Official Transcript of Proceedings

NUCLEAR REGULATORY COMMISSION

Title:	Advisory Committee on Reactor Safeguards Open Session
Docket Number:	(n/a)
Location:	teleconference
Date:	Thursday, April 9, 2020

Work Order No.: NRC-0871 Pages 1-82

NEAL R. GROSS AND CO., INC.
Court Reporters and Transcribers
1323 Rhode Island Avenue, N.W.
Washington, D.C. 20005
(202) 234-4433

DISCLAIMER

UNITED STATES NUCLEAR REGULATORY COMMISSION'S

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

The contents of this transcript of the proceeding of the United States Nuclear Regulatory Commission Advisory Committee on Reactor Safeguards, as reported herein, is a record of the discussions recorded at the meeting.

This transcript has not been reviewed, corrected, and edited, and it may contain inaccuracies.

UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

+ + + + +

672ND MEETING

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

(ACRS)

+ + + + +

OPEN SESSION

+ + + + +

THURSDAY

APRIL 9, 2020

+ + + + +

TELECONFERENCE

+ + + + +

The Advisory Committee met via teleconference at 8:30 a.m., Matthew Sunseri, Chairman, presiding.

COMMITTEE MEMBERS:

MATTHEW W. SUNSERI, Chairman

JOY L. REMPE, Vice Chairman

WALTER L. KIRCHNER, Member-at-Large

RONALD G. BALLINGER, Member

DENNIS BLEY, Member

CHARLES H. BROWN, JR. Member

VESNA B. DIMITRIJEVIC, Member
JOSE MARCH-LEUBA, Member
DAVID A. PETTI, Member
PETER RICCARDELLA, Member

DESIGNATED FEDERAL OFFICIAL:
LARRY BURKHART
MIKE SNODDERLY
WEIDONG WANG

ALSO PRESENT:

STEPHEN BAJOREK, RES
ANTONIO BARRETT, NRR
ALEXANDER CHERESKIN, NRR
TIMOTHY DRZEWIECKI, NRR
MARGARET ELLENSON, Kairos Power
DARRELL GARDNER, Kairos Power
PETER HASTINGS, Kairos Power
ALAN KRUIZENGA, Kairos Power
STEWART MAGRUDER, JR., NRR
SCOTT MOORE, Executive Director, ACRS
QUYNH NGUYEN, ACRS
DREW PEEBLES, Kairos Power
PER F. PETERSON, Kairos Power
JOHN PRICE, Kairos Power
BRIAN SMITH, NSIR
NICOLAS ZWEIBAUM, Kairos Power

CONTENTS

P R O C E E D I N G S

8:30 a.m.

CHAIRMAN SUNSERI: Good morning. The meeting will now come to order. This is the second day of the 672nd meeting of the Advisory Committee on Reactor Safeguards.

I am Matthew Sunseri, the Chair of the ACRS. We are going to do a roll call of the members. As I call on each member, I ask that you acknowledge your presence.

Ron Ballinger?

MEMBER BALLINGER: I'm here.

CHAIRMAN SUNSERI: Dennis Bley?

MEMBER BLEY: Here.

CHAIRMAN SUNSERI: Charles Brown?

MEMBER BROWN: Here.

CHAIRMAN SUNSERI: Vesna Dimitrijevic?

MEMBER DIMITRIJEVIC: Here.

CHAIRMAN SUNSERI: Walt Kirchner?

MEMBER KIRCHNER: Present.

CHAIRMAN SUNSERI: Jose March-Leuba?

MEMBER MARCH-LEUBA: Here.

CHAIRMAN SUNSERI: Dave Petti?

MEMBER PETTI: Here.

CHAIRMAN SUNSERI: Joy Rempe?

VICE CHAIR REMPE: Here.

CHAIRMAN SUNSERI: Pete Riccardella?

MEMBER RICCARDELLA: Present.

CHAIRMAN SUNSERI: And myself, Matt Sunseri. And I note we have a quorum.

The Designated Federal Official for this meeting is Mr. Weidong Wang.

Today during our meeting the Committee will consider the following: Item No. 1, Kairos Advanced Reactor Design, specifically the Scaling Methodology and Reactor Coolant Topical Report.

And then we will have preparation of ACRS reports on those topics and several of the NuScale topics that we reviewed yesterday. As reflected in the agenda, portions of the NuScale section may be closed in order to discuss and protect information designated as sensitive and proprietary, and I believe that may go as well for Kairos Power.

At this point, I would like to ask Scott Moore, Executive Director, to add some additional comments regarding today's agenda.

Scott?

MR. MOORE: Thank you, Chairman Sunseri.

So, a few administrative comments for everybody. One is for everybody. There's an error in

the public agenda that was placed on the public website. It shows lunch is going from 12:00 noon until 2:00 p.m. In fact, we're going to return from lunch at 1:00 p.m. today. We had been planning some training for the members of the Committee from 1:00 to 2:00, but that's not going to take place. So we will be returning at 1:00 p.m. today.

The second message is for the members. Weidong, the DFO, will be providing you with the link that you will be going to for the closed meeting in your email right after I've made this announcement. So please watch your emails for that link. And you'll get very clear direction on when we are closing the open meeting and going to the closed meeting.

Weidong, is that correct?

MR. WANG: Correct. In particular, this is for letter writing only. For the meeting here, if there's a proprietary question asked, then we can use the Skype line. The plan was open, but, in case if there's a closed proprietary question that needs to be asked, then we will make it at the end of this meeting.

Thank you.

MR. MOORE: Sure. So, stay in the open meeting until you get directions to go to closed. And

then, if we need to go to closed, your directions will be in your emails.

The third item is just an open reminder to the public that, per the agenda that's already out there, if we do go to closed, we can come back to the open public line, the line that we're on right now, at any time during the agenda. So, we may have to go back and forth between open and closed, but that's just a reminder that we may come back to open at any time after we're in closed.

PARTICIPANT: Scott?

MR. MOORE: Yes?

PARTICIPANT: Sorry for the interruption, but Larry Burkhart is reporting that there's nothing on the public phone. Right now he can't hear.

MR. MOORE: So, Chairman, obviously, some of this is for the public. So, we need to wait until they can hear.

