER: And you have to know where the potential actually is with respect to --

MEMBER PETTI: And if they do what they're going to do, which again, I don't want to get into details, the way they're going to control the redox, you keep it fairly low. So they should be elemental.

But those elements, it's coming off all the metal. That's why there's a lifetime on the vessel. Go ahead, keep going.

MR. LATTA: Okay. We can move to the next slide if there's no more comment.

Okay? The next two slides talk to these --

COURT REPORTER: Just a friendly reminder from the court reporter to identify yourself as you speak.

MR. LATTA: Okay. This is Ryan Latta speaking. The next couple of slides talk to the issue you brought up about elutriation testing for the test reactor, some technical discussion and discussion of the licensing of a test reactor.

So this first slide, fuel causation methodology ensures the reasonable assurance and demonstrates that through the test program that's proposed. Additionally, in this reactor, there's the additional barrier in the core of having FLiBe present as an additional and separate barrier for the release of fission products.

And that mitigates safety concerns within the reactor itself. The AGR Program extensively tests radiation tested TRISO particles, and that defines our qualification envelope.

Kairos, as I've discussed, leverages the TRISO particle design and ensures, through manufacturing and inspection, that a high quality fuel form is produced. And that is in compliance with the

fuel specification for this particle type.

Speaking to the test reactor itself, there's a defense-in-depth philosophy here within the core, use of TRISO particles plus five coolants, previous discussion of different gas reactors operated at higher normal operating and accident temperatures, whereas these FHR temperatures and accidents in normal operations are on the lower end. The combination of these diverse and defense-in-depth approaches ensure the safety of the reactor.

Additionally, in the case of fuel failure, surveillance is being performed, activity is monitored in the cover gas space and in the coolant spaces on the reactor. And there's a circulating limit on maximum allowable activity that will affect operations as it's approached. Because of this, it represents no challenge to the public health and safety.

Next slide, please.

MEMBER KIRCHNER: Excuse me.

(Simultaneous speaking.)

MEMBER KIRCHNER: This is Walt Kirchner. Oh, sorry, Dennis, go ahead.

MEMBER BLEY: Okay, thanks. I've been stewing over that last discussion, Dave, and Ron, and you folks from Kairos' discussion. The PORV diagram,

and showing where you live on that, and the different processes ought to be helpful. You said -- Kairos says they have one. But they don't think they need it here. We seem to have a difference of opinion which perhaps that would help.

Is that something you could share in a closed session? And, Dave, I wonder if that would help from your point of view?

MEMBER PETTI: I think I know what Ron was asking for. I mean, have it in my head.

MEMBER BLEY: I mean, you've got the PORV diagram in your head is what it sounds like.

MEMBER PETTI: Yes.

(Laughter.)

MR. MERWIN: This is Gus Merwin, manager of salt chemistry. We can talk in more detail in the closed session. There is boundary limits for redox control that are stated as part of source term topical that limit the, at least on the fluoride scale, the redox potential of the salt.

But we are intentionally not crediting it for fuel performance strictly because we do not believe that salt chemistry is related to fuel performance, because interaction of the salt liquid with the TRISO is precluded by design.

So the chemistry control system and how we operate the salt chemistry, in our opinion, I don't want to be to bold here, but it's not related to TRISO performance. That's in the boundary of the statements in the topical.

MEMBER BLEY: Well, I kind of got that was your position, but it might help.

PARTICIPANT: Certainly an added supporting thing though.

MR. MERWIN: Certainly.

MR. TOMPKINS: Well, could we provide more discussion in a closed session, Gus? Do you have --

MR. MERWIN: Certainly.

MR. TOMPKINS: Okay, all right. Maybe that's something we do in the closed session.

MR. LATTA: Okay. Ryan Latta speaking again. So this is our final slide. So the Hermes test reactor provides important confirmation of the FHR technology and supported deploying our commercial reactor. The Hermes reactor is a full integral test of Kairos fuel for the application in the power reactor.

And in looking at the Atomic Energy Act, licensing of test reactors, there is significant latitude related to the licensing of test reactors.