CHAIRMAN SUNSERI: Understood.

MR. BURKHART: Yes, this is Larry. I am on the phone bridge and I cannot hear anything on the phone bridge still.

MR. MOORE: Okay. Larry, can you let us know as soon as you can hear?

MR. BURKHART: Yes, sir.

MR. MOORE: Larry, are you on both lines?

MR. BURKHART: I am on Skype, Meetings with Skype, and then listening in on the phone bridge, yes.

MR. MOORE: Okay. Thomas is working on it.

(Pause.)

MR. MOORE: This is Scott. Is the phone bridge up yet?

MR. BURKHART: This is Larry. I can hear you now.

(Pause.)

MR. MOORE: Okay. Can I go? Can the public line hear?

MR. BURKHART: I can hear you on the public phone bridge, yes.

MR. MOORE: Okay. Then, Chairman Sunseri, I'm going to go back and repeat just a couple of things.

CHAIRMAN SUNSERI: Just the stuff that was relevant to the public, please.

MR. MOORE: Yes, sir. Okay. The first thing was, for the public, there's an error in the public agenda. We will return after lunch at 1:00 p.m.

I'd asked that everybody on the line mute their phones because we're getting a lot of background noise.

So, we're returning at 1:00 p.m. today. The members were going to have training between 1:00 and 2:00 p.m.; the public agenda shows 2:00 p.m. That's incorrect. We're returning at 1:00 p.m. Eastern today.

The other is just a reminder to the public that we can come back to this public line at any time. We may have to go to a closed line for proprietary information, but, as the agenda shows, we would come back to this public line for open meeting at any time during the agenda.

Chairman, that's it for me. Thank you.

CHAIRMAN SUNSERI: Thank you, Scott. Okay. So, all that business about the public line, there will be an opportunity for the public to comment. And we have set aside time in the agenda for comments from members of the public attending or listening to our meeting. Written comments may also be forwarded to Mr. Weidong Wang, the Designated Federal Official.

A transcript of the open portion of the meeting is being kept, and it is requested that the

speakers identify themselves so that the transcriber can relate your comments.

Finally, as I reflect on yesterday's session, I note that all participants did a nice job of practicing good virtual meeting behaviors. Before we start today, I just want to reemphasize a few, the first one being how important it is to mute your microphone. It becomes very difficult to hear the presenters and other people that have speaking rights, if you will, when there's background noise and open mics that people aren't using to speak.

Presenters yesterday did a nice job of pausing to allow member interaction. I thought the interaction was good. So, please continue to pause during the slides or your presentation periodically to let members interact.

And the last point is we have this IM messaging panel for those participating on the Skype session. And I noted yesterday that, as the day went on, people became more comfortable and more proficient at using this. So I just want to remind people not to post any technical sidebar discussions out there because any such discussion would be out of the public record. And we don't want that to happen. We want everything to be transparent. So, I didn't see

anything yesterday, but, as we become more proficient at using it, I just want to remind everybody about that.

So, at this point, we are ready to pick up the agenda. Yes, okay, here we are. So, we will begin with the Kairos Advanced Reactor design. I'm going to ask Dave Petti if he has any opening remarks, as Subcommittee Chair.

MEMBER PETTI: No, none at this time, Matt. Let's just get into it.

CHAIRMAN SUNSERI: Okay. All right. So, I don't have any other notes. I guess I turn this now over to NRC staff, is that right? Or straight to Kairos?

MR. SMITH: This is Brian Smith. I was going to do some opening remarks for the NRC staff.

CHAIRMAN SUNSERI: Okay. Thank you, Brian. I appreciate that. I didn't have that in my notes. So I apologize. Please go ahead.

MR. SMITH: Okay. I'll be brief. Good morning. My name is Brian Smith. I'm the Deputy Director of the Division of Advanced Reactors and Non-Power Production and Utilization Facilities.

The staff is looking forward to the discussions today with the ACRS regarding the staff's

review of Kairos' two Topical Reports on the scaling methodology for their Kairos testing program and the reactor coolant for the Kairos Power fluoride salt-cooled high temperature reactor.

We last presented on these reviews in February, in front of most, if not all, of ACRS members. Today, we'll provide a high-level overview of our review and findings. At the last meeting, we received some good feedback from the members and, as a result, we have made a few changes to our Safety Evaluations. The staff presenters will address those changes in their presentation.

We look forward to receiving the letters on the staff's review of these two Topical Reports following this meeting. We also look forward to future interactions with the ACRS as we complete additional reviews of additional Kairos Topical Reports.

And, with that, unless you have any questions, I can turn it over to Peter Hastings for some opening remarks.

CHAIRMAN SUNSERI: Go ahead.

MR. GARDNER: Good morning. This is Darrell Gardner. I'm the Senior Director of Licensing for Kairos Power. I do have a couple of opening

remarks, and I will be brief.

First of all, we have benefitted significantly from the extensive pre-application engagement that we've had with the NRC staff, and we appreciate this specific invitation to describe to this full Committee meeting two of our Topical Report methodologies for developing and deploying the fluoride salt-cooled high temperature reactor.

Today, we're talking specifically about the Scaling Methodology Topical Report and the Reactor Coolant Topical Report. I would note that these reports are being discussed in an open session and we have limited our discussion and presentation slides to areas that we believe can be appropriately discussed in this open forum. If during this presentation we see questions or answers straying into proprietary content, we will bring it to the Committee's attention. I would request that these discussions be moved to the closed session.

I would also note that, in many cases, Kairos Power considers our business and technical strategies to be business-sensitive proprietary information, as well as certain technical content that might represent commercially valuable intellectual property.

We have two primary presenters today from our team to present an overview of these two reports: Dr. Nicolas Zweibaum, who's the senior manager of engineering testing; and Dr. Alan Kruizenga, who's the director of salt chemistry. Other members of our team that are present on the call today include Peter Hastings, our vice president of regulatory affairs and quality; Dr. Per Peterson, our chief nuclear officer; Drew Peebles, our manager of safety and licensing integration; and two senior licensing engineers, John Price and Margaret Ellenson.

And that concludes my comments. Thank you. We'll turn it over to Nico.

CHAIRMAN SUNSERI: Yes, please proceed.

DR. ZWEIBAUM: All right. Good morning, everyone. I'd like to first confirm that everyone can hear me and see my screen one more time.

CHAIRMAN SUNSERI: You're loud and clear.

DR. ZWEIBAUM: Good morning, Members of the ACRS Committee and the NRC. My name is Dr. Nicolas Zweibaum. I am the senior manager of engineering testing at Kairos Power, and I was one of the main preparers of the Scaling Methodology Topical Report for which I'm going to provide an overview this morning.

First, Kairos Power is a mission-centered company. As such, we like to start our public presentations with our mission, which is to enable the world's transition to clean energy with the ultimate goal of dramatically improving people's quality of life while protecting the environment. This mission and message resonates particularly in these times when everyone, or most people, are stranded at home. So, I hope everyone is staying safe out there.

This is an outline of the main talking points today, which follows the main points in the Scaling Topical Report that was submitted to NRC staff review. I will start by outlining the purpose of that Scaling Methodology Topical Report. I'll have a brief slide on the use of the hierarchical two-tiered scaling, or H2TS, methodology.

I will then go on and explain how we are using surrogate fluids in scaled experiments, thermal fluids experiments. Then I will talk about the application of the scaling methodology to integral effects tests as well as separate effects tests that support Kairos Power's evaluation methods validation. And, finally, I'll have a few words of conclusion, including what we asked the NRC to review and approve in this Topical Report.

Moving on, and for those of you who can't see the screen but have the slides available, this would be Slide 4 on the purpose of the Scaling Methodology Topical Report. This methodology is used to scale both integral effects tests, or IETs, and separate effects tests, or SETs, supporting the KP-FHR, which is the Kairos Power fluoride salt-cooled high temperature reactor, evaluation model assessment base.

Important to note, this is a salt-cooled reactor. Our primary coolant is fluoride, which will be described in a lot more detail in the next presentation. So this scaling methodology is limited to single-phase fluoride systems and related phenomena.

The use of surrogate fluids enables direct and comprehensive local measurements of the phenomenon during investigation. And this is due to the higher compatibility of existing high accuracy instrumentation with low temperature surrogate fluids, such as temperature and flow velocity, as opposed to developing dedicated instrumentation for a high temperature salt system.

And what Kairos Power asked the NRC staff during their review was to approve our use of this

scaling methodology as laid out in the report with surrogate fluids, also described in the report, including heat transfer oils and water, for testing that's included in the assessment base of the evaluation models that support KP-FHR safety analysis.

I'll pause here, if there are any questions so far.

(No response.)

DR. ZWEIBAUM: Okay. I don't hear anything. I'm going to move on to the next slide, Slide 5.

Why are scaling methods important to us? They support acceleration of our validation testing program, and it's key to note that validation testing will be important to support the assessment base for the safety case for the FHR. As such, we have already developed important laboratory infrastructure.

The first one is our Rapid Lab, or R Lab, which is located in our headquarters in Alameda, California. There we have already developed Kairos Power separate effects tests that are currently up and running. These include fluid dynamics tests using room temperature water at 40 percent geometric scale, which allows us to match key non-dimensional numbers relevant to flow dynamics phenomena, as well as heat

transfer tests using a heat transfer oil as a surrogate fluid, which, again, at reduced geometric scale and powering, allows us to match key non-dimensional numbers that are relevant to heat transfer phenomena.

Important to note that those heat transfer oils, we have run them around 72 degrees Celsius, and this is to match a particular Prandtl number of the fluid, which, compared to the Kairos Power reactor operating with fluoride between 550 and 650 degrees Celsius, is significantly lower.

In addition to those Kairos Power separate effects tests, we are in the conceptual design phase for our first Kairos Power integral effects test, which would be, roughly, a house-height facility and reduced area as well. And this will be located, also, in this R Lab facility in Alameda, California, and should be up and running before the end of the year.

These sets of experiments, all using reduced scale of size, power, and temperature, surrogate fluids and surrogate materials, will be used to validate our KP-FHR evaluation models and will be key in supporting deployment of our first demonstration reactor that we're calling KP1. And there's a very early schematic shown on the right of

our reactor vessel.

Any questions on this?

CHAIRMAN SUNSERI: No questions. Thanks.

DR. ZWEIBAUM: Excellent. I'll move on to Slide 6. This is more of a background slide on the hierarchical two-tiered scaling methodology. This is a generic scaling method that was previously developed and approved by the NRC. It has been used for development of previous, as well as current, experimental programs for both lightwater reactors and non-lightwater reactors. And, most importantly, why this is mentioned here. is that this is the methodology we have selected at Kairos Power for scaling of our thermal fluids IETs and SETs as part of the Evaluation Model Development and Assessment Process, or EMDAP, that's described in Regulatory Guide 1.203.

The illustration at the bottom is directly inherited from an article by Novak Zuber describing this methodology at a high level, which consists in systemic decomposition, scale identification, then a combination of top-down and bottom-up scaling. And for those of you who read and reviewed the Scaling Methodology Topical Report, this is the exact same process we have been following to develop our scaling

arguments for the Kairos Power IETs and SETs.

If there are no comments or questions, I will move on to the next slide, Slide 7, which covers the use of surrogate fluids in scaled experiments.

So, why do we use surrogate fluids? As briefly mentioned earlier, these allow us to investigate the fluid flow and heat transfer phenomena that are relevant to our design at significantly smaller scale and required resources in terms of power and temperature. More specifically, heat transfer oil, a specific class of those, at room temperature or close to room temperature, may simultaneously match Reynolds, Prandtl, Grashof, and Froude numbers for fluoride, matching those numbers for average operating temperatures in the KP-FHR primary heat transport system.

So, we are operating, as illustrated a couple of slides back, around 72 degrees Celsius for average operating conditions, which matches the average properties of fluoride at 600 degrees Celsius.

In addition to those heat transfer tests, we can also use water for flow dynamics testing, which can simultaneously match Reynolds and Froude numbers from fluoride systems. And this would be at room temperature around 20 degrees Celsius.