I'll just read the first quote here, but it says in issuing licenses under the subsection of the AEA, the Commission shall impose the minimum amount of such regulations to fulfill its obligations under the act.

And so in conclusion, there's been extensive testing of TRISO fuel under the DOE AGR Program along with Kairos Power's laboratory test program of the fuel pebble form and its manufacturing programs.

And this also, in addition to the defense-in-depth and diverse safety of the FHRs and retention of radionuclides, cites the TRISO fuel, combination of the TRISO fuel with the five coolants and the monitoring of fuel, provides the reasonable assurance of the protection of public health and safety which is consistent with the AEA.

When considering this project as a whole and its application to the FHR, we're able to demonstrate that we meet the public health and safety consistent with the Atomic Energy Act.

MEMBER KIRCHNER: This is Walt Kirchner. Let me just understand what you're saying here. So Hermes is part of your fuel qualification methodology AGR then? And the testing in Hermes will be the qualification of your fuel --

MR. TOMPKINS: No.

MEMBER KIRCHNER: -- for reactor application.

MR. TOMPKINS: No, actually not. The testing for the power reactor will probably be done in an oxide test facility like a patent or something like that. Because we're trying to expand the qualification envelope. We need it to expand the qualification envelope for the power reactor.

But, you know, I -- this is James Tompkins, sorry about that. But clearly, we're going to, you know, we're going to look at what happened in Hermes, and we're going to factor that. That'll be part of the qualification, in a sense.

But it's not directly tied to it. I mean, and part of the reason for that is that we might decide at some point we're not going to it in Hermes. I mean, I can't guarantee that we're going to go over. I mean, we plan to. So we need a way to expand that envelope so we would do that testing, most likely in an outside facility. That answer your question, Walt?

MEMBER KIRCHNER: Yes, part way. Can you go back to the previous slide?

MR. TOMPKINS: Okay.

MEMBER KIRCHNER: Well, the reason

irradiation testing was done for all HTGRs wasn't the temperature. It was to qualify the fuel, because the whole argument is that this is functional containment. And you had to take production scale fuel and test it, and irradiate it to demonstrate that the finished product didn't have defects from the manufacturing process.

Let me ask a few other questions. Who's going to make your fuel?

MR. TOMPKINS: I think, ha, ha, I don't want to --

MEMBER KIRCHNER: And a manufacturing spec process is, this is, you know, operating these coating machines at scale is something of a black art.

MR. TOMPKINS: Yeah.

MEMBER KIRCHNER: And one needs to have a lot of trial and error before you get to the quality that's required from the EPRI spec.

MR. TOMPKINS: I don't think we can announce who's making our fuel yet. But I will say that we've expended significant resources in the last year or so making pebbles, and also testing how to make particles. And so that's underway.

MR. LATTA: And also through the ARDP we worked with the National Laboratories through CRADAs

with Oak Ridge and INL.

MEMBER KIRCHNER: Well, my point's a subtle one. It's not until you actually, whether you make it or you contract for someone to make the fuel, you've got to stand up that production line and make significant quantities of fuel and test it before you have confidence that you've got a product that you can actually put in the reactor. And I'm assuming that's part of the Hermes demonstration.

MR. MERWIN: Yeah, and that's part of what Ryan talked about, the pebble development process that we're doing where, as we make pebbles, and we make particles, we learn from that. And we've already made some adjustments that were discussed at the last meeting.

For example, we found in making pebbles that the pressures were too high. And we were breaking, you know, we were causing breakage. And so we revised the process to reduce the pebbles, or to reduce the suppressing pressure.

MR. LATTA: Yeah, so this is Ryan Latta speaking. So in the development program there's, you know, there's extensive characterization of the fuel post fabrication, you know, use of the big consolidated leach-burn-leach process, use of other

characterization techniques to inspect the TRISO particles after they've been incorporated into a fuel form.

Additionally, in talking to defense in depth here and the difference between -- with gas reactors, you know, in this core we also have FLiBe as a containment. And it was just pointing out that temperatures are low in an FHR which, you know, reduce the transport of fission products. And these are additional barriers of safety that are not present in other reactors that have been licensed with TRISO fuel.