The use of surrogate fluids enables direct and comprehensive local measurements of the phenomena under investigation, and this is due to higher compatibility of high accuracy instrumentation with a low temperature environment. The ability to provide those local measurements, and have a lot of those, enables us to have extensive and high accuracy local data that we can collect from those scaled Integral effects tests and separate effects tests to support the assessment base of our safety analysis tools.

Also, for the water testing, the use of transparent surfaces can be used for direct visual access, which obviously is not an option when you start working with high temperature molten salt above 600 degrees Celsius.

Those surrogate fluids, it's important to note we're not exactly breaking new ground here in terms of using surrogate fluids for experimental efforts in nuclear reactor development. This has been done in the past for both single- and multi-phase flow systems in support lightwater reactor development, sodium-cooled reactor development, and, also, actually, salt-cooled reactor development. This is inherited from a long series of historical experiments using similar surrogate fluids in early stage

development of FHR technology.

MEMBER PETTI: I have a question. I think you touched on it in the Subcommittee, but I wanted to hit again and remind folks that there is other testing. You know, this has limits, this approach, and I think you've outlined them. But you can't deal with pebble contact friction as a result of that potential particulate generation or looking at some salt behavior, that you need to be at the actual temperature of the actual material to understand. Is that true?

DR. ZWEIBAUM: Absolutely. So, I think the key here, which is laid out in the Topical Report as well, is that any of those experiments -- and this is the case where any scaled experiment -- will have a number of distortions that have to be identified and clearly laid out. In particular, when we run tests that rely on the scaling methodology, that's laid in the Topical Report. This will be accompanied by a report that specifically lists the distortions and the phenomena that they arise from.

So, the two examples you provided are perfect examples of that. The key here is that we're matching very closely a lot of the relevant phenomena, but there will be a number of small distortions that

we will have to address and clearly look at.

MEMBER PETTI: Yeah, I think, you know, just as a comment from one member, it would be useful to have sort of a graphic that shows the whole landscape of the technology development, and a little box that says, okay, we're starting here, this is what we're working on, I think to give people a better understanding of the full set of things you plan to do versus what you're talking about today.

DR. ZWEIBAUM: Mm-hmm.

MEMBER PETTI: Thanks.

MR. MOORE: This is Scott Moore. For all the members, we do plan to have an overview presentation by Kairos, but we felt that this first virtual meeting probably wasn't the optimal point for them to give it to us. So, we will schedule that. Thank you.

CHAIRMAN SUNSERI: This is Matt. There are several open mics, I can tell from my screen here. So I'm going to ask everybody right now to look at your microphone setting. Mute your microphone if you're not one of the speakers or asking a question. Thank you.

DR. ZWEIBAUM: Speaking of questions, do we have any others on this specific content?

If not, I will move on to the next slide. This is Slide 8 for those of you who are not following on the screen.

So, this is a very high-level summary of how we intend to apply the scaling methodology that's laid out in the Topical Report to our integral effects test. So, the scaling analysis that's performed in the report is for a surrogate fluid -- specifically, a heat transfer oil -- integral effects test that replicates phenomena in the KP-FHR primary heat transport system.

The illustration on the right is a much simplified schematic that gives you a very rough sense of the pumping duration of the Kairos Power fluoride salt-cooled high temperature reactor. This is a pebble-bed reactor. So you see the reactor core on the left. We actually have two primary salt pumps in our baseline pumping configuration flowing, actively flowing, molten salt to an intermediate heat exchanger, that's shown on the right, that transfers heat to an intermediate heat transfer system that uses a secondary nitrate salt system. And then, after going through the intermediate heat exchanger, or IHX, the coolant goes back to the core through cold-leg piping.

The scaling methodology that's played out in the report covers specific classes of licensing basis events, and those are steady-state, normal forced circulation operations with primary salt pumps active, as well as transients that involve a loss-of-force flow and transition to natural circulation. Examples of initiating events for that would be a pump trip, loss of heat sink, station blackout.

And the methodology in the report is illustrated using an idealized model of the KP-FHR primary heat transport system and scaled IET. However, the way the methodology is laid out in the report can be extended to more representative KP-FHR architectures with a number of branches and several loops in parallel, in particular.

Are there any questions on this IET portion?

If not, I will move on to the next slide, which is Slide 9, on application of our scaling methodology separate effects tests, or SETs. Those SETs are used to develop closure models and correlations for module-level or component-level phenomena. And in the case of the Topical Report that the staff reviewed, those specific tests relate to fluid dynamics and heat transfer phenomena, as well as

KP-FHR design-specific phenomena. Those cover forced circulation fluid dynamics; convective heat transfer; conjugate heat transfer of salt structures; twisted elliptical tube experiments, which is relevant to design options for our intermediate heat exchanger, or IHX, that couples the primary and intermediate heat transport system. Pebble-bed granular flow dynamics experiments. This reactor is a pebble-bed reactor. So, the dynamics of the fuel moving through the core are of particular interest to us. And, finally, porous media or packed bed heat transfer experiments, which, again, is of particular relevance to heat transfer in our reactor core.

Any questions on this?

Okay. If not, I will move on to my last slide, Slide 10.

As a summary, Kairos Power has adopted the hierarchical two-tiered scaling methodology for scaling of our integral effects and separate effects test experiments that support KP-FHR evaluation models. The Topical Report that was submitted for review details the scaling methodology that we're using for thermal fluids integral effects tests. That models our primary heat transport system under both normal operation and transients that involve

transition to natural circulation. The Topical Report details the scaling methodology that's used for thermal fluids separate effects tests that are relevant to specific KP-FHR components and phenomena.

And, finally, the record describes the motivations and rationales behind using specific classes of surrogate fluids -- namely, heat transfer oils or water -- in scaled KP-FHR IET and SET experiments.

As a result of this, what Kairos Power asked the NRC to review and approve is the specific use of the scaling methodology as laid out in the report with those surrogate fluids, heat transfer oil and water, for testing that's included in the assessment base of the evaluation model to support our safety analysis.

And with this, if there are any questions, I'd be happy to answer.

MEMBER PETTI: I have another question, to remind myself from the Subcommittee meeting. In terms of the testing, when you have heat generation and you're looking at the response of the system in an IET sense, are you planning to actually heat pebbles, static pebbles, in the experiment or were you going to pick a simpler geometry? And I was trying to remember

the rationale for the laterals decision.

DR. ZWEIBAUM: So, in the context of integral effects tests, it is not required to use a pebble bed to match the relevant non-dimensional numbers at the system level. So, our options are open. I will not go into the details of the design of the first integral effects test facility. This is still under development. But I will say it's not required to use the pebble bed core in the integral effects test to match the relevant heat transfer properties, as well as flow dynamics properties.

One of the assumptions clearly stated in the Topical Report is that we're focusing on 1D phenomena, and, as such, in integral effects tests, we are not looking at 2D or 3D flow distribution or heat transfer within the core. That would be for integral effects tests, if that was the question.

MEMBER PETTI: Yeah, I can remember this discussion about the VF (phonetic) number and when it was important. It required a different approach than if it wasn't important in terms of the heat moving into, you know, out of the pebbles.

DR. ZWEIBAUM: So, the VF number in the application is only important for reflector structures. And for that, we'll have to do some

scaling, but not for the pebble bed itself.

MEMBER PETTI: Okay. That's what it was. Good. Thanks.

MEMBER MARCH-LEUBA: So, this is Jose. One issue raised during the Subcommittee was the 3D flow effects. If you're concerned about the integrity of the structural materials due to heatup by the coolant, 3D effects might give you some streaming that direct coolant to a particular component. How do you plan to address that?

DR. ZWEIBAUM: We would probably start by investigating this at the separate effects test level to understand if this is, indeed, a concern, before we make decisions on carrying that over to the integral effects test level.

MEMBER MARCH-LEUBA: Yeah. I suspect that mostly it would be dependent on how much margin we have at different temperatures. So, I mean, if you have 500 degrees of margin, you don't care; if you have 5 degrees of margin, then you care. So, yeah, don't forget that can happen.

DR. ZWEIBAUM: Absolutely. But I will just tell everyone that we expect to have more than 5 degrees margin, including for our structural materials, which are the limiting factor in our safety

analysis.

MEMBER MARCH-LEUBA: Yeah, I was trying to cover both ends of the 5 to 500.

MEMBER PETTI: So, at this point, for seed conditions, will you need to test pebbles to validate any of the scaling?

DR. ZWEIBAUM: To use pebbles -- do you mean prototypical pebbles or just the pebble-bed geometry in general?

MEMBER PETTI: Well, you can answer both. The first step would be just the pebble-bed geometry, and the second would, you know, be a more complex test.

DR. ZWEIBAUM: So, in the context of pebble-bed geometry, as mentioned earlier, we would start with separate effects testing to see if there is anything relevant to see there that has to carry over to the integral effects testing. We would use separate effects tests, and we have started doing that actually, to measure convective heat transfer in the core, and that would use the pebble-bed geometry.

MEMBER PETTI: Okay.

DR. ZWEIBAUM: Did that answer the question?

MEMBER PETTI: Yeah, yeah.

MEMBER KIRCHNER: Nicolas, this is Walt Kirchner. I'd like to go back to David's observation earlier. It would be useful, going forward, if we were to see the intersection of -- for example, we're going to hear shortly about the fluoride fluid characteristics, et cetera. You've done a good job of showing that, with your scaling methodology, you can get to a place where you match important fluid dynamics and heat transfer properties at nominal operating conditions. And the purpose being, among others, to benchmark your safety evaluation methods.

But when you get to off-normal conditions, fluoride has behavioral characteristics, so to speak, that are much different than heat transfer oil or water. So I think it would be useful to see the intersection of the fluid TR with the scaling methodology and where the gaps are going forward, looking at, in particular, transients, off-normal conditions, where some of the characteristics of a salt are much different than heat transfer oil and/or water.

So, I'm not looking for an answer, but that's a consideration, I think, going forward.

MEMBER PETTI: So, on chat, it says his connection dropped. So he may not have heard that

question.

MR. HASTINGS: Yes, apologies. This is Peter Hastings. His connection dropped. He's trying to reestablish. But we did hear the question. So we'll take it under advisement. Thank you.

DR. ZWEIBAUM: Hi. This is Nicolas. I just came back. I'm very sorry, it dropped off at the very beginning of the question. Unfortunately, I didn't hear the question at all.

MEMBER KIRCHNER: Nicolas, this is Walt again. Just an observation, not so much a question, that it would be interesting going forward for us to see the intersection, for example, of the fluid TR with the scaling TR. And given the unique characteristics of fluoride, where using heat transfer oil and water might not necessarily be -- at nominal operating conditions, you've done a good job of showing that the scaling factors, the important things like Prandtl number in salt, all the rest of those parameters, are in good agreement, you don't have a large divergence. But, as you get off-normal and temperatures change and such, then the characteristics of a salt are much different than the characteristics of heat transfer oil or water.

DR. ZWEIBAUM: Absolutely. No, I

appreciate that. And I will say, at a high level, as mentioned earlier, or at a minimum, when we do apply this methodology, we'll make it clear what the distortions are. That being said, to illustrate the point here, I can cite, for instance, thermal radiation, which obviously is something that people care about when you operate at high temperature like we do with the salts, as opposed to the surrogate fluid. But the relative importance of thermal radiation in the primary heat transport system compared to convective heat transfer is pretty minimal. So, this is the kind of argument that we would develop in more detail when we list distortions in our applications.

MEMBER PETTI: So, Nicolas, just on that thermal radiation, I remember having a discussion with Charles Forsberg from MIT about that was important, that we didn't know enough about, whether it's the emissivity or how thermal radiation propagates through the salt. Can you shed any light on this? It was surprising to me. I thought this would have been something understood and it sounded like something very fundamental that wasn't understood.

DR. ZWEIBAUM: So, we can probably bound that and it would be related to the specific

properties of the salt and how it evolves in the specific context of the operations of a reactor. So, this is something that we would have to better quantify and list as a specific distortion later. I can't speak to specific numbers right now.

MEMBER PETTI: Yeah. Okay. So, it's more of the scientific perspective than the engineering perspective? There's ways to accommodate it.