MR. TOMPKINS: And by the way, we know who's going to make our fuel. I don't think we've, you know, officially announced it yet. So that's why I'm hesitant to say.

MEMBER KIRCHNER: Thank you.

MR. LATTA: Are there questions?

MEMBER PETTI: Yeah. So what I'm struggling with, and members, I need help here, is that this is new information that's not in any of the written documentation. And I was told once by senior ACRS members that this is nice. But we have to go by the written record.

This is very helpful. I mean, I expected

the last slide that did say, because of the test reactor, they got a light touch. That's not written down anywhere. But that, they're saying that. It's not in the SE. It's not in the topical report. And so it is this missing context in my opinion.

And just read the topical report because, A, because it's time to do both, it's time to do it for the power reactor and for Hermes. But some of this would be, if it was in the written documentation, would help put more context around this.

CHAIR REMPE: And, again, the latest version of a draft letter that I've seen basically points out that the draft SE needs some enhancement before it should be issued. And we may want to change some of this. But again, I mean, that's where we're at on what should be said. Because, again, if there's also discussion about the chemistry and to go like that, that needs to be documented.

MEMBER PETTI: Okay. Any other comments, members?

MEMBER KIRCHNER: Can we see the last slide again? I'm just saying, so the intention is, going forward, Kairos will do pebble testing in another reactor to get up to the temperatures and exposure that you would see for an actual power

reactors.

MEMBER PETTI: Right.

(Simultaneous speaking.)

MEMBER PETTI: Yes.

MEMBER KIRCHNER: Yeah, okay.

MEMBER PETTI: You know, historically, in TRISO irradiation, your radiation comes as two functions. One is performance. The other is confirmation of manufacture. Because the spec historically has been viewed as never being absolutely, 100 percent, you know, perfect, just because of the history of TRISO fuel. So they're separate here. And that's the subtlety.

Any other questions, members? If not, I guess we can turn to staff.

MR. CUADRADO: Yeah, this is Samuel Cuadrado from the staff. I'll be running the slides for the staff.

MEMBER PETTI: Okay. Give us a minute.

MR. CUADRADO: Okay.

MEMBER PETTI: They're getting up to the front table here.

MR. CUADRADO: All right.

MR. VAN WERT: Good morning, my name is Chris Van Wert. I'm staff, and I will be presenting

our review on the Kairos Power Topical Report, KP-TR-011, field qualification methodology for the Kairos Power fluoride salt-cooled, high temperature reactor.

Next slide please. So Kairos requested staff review approval of the topical report. And as mentioned this morning, it covers both the power and the non-power versions of the KP-FHR. The staff's review focused on the overall fuel qualification framework, which includes but is not limited to the use of existing data, surveillance, unirradiated testing, and irradiation testing.

All right. And next slide, please. I keep trying to advance the slides myself. I apologize. So just quickly, the regulatory basis here is the same slide as from the subcommittee meeting. We cover 50.34(a) and (b), 50.43(e), as well as 10 CFR 111, additionally, PDCs 10 and 16 which were previously approved in a PDC topical report for the basis as well.

Next slide, please. The Kairos fuel qualification topical report builds heavily upon existing data, namely the EPRI topical report which provided fuel qualification for the particle level for TRISO particles from the AGR-1 and 2 program. In

addition to that, existing data regarding carbon matrix property data is used to inform their testing matrix. The staff reviewed the data that they were using and confirmed that it was applicable to given the operating conditions for the Kairos reactor design.

As in Section 39 of the topical report, they present the fuel surveillance plans for the fuel qualification. This includes cover gas monitoring, un-destructive examinations, and planned destructive examinations. And the staff found that these were acceptable for monitoring fuel performance and detecting particle failure.

Next slide, please. Section 3.6 of the topical report covered planned fuel pebble laboratory tests. And these included mechanical, tribology, buoyancy, salt infiltration, and material compatibility testing.

The staff reviewed the test plans and confirmed or determined that they were acceptable for use for determining the pebble conditions. And this is based on the sort of test conditions that were going to be used of un-radiated tests in consideration with the planned operating conditions.

And as far as the radiation testing, if I

talk a little bit more on this, this follows from this morning, but the Kairos plan is to include radiation in a gas environment, purge gas monitoring for fission gas, and also post-irradiation examinations. This was presented in 3.7 of the topical report.

And the testing methods that were used were similar to the ones used for the EPRI TRISO particle topical report and the non-destructive PIEs which include looking for damage to the fuel pebbles, as they go through the EHSS. That would help determine if there was a manufacturing flaw which would lead to damage to the pebbles as it circulated around.

And then the post-radiation examination includes the consolidated leach-burn-leach investigations to determine, or to confirm the particle fraction, failure fraction.

The staff reviewed the irradiation testing plans as presented in Section 3.7 of the topical report, and noticed again that it closely follows previously accepted testing conditions and methods and that it's acceptable for the purposes that Kairos laid out.

Next slide, please.

MEMBER KIRCHNER: Just a minor --

MR. VAN WERT: Yes.

MEMBER KIRCHNER: -- Chris. Looking ahead to the power reactors, and you would either use the results from Hermes to demonstrate the compatibility with FLiBe under the irradiation environment. I mean, irradiation and gas for a gas cooled reactor which is going to be cooled with helium --

MR. VAN WERT: Right.

MEMBER KIRCHNER: That's, you know, it's an inert gas. So that's a lot different than being in a FLiBe environment.

MR. VAN WERT: So I think we heard this morning from, I believe, from Jim Tompkins who was answering a related question. If they have results from Hermes, they'll obviously use that for informing their process and informing their decisions on the power reactor.

However, they are running pebble tests in the patent type of reactor. I don't think they've decided on where, but that will support their power reactor. So they will have that data too. So it's not completely necessary, but obviously they will be using it, and they will have that at their hand as long as Hermes is built and operated.

Next slide, please. Oh, yeah. All right, so based on conversations that we had at the subcommittee meeting and in further conversations with Kairos, of course, we went wanted to add this discussion as well.

You heard the physical description this morning in the Kairos presentation that the staff was looking at the possible sources of impurities, you know, corrosion products or LNL, iron, chromium, nickel, that can be present.

You know, the staff's review, of course, is focused on not only the transport mechanism that would potentially lead to these TRISO particles being attacked by these products, but also how would this work overall from a, or how would it be viewed from a safety standpoint?

Are we reaching that reasonable assurance of safety for the public and the environment? And so we're looking at the transport mechanism, but we're also looking at how this would play out with the reactor.

And so, you know, as you heard this morning they have the chemistry control system which will help minimize the amount of the corrosion products or elemental articles in the molten salt. If

it were to be transported, you know, they have their testing to show that the salt is not going to be infiltrating down to the fuel layer.

They also have, you know, the level of assurance when they're investigating the pebbles as they go around to ensure that there's no damaged fuel beyond the specifications that they include, their criteria for damaged pebbles.

So with this in mind, the salt should not be reaching the fuel layer. The overall system would also detect any particles that did become compromised through the cover gas monitoring system as well.

So with the entirety of that combined, so the difficulty in the transport mechanism along with the ability to detect damaged particles, sorry, damaged pebbles, as well as, you know, any early failures that were to occur, the staff found that reasonable assurance was reached in terms of public health and safety. Any questions?

MEMBER PETTI: If they could have an indication from the gas monitoring that a pebble somewhere is involved, but you don't know which one it is --

MR. VAN WERT: Right.

MEMBER PETTI: -- and you will not know

which one it is even when you to run it through the pebble monitoring system, right, you'll not do that.

It's not an issue, in my opinion, on solubility limits. They're not going to be precipitating metals stock. But, you know, real engineered system, not a perfect laboratory, 100 ppm of some of these materials could be quite reasonable.

And my mental picture, and again, I could be wrong, is anything being done outside the core is a little too late in terms of filtering. Because that graphite is huge filter. I mean, you know, graphite combination materials are used all over the place as filters, right.

And I'm pushing all this salt through. And again, it doesn't have to get into the fuel layer. That pebble is a very porous layer. It just has to get to the surface, and it'll start migrating down the surface.