DR. ZWEIBAUM: Yes.

MEMBER PETTI: Yeah. Thank you.

CHAIRMAN SUNSERI: Anything else on this topic?

MEMBER PETTI: I think we're good, Matt.

CHAIRMAN SUNSERI: So we are going to move into the next presentation, then?

MEMBER PETTI: Yeah, I think so.

DR. ZWEIBAUM: Thanks, everyone. I'm going to mute myself.

CHAIRMAN SUNSERI: Okay. Thank you. And for the Kairos folks, are you ready for the next presentation?

VICE CHAIR REMPE: The agenda says it's NRC staff now.

MR. MAGRUDER: Yeah. Good morning. This is Stu Magruder. I'm the lead project manager for the

Kairos project in the Office of Nuclear Reactor Regulation. Can you hear me okay?

CHAIRMAN SUNSERI: I can. It wasn't clear to me if these were going to be back-to-back Kairos presentations followed by back-to-back staff, or what. The agenda is not that clear.

MR. MAGRUDER: Oh, I apologize. I think the intent was to have the NRC staff presentation on the scaling topical, and then we'll move to the next topical.

CHAIRMAN SUNSERI: Okay. That's fine. Go ahead, then.

MR. MAGRUDER: Okay. So, I think I've shared my screen. Can someone confirm that you can see the NRC slides?

CHAIRMAN SUNSERI: You're there.

MR. MAGRUDER: Great. Great. Well, good morning, everyone. The presentation this morning with be brief from the staff. As Brian Smith said earlier, we appreciated the feedback from the members of the ACRS at the Subcommittee meeting in February. The staff has made a number of changes to our Safety Evaluation as a result of that discussion, and as a result of further discussions with Kairos as they reviewed our Draft Safety Evaluation.

The primary presenter this morning will be Mr. Antonio Barrett from NRR. But also on the line supporting Antonio are Dr. Tim Drzewiecki and Dr. Steve Bajorek. They were also kind of the primary reviewers of this topical. So, I will drive the presentation and Antonio will lead the discussion.

Antonio, take it away.

MR. BARRETT: Thank you, Stu. This is Antonio Barrett from the Office of Nuclear Reactor Regulation from the NRC staff. Can you go to the next slide, please?

Yeah. So, for an overview of the scaling methodology, the staff reviewed the Kairos Power scaling methodology with respect to its application to integral effects tests, separate effects tests, and use of surrogate fluids. The staff developed its limitations and conditions to support its conclusions and findings based off that review.

Okay. Stu, can you go to the next slide? Okay.

Scaling methodology is to design test facilities that provide data for correlations, analytical tool assessment, and demonstrate safety function features of the design. For applicable regulations, there's 10 CFR 50.43(e), which requires

that sufficient testing data exist on the safety features of the design to assess the analytical tools used for safety analyses of a sufficient range of normal operating conditions, transient conditions, and specified accident scenarios.

There's also 10 CFR 50.34, 52.47, and 52.79, "Contents of Applications". These require a Safety Analysis Report to analyze the design and performance of structures, systems, and components. These analyses are typically performed with evaluation models. There is guidance for the development of the evaluation models in Reg Guide 1.203, using the Evaluation Model Development and Assessment Process.

Stu, can you go to the next slide?

MR. MAGRUDER: Yes. And for everyone on the phone, we're on Slide 4 now, "Review Scope and Approach".

MR. BARRETT: Thank you. For the review scope and approach, for integral effects tests, the scaling methodology is applied to the Kairos Power primary heat transport system for three scenarios, the first being forced circulation, which is steady-state normal operation, and then the second being a transient transition from natural circulation down to the third scenario, which is a quasi-steady natural

circulation.

The top-down scaling is based on a control volume approach using 1D conservation equations. The bottom-up scaling identified additional scaling routes to preserve the scaling routes from the top-down analysis with a focus on the individual component processes.

The NRC staff was able to independently verify the identified scaling groups from these analyses. The staff finds this approach to be acceptable because it's consistent with the hierarchical two-tiered scaling methodology, which is standard practice, and the use of non-dimensionalized equations to develop similarity or scaling parameters is also standard practice.

For separate effects tests, the applicant addresses the treatment of fluid dynamics and heat transfer phenomena with the use of scaling parameters and values obtained from non-dimensionalized transport equations. The staff finds that these scaling approaches are acceptable because they are consistent with standard practice for single-phase flow and heat transfer.

For the use of surrogate fluids, they are assumed throughout the entire Topical Report for the

integral effects tests and separate effects tests scaling. The NRC staff was able to reproduce the results from a comparison of the thermal physical properties applied to heat transfer oil that was presented in the Topical Report. The NRC staff finds that the use of surrogate fluids is acceptable because the use of the fluids has a history of use in single-phase fluid flow and heat transfer.

Additionally, the analyses presented in the Topical Report demonstrate that the use of surrogate fluids results in experimental facilities that exhibit small scaling distortions.

All right. Stu, can you move on to Slide 5?

MEMBER KIRCHNER: Antonio?

MR. BARRETT: Yes, sir?

MEMBER KIRCHNER: Walt Kirchner. You didn't talk to the last bullet on your slide. Could you just mention why that's there?

MR. BARRETT: Yes. So, one of the main things is to limit it to the single phase. You know, we don't go to freezing or anything else like that. And this is part of the limitations and conditions that we applied on the Scaling Topical Report. So, that was the point of that bullet. It is basically

single phase. So it's not as complex as it would be, and would not go to anything else other than the single phase.

MR. MAGRUDER: Are there any other questions on Slide 4 before we move on?

CHAIRMAN SUNSERI: Use the 5-second rule.

MR. MAGRUDER: Thank you.

MR. BARRETT: So, for changes to the SE, there were only minor changes that were made to the SE that don't affect any of the conclusions that were made that have previously been seen. Updates were made to clarify the applicant's motivation for the use of surrogate fluids. And, also, there was a change to the conclusion section, which updated to call out the relationship to the regulations and the Evaluation Model Development and Assessment Process from Reg Guide 1.203. I've pasted into this the two changes that were made. And there were no open items that were identified from the Subcommittee meeting back in February.