You know, that's the concern. And again, I said this in the subcommittee, if you take two technologies, and you bring them together, you don't bring just the good. You also potentially bring some negatives. And you've got to think in the negative space. And that's what struck me, was that I didn't even see it.

Talk about acknowledge, there's references in the draft letter, this has been studied for electronics, actually. And it's more simple. They put iron, chromium, and nickel up against silicon carbide. And even at 600 degrees, it moves really quickly to calculate through 35 methods. So, you know, it's not purely a high temperature, you know. It can happen at low temperature.

CHAIR REMPE: Once you go on, I mean, listening to this, the subcommittee meeting and today, and I'm looking through the 11-page draft SE, do you think maybe it needs to be beefed up a bit in some of the discussion based upon, I mean, I'm seeing some more discussion in your slides than what we saw in the subcommittee. Are you guys in agreement, yeah, we probably need to revise the SE and add a bit more detail?

MR. VAN WERT: I mean, that's something that we can definitely investigate. And if you're talking about the SE, I think that's easier for the staff to do. I don't know if -- and I'm looking over at Billy a little bit here, but the current state on that, we can open up the SE, correct, and make adjustments if necessary here.

PARTICIPANT: I tend to agree with that.

CHAIR REMPE: Thank you.

MEMBER PETTI: My concern, I mean, look at this at 100,000 feet. Take Kairos out of it. You've got a new fuel flow. I'm sorry, go read the EPRI topical report. All it says is the particles are good. It doesn't say anything about the fuel element. And it says you have to qualify that yourself, each vendor, right.

At 100,00 feet, I've got a reactor, I'm going to put this fuel in with a novel coolant, and we're not actually ever going to see neutrons before the thing is actually operated. That precedent is what bothers me, because there's others out there whose fuels are nowhere near as mature this, potentially.

That's the other concern I have in the back of my mind, is that there's not enough guardrails in the SE to kind of say why you went down this road. So it doesn't look like it's a precedent for everybody, because of the importance in fuel.

MR. VAN WERT: And I definitely understand that, and I think maybe it's something you touched on earlier, I think. Also it's something maybe I should have been more clear in the SE. It was the separation between Hermes and full power.

So yeah, if another full power came in and wanted to jump straight to this, that would be different. And we are talking about Hermes here. So the purpose of the Hermes reactor is, to some extent, proved a concept. It's also to provide data, you know, for Kairos to use.

And so our approval is specific to this. They will be running their separate tests for the power reactor as well. So I do think we have to kind of keep that in our mind. They're running the best integral testing you could ever do. You know, they're building a one-third scale reactor. They will be getting the data.

I understand that it would be great to know everything before we build it, but I think we have to consider the safety impacts. So we have a good feeling that the fuel, a very good feeling that the fuel will not have these failures to begin with.

And then if you look at the rest of the, you know, the Hermes design, I think that that's the purpose of the test reactor, is to get this information.

MEMBER KIRCHNER: That was the problem I'm having is like Dave. Conceptually, I mean, Kairos should be lauded for what they're doing. And one

would hope that other advanced reactor concepts would also build what I'll call a prototype.

And I just -- it would seem to me that then the Hermes is an integral part of the fuel qualification methodology. Or if you accept the methodology without explicit reference to Hermes or a follow-on power reactor, then your limitations and conditions are subject to demonstration of integral fuel performance in Hermes. You see where I'm going logically?

MEMBER SUNSERI: Like Dave, yeah. This is -- it kind of sets a precedent. I think what Kairos is doing, personally, one person's opinion, I missed the subcommittee meeting, it's laudatory that they're building a prototype.

MR. VAN WERT: Right.

MEMBER SUNSERI: And they can test out things like quality issues of taking a novel coolant and mixing it with the pebble TRISO fuel technology.

MEMBER KIRCHNER: Yeah. Well, we'll let you go. And when you get to the conclusion, this somehow seems like that should be explicit in the SE, that this Hermes, in effect, is the fuel quality --

MEMBER PETTI: Is a part of it.

MEMBER KIRCHNER: Is a part of it, yeah.

MEMBER PETTI: No, I think that would help. It's a context issue, really. Think about reading these things four years from now or something, you know, when you've lost all of it. That's the concern that I have.

MEMBER KIRCHNER: Yeah.

MR. VAN WERT: I do want to hesitate some because, you know, I don't want to put words in Kairos' mouth as well as far as their business plans. As you heard this morning, they were saying that it's also possible they decided that, you know, Hermes costs too much, licensing is too difficult, or whatever. And so if they decide not to do that, you know, that's a business decision on their part.

And another applicant could come in, you know, or another method would have been if they were to run these simply in a laboratory setting, you know, patent or whatever, and not even do Hermes whatsoever. That's an option. That's their decision.

I do want to say hats off to them for building a prototype. Because I do think that's the best test that they could do. So I don't want to say that they have to build the prototype. But I do think that if they do they're going to -- this is what they're going to be using to inform their future

decisions.

And I think with that in mind, what they, you know, our determination was that what they have supplied is sufficient for its purpose, for building Hermes and for doing the testing there.

MR. TOMPKINS: Yeah. And if I could just add, we have no plans to not do Hermes. I don't want to kind of give a --

(Laughter.)

MR. TOMPKINS: But, you know, things change, right.

MR. VAN WERT: Yeah. There is no requirement as staff limitations that they must build it, just to be clear. Any other questions on this before we go to the next slide?

All right, next slide, this is approaching the end. Again, we're just mentioning here that in addition to the, you know, what Kairos calls limitations within their topical report, we have the one single additional staff limitation which is that future license applications for non-power, read Hermes, will include justification for the applicability of this methodology during rapid reactor transient events.

And then the next slide is conclusions.

Simply that, in conclusion, as discussed in the previous slides and presented in the staff's safety evaluation report, the staff reviewed the topical report and concludes that the fuel qualification methodology contained within is acceptable for supporting fuel qualification of the Kairos fuel pebbles in either a non-power or a power version of the KP-FHR.

And that is all. If there is any further questions, I'd be happy to answer them.

MEMBER PETTI: Okay, no other questions.

MEMBER BIER: Dave?

MEMBER PETTI: Yeah?

MEMBER BIER: Quick question which is probably for the Hermes folks, not for the staff, the Kairos folks, sorry. Is there any expectation for the timing of Hermes, assuming that things to ahead as currently planned? I probably read that someplace and have forgotten it.

MR. TOMPKINS: Yeah. I think it's in the 2026 timeframe, something like that. To start up, you mean?

MEMBER BIER: Yeah, just when is the ACRS going to see information, you know, regarding detailed plans and that kind of stuff?

MR. TOMPKINS: Well, ACRS is going to see the Hermes CP application in April, I believe.

MEMBER BIER: Perfect. Thank you.

MR. TOMPKINS: Okay.

MEMBER PETTI: Okay. I guess we'll open up for comments from the public. Identify yourself and state your comment.

Okay, not hearing any. Then I think --

CHAIR REMPE: Okay. So we --

MEMBER PETTI: Back to you.

CHAIR REMPE: Okay. We've been in session about an hour. And there was talk about a closed session. Do you want to do that? Because I don't think it'll last more than ten or 15 minutes before we take a break and read the letter, the draft letter in?

MEMBER PETTI: Do members want the closed session? No?

CHAIR REMPE: Oh, does anyone want the closed session to discuss this?

MEMBER BALLINGER: I sent stuff direct to Dave.

CHAIR REMPE: You don't want to see what they've got on their chart at all?

MEMBER KIRCHNER: Not at this point.

CHAIR REMPE: Okay.

MEMBER BIER: Are there additional Kairos presentations that were planned for closed session or just Q&A.

MR. TOMPKINS: No, no.

MEMBER BIER: Okay, thank you.

CHAIR REMPE: Because it's not in their submittal, and it's not in the SE, or maybe it's just not needed to discuss it.

So if that's the case, then let's take a -- let's see, it's almost 9:40. Let's wait until about five until, and come back, and read in the letter. Does that sound okay? It's a little bit more than 15 minutes for people like Charlie who say I never give you enough of a break.

So, okay, we're going to recess and come back in five minutes. Thank you.