Thank you, Stu. Can you move on to the next slide, Slide 6?

For the conclusions, the NRC staff approves the Kairos Power Scaling Topical Report methodology for scaling the heat transfer phenomena

for the KP-FHR primary heat transport system under normal operations and transient conditions, subject to the limitations and conditions.

The application of the scaling methodology to integral effects tests and separate effects tests identifies the appropriate scaling groups to capture the relevant physical phenomena, subject to the limitations and conditions.

The use of surrogate fluids, as described in the scaling methodology, is capable of preserving the appropriate scaling groups.

And that is the end of the staff's presentation.

CHAIRMAN SUNSERI: Members, any other questions or comments regarding the staff's presentation?

MEMBER MARCH-LEUBA: This is Jose. Not from me.

MEMBER KIRCHNER: This is Walt Kirchner. Just looking at this, with regard to the limitations and conditions, have you identified areas -- I'm going back to 10 CFR 50.43(e). Do you feel that you have, I'll use the exact terminology, "sufficient range" in using these surrogate fluids to cover the transient space that you may see with this particular design?

MR. BARRETT: So, there's a limitation on just basically the three scenarios, to apply this just to the three scenarios of the forced circulation, and then down to the natural circulation and that transition. So there may be transients outside of that. And, if so, then this would not be applicable. So, with the details that we have now, it's unknown where exactly the transients will go, but this has been limited to only these specific scenarios.

DR. DRZEWIECKI: I do want to add onto that. This is Tim Drzewiecki from the staff.

The way it's described in the Topical Report is that, if you did have a trip and you are going to natural circulation, like a delta-T across the core, it should be similar to what you have in normal operation. And so the range of the calculated distortion, which is I think 550 and 750 C, it should be close to that in your transient. However, whatever it is, there should be a calculated distortion and the impact of that should be quantified. A limited kind of method is going to reference for this Topical Report.

Stu, can you hear me?

MR. MAGRUDER: Yes. Tim, I could hear you.

CHAIRMAN SUNSERI: Okay. Very good. All right, members, any other comments or questions?

(No response.)

CHAIRMAN SUNSERI: All right. Dave Petti, I'm turning it back to you.

MEMBER PETTI: Okay. I guess, for both conditions, we have a Topical Report, then. Kairos?

DR. KRUIZENGA: Good morning. This is Alan Kruizenga, Kairos Power. I'm the director of salt chemistry. I just wanted to confirm that you can both hear me and see my screen.

MEMBER PETTI: I can hear you. Yeah, I can see it.

RR. KRUIZENGA: Very good. Well, good morning. Great to be here. It's great to be here virtually.

So, this Topical Report is the overview of the Reactor Coolant Topical Report. I'll move on to the next slide. There's a bit of a lag. It will take a second, I think.

As was mentioned earlier, we're a mission-driven company. Our mission is to enable the world's transition to clean energy with the ultimate goal of dramatically improving people's quality of life while protecting the environment.

The outline for today is just to give a little bit of information on the purpose of the Reactor Coolant Topical Report, some of the criterion that came into it from historical information, and then some of the high level details behind the specification for our fluoride coolant.

Now moving on to Slide 4. The purpose of the Reactor Coolant Topical Report was really just to get review and approval so that we have some basis of understanding between ourselves and the NRC for the design specification limits and thermal physical properties for the KP-FHR as we begin to do our safety analysis. So, that's the primary purpose and driver behind this Topical Report.

VICE CHAIR REMPE: Alan?

DR. KRUIZENGA: Yes?

VICE CHAIR REMPE: Go ahead, finish. I'm sorry, go ahead and finish.

DR. KRUIZENGA: No, that was it. I'd actually ask if there's any questions.

VICE CHAIR REMPE: This is Joy Rempe, and I do have a question. If I look at this, and the remaining slides in this presentation, and even in some of the staff slides, I might, as a member of the public, not understand what approval of this Topical

Report means. So it would be good to have you explicitly state what is meant by approval. And I actually went back and looked at the staff SE when I was thinking about this question last night.

So, could you explicitly address the topic of whether you'll have to resubmit the updated version of this Topical Report and if any additional testing is required in order to come into the staff limitation about bringing the properties listed in this report into the QA program?

DR. KRUIZENGA: Yeah. No problem. Thank you for the question. So, the purpose of the report is really to establish the thermal physical properties, as provided in the document.

VICE CHAIR REMPE: It's an initial step of thermal physical properties where some of it is going to have to be updated with an updated version of this report. Again, look at the non-proprietary sections of the SE the staff has issued, or the updated version of it.

DR. KRUIZENGA: I understand. So, there are several ways to go about qualifying the thermal physical properties. Our preference is to work through the qualification of the thermal physical properties with methods not directly using testing,

using historical information to work through that. There is precedence for qualifying legacy data. That's our primary desire. If needed from a safety basis, safety significant standpoint, we would do testing as needed. But our desire is to qualify it using legacy data, primarily.

VICE CHAIR REMPE: And irrespective of whether you are able to qualify with or without testing, are you going to have to resubmit this Topical Report with --

DR. KRUIZENGA: Could you repeat it one more time?

VICE CHAIR REMPE: -- your qualification methods?

DR. KRUIZENGA: I lost a little bit of your question.

VICE CHAIR REMPE: Okay. Let me try again. Are you going to have to resubmit an updated version of this Topical Report demonstrating summarizing the results of as you bring in the qualified data to the staff?

So, this is kind of an initial step, is my interpretation of what I read in the SE, and I think I can even get that interpretation from what publicly available information going to be released by the

staff. Are you going to have to resubmit the Topical Report?

MR. GARDNER: This is Darrell Gardner. Let me step in here. So there's more than one way to resolve the limitations and conditions. One way might be to elect to provide a revision to the topical report that addresses the limitations and conditions. Another way would be to address those limitations and conditions as part of the license application. So I don't think that we're prepared to say today which way we want to go. But either way, at the end of the day we have to address the limitations and conditions in the report.

VICE CHAIR REMPE: So what I think I heard you say is that you may do it as part of your licensing application -- which means, again, another document needs to be submitted -- or you may do it independently. Is that what you said, Darrell?

MR. GARDNER: Yes, I mean I don't think that's any -- that's not really atypical of how methodology topical worked in general. They represent information, limitations and conditions are imposed. And then when the license application uses that topical, it's obligated to address the limitations and conditions of the topical report.

VICE CHAIR REMPE: Okay. And then I'd like an overview from Kairos on your take at this time, realizing that it's not completed all the work, how much additional testing do you think you need in order to cover the range of conditions required for your -- I think earlier in the first presentation you talked about a prototype?

MR. GARDNER: Yes, I don't think we'd be prepared to have that conversation this -- one, in open forum. I don't think we're prepared to have that conversation today. This topical report is about the properties themselves and agreement on the properties. And then towards the limitations and conditions, we would have to go back and make those decisions how we're going to address those. I don't think we're prepared today to outline our plans to close those limitations and conditions.

VICE CHAIR REMPE: So you don't have a feel yet, today, whether you've covered, for example, the range of temperatures required, pressures required -- whatever -- with respect to operating conditions or activating conditions for your prototype even?

MR. GARDNER: I think I'm saying, we're just not prepared to have the discussion about the future testing program.

VICE CHAIR REMPE: Okay, thank you.

DR. KRUIZENGA: So if there are no other questions, I'll move on to slide 5.

MEMBER PETTI: Yes, go ahead Alan.

DR. KRUIZENGA: So one of the -- a lot of the information can be referenced in this 2006 report from Oak Ridge. It's an excellent compilation we heavily leveraged during some of our initial screening and work in this area. So there is roughly nine criterion that was used for the molten salt reactor experiment during the '60s and '70s -- for selecting the salt. So the idea was that it had to have high temperature stability, stability under radiation, melting point that was below 500 degrees -- this was really more due to engineering considerations. Had to be compatible with containment materials, have low corrosion rates.

Product choice is extremely important because it was a liquid fueled reactor to have -- to be an effective solvent for fissile material and fission products. So we are not that. We are a pebble reactor where the pebble is contained in the fuel and the fission products. But it was fluoride was chosen as an excellent solvent. And that's one of the reasons, again, it was chosen. Both for its

neutronic characteristics and for its ability to act as a solvent. It has negative coolant reactivity, really short-term activation -- no long term activation of the actual salt itself. It's fairly low level of neutron capture and the thermal physical properties are amenable to engineering and designing the system.

MEMBER PETTI: Hey Alan?

DR. KRUIZENGA: Yes?

MEMBER PETTI: Just a question. What corrosion rate -- is a little on the high side of a number that I've seen, you know, for advanced reactors. But it depends on the lifetime of the reactor. Remind me, is this a 40-year reactor? Or a 60 or a 20? What?

DR. KRUIZENGA: Well, I think we're -- Darrell, though I am not sure if that's public or not at this point.

MR. GARDNER: Oh. Copy that, I'm -- that's very -- we have addressed the appropriate life as part of the application.

MEMBER PETTI: Okay.

DR. KRUIZENGA: Is there any other questions?

(No response.)

DR. KRUIZENGA: Moving on to Slide 7. So I haven't really said it explicitly before, but what is FLiBe, FLiBe is a mixture of lithium fluoride and beryllium fluoride. These are two salts. We chose it for a variety of different reasons. But the FHR using FLiBe is -- has an enhanced safety feature. So it has a large thermal inertia, meaning that if there are changes in temperature, it takes a lot of power to change temperatures, so that helps to minimize rapid temperature transients. The negative temperature coefficient supports reactivity control and there are minimal short term, long term activation products.

And it's really good on optimization for nuclear reactor operation having high density and high heat capacity and responds to thermal inertia. Viscosity is comparable to water. Again, it's stable under radiation at high temperatures. And then lastly, I alluded to this a little bit before. But it supports a safety barrier -- a safety basis as a barrier to fission product release.

So since it's an excellent solvent, it helps to capture products if they -- as they escape from the TRISO protective barrier, providing extra functional containment to the reactor. Are there other questions on this slide?

(No response.)

DR. KRUIZENGA: Moving on to slide 8. So this is the phase diagram. So what is being looked at right here on the bottom is beryllium fluoride concentration, amount of beryllium fluoride. So if it's 100 percent beryllium fluoride, the melting temperature is at 555 degrees -- at the top of that light blue curve. It's 100-percent lithium fluoride melting point is 848 degrees. Again, that's at the very top of the blue curve, on the left. Where the red lines are is our operating range. So we're operating between temperatures of 550 to 650 degrees. And in this white region along the vertical dotted line -- all that means is that we're fully liquid in this range. Are there other questions on this slide?

(No response.)

DR. KRUIZENGA: Moving on to slide 9. So the scope of this topical report is to really just lay out thermal physical properties -- density, viscosity, thermal, capacity, thermal conductivity, melting temperature. If this were water, we probably would not be having this particular topical report. But since it's a salt and it's so new to the community, coolant is needed. And then you also have the chemical specifications for the reactor. So we have

limits on impurities due to corrosion considerations. And we also have limits on impurities for neutronic considerations. Are there other questions on this slide?

MEMBER BALLINGER: This is Ron Ballinger. Are they prepared to discuss whether or not -- how you're going to measure in real time the chemistry to ensure that your parameters are met?

DR. KRUIZENGA: We are not ready to discuss that feature right now. That's a good question. Very good question.

MEMBER BALLINGER: Thank you.

(Pause.)

DR. KRUIZENGA: And that is the end of our slide presentation.

MEMBER KIRCHNER: Alan? This is Walt Kirchner. Can you go back to the slide that I will call the phase diagram?

DR. KRUIZENGA: Yes.

MEMBER KIRCHNER: Please. Would you one more time outline the meaning of that red box and where you expect to operate?

DR. KRUIZENGA: So our operating region is right here. Can you see my mouse on the screen, or no?

MEMBER KIRCHNER: Yes.

(Simultaneous speaking.)

MR. GARDNER: -- we're not to get into what's previously been proprietary. So maybe we need to hold that to the closed session?

DR. KRUIZENGA: Well, I don't have -- there's no -- I am just going on the vertical line. And this is -- for illustration and details are in the topical report. Darrell