(Whereupon, the above-entitled matter went off the record at 9:37 a.m.)

Kairos Power

KP-FHR Fuel Qualification Methodology Topical Report

ACRS FULL COMMITTEE MEETING

NOVEMBER 30

2022

OPEN SESSION

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Fuel Qualification Scope/Applicability

- “Qualified fuel” is defined as fuel for which *reasonable assurance* exists that the fuel, fabricated in accordance with its specification, will perform as described in the safety analysis (NUREG-2246)
- Fuel qualification methodology is applicable to KP-FHRs
  - Test and power reactors
  - Qualification is subject to the methodology and limitations described in topical report
- Demonstration of qualification will be documented in safety analysis report documents as part of a licensing application under Part 50 or Part 52

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Fuel Qualification Methodology

- U.S. and International Experience
  - Foundation of TRISO fuel particle technology
- Kairos Fuel Pebble and Particle PIRT
  - The fuel element PIRT is used to identify high priority phenomena for investigation in the fuel qualification program
- Fuel Specification, Manufacturing, and Quality Control through Inspection
  - Fuel specification equivalent to the AGR program
  - Fuel Manufacturing Development Program (e.g. pebble pressed at pressures comparable to AGR compacts)
- Fuel Qualification Envelope
  - Operation is within the bounds of existing AGR TRISO particle qualification envelope
    - If not, an irradiation test is needed to expand the operational envelope
  - Large temperature margins exist between AGR data and the KP-FHR designs for both test and power reactor

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Fuel Qualification Methodology *(continued)*

- Fuel Pebble Laboratory Qualification Testing
  - Pebble laboratory testing program will ensure that pebbles protect the particles from physical damage and interaction with Flibe
  - Pebbles tested for compression, impact, wear, infiltration, buoyancy, and compatibility with air and Flibe
- Fuel Irradiation Qualification Testing
  - A method is included for future irradiation test of a statistically significant number of TRISO fuel particles at conditions beyond the bounds of existing AGR irradiation test data to support a wider operational envelope
- Fuel Performance Model
  - Physics based models in KP-BISON are a quantifiable representation of fuel knowledge used for core design and source term analysis
- Fuel In-Service Surveillance Program
  - Pebbles inspected multiple times for damage and burnup during lifetime
  - Cover gas and Flibe monitored for radioactivity
  - Destructive PIE for both the test and initial power KP-FHR

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Questions from the Subcommittee Meeting

- There were two questions from the Subcommittee Meeting that we would like to address in more detail
  - Presence of transition metals in the Flibe and their effect on the SiC layer
  - Pebble Irradiation Program

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Presence of Transition Metals in the Flibe

- Laboratory testing program described in the topical report will demonstrate that infiltration into the fuel region does not occur
- Flibe has to infiltrate to the fuel annulus to bring transition metal fluorides to TRISO
- It is not credible to have metallic transition metals to transport to TRISO because they are solids, which is different than AGR where metallic elements were liquids or gases
- Particle temperatures for KP-FHR fuel are well below AGR irradiation temperatures where Ni attack was observed (~500°C lower)
- Because of the low operating temperatures, any detrimental effects are expected to progress slowly
- TRISO failures would be observable by fission product monitoring in the gas and coolant spaces for the reactor and limited by the technical specification circulating activity limit

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Pebble Irradiation Testing for the Hermes Test Reactor

- The KP-FHR fuel qualification methodology ensures fuel meets the reasonable assurance criteria for qualification AND there is no safety concern due to the Flibe being an additional separate barrier to the release of radionuclides
- The AGR program extensively irradiation tested TRISO fuel particles that define the fuel qualification envelope for KP-FHRs
- Kairos Power is developing the pebble and particle manufacturing which ensures high quality fuel which is demonstrated through inspection to be in compliance with the fuel specification
- Defense-in-depth – TRISO fuel particles + Flibe coolant
    - Irradiation testing cited in subcommittee meeting for prior precedent fuel designs were all for HTGRs which have higher normal operating and accident temperatures
- Fuel in-service surveillance and monitoring activity in the cover gas and coolant during operations provides further assurance fuel does not present a challenge to public health and safety

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Pebble Irradiation Testing for the Test Reactor *(continued)*

- The Hermes test reactor will provide important confirmation of the technology to support the deployment of a Kairos Power commercial power reactor
  - Hermes is a full integral test of the Kairos fuel for a power reactor
- The licensing of test reactors is provided significant latitude in the Atomic Energy Act (AEA):
  - *"In issuing licenses under this subsection of the AEA , the Commission shall impose the minimum amount of such regulations to fulfill its obligations under the act." (AEA Section 104b)*
  - *"The Commission is directed to impose only such minimum amount of regulation of the licensee as the Commission finds will permit the Commission to fulfill its obligations under this Act to promote the common defense and security and to protect the health and safety of the public and will permit the conduct of widespread and diverse research and development." (AEA Section 104c)*
- The extensive TRISO particle irradiation testing performed under the DOE AGR program along with the Kairos Power laboratory qualification program of the fuel pebble design and the defense-in-depth provided by radionuclide retention in the Flibe coolant provides reasonable assurance of the protection of public health and safety consistent with the AEA

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NRC Evaluation of KP-TR-011-P, "Fuel Qualification Methodology for the Kairos Power Fluoride Salt-Cooled High Temperature Reactor (KP-FHR)", Rev. 2

Chris Van Wert
US Nuclear Regulatory Commission

November 30, 2022

Introduction

- Kairos Power, LLC requested staff review and approval of KP-TR-011-P, Rev. 2, “Fuel Qualification Methodology for the Kairos Power Fluoride Salt-Cooled High Temperature Reactor (KP-FHR)”
- Provides a methodology by which the Kairos fuel pebble design will be qualified for use in either a KP-FHR non-power or KP-FHR power reactor
- The staff’s review focused on the overall qualification framework including:
  - Use of existing data
  - Surveillance
  - Unirradiated testing
  - Irradiation testing

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Regulatory Basis

Title 10 of the *Code of Federal Regulations* (10 CFR) Sections 50.34(a), 50.34(b), 50.43(e), and corresponding regulations for design certification applications, combined license applications and standard design approvals

10 CFR 100.11 “Determination of exclusion area, low population zone and population center distance”

Kairos PDC 10 – “Reactor design” which has been approved by the staff (KP-TR-003-NP-A)

KP-FHR PDC 16, “Containment Design” which has been approved by the staff (KP-TR-003-NP-A)

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Staff Evaluation

Applicability of Existing Data

- KP-TR-011, Rev. 2 is applicable based on a comparison of the Kairos and AGR-2 particles as well as the operating conditions
- Use of existing carbon matrix property data is applicable for determining pebble testing conditions for fuel qualification

Fuel Surveillance

- Surveillance of the cover-gas, non-destructive examinations, and planned destructive examinations are acceptable for monitoring fuel performance and detecting particle failure

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Staff Evaluation (cont.)

Unirradiated Testing

- Planned tests include mechanical, tribology, buoyancy and salt infiltration, and material compatibility
- The planned unirradiated pebble testing is acceptable based on the conservative test conditions and plant operating conditions

Irradiation Testing

- Fuel pebble irradiation in a gas environment
- Purge gas monitoring for fission gas
- Post Irradiation Examinations

Coolant Salt Impurities

- The staff considered sources available for impurities which could attack the particles (e.g. Fe, Cr, Ni, etc.)
- The transport of significant impurities to the fuel particles is not feasible given the chemistry monitoring system, solubility limits in molten salt, cover gas monitoring system, and significantly lower temperatures as compared with AGR-5

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Staff Limitations

The staff's approval of KP-TR-011-P includes the following staff limitation in addition to the limitations provided by Kairos in Section 4.2 of the topical report:

> *Future license applications for non-power KP-FHRs will include justification of the applicability of this methodology during rapid reactor transient events.*

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Conclusions

The staff reviewed the topical report KP-TR-011-P, Rev. 2 and concludes that the fuel qualification methodology contained within is acceptable for supporting fuel qualification of Kairos fuel pebbles in either non-power or power reactor versions of the KP-FHR.

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Questions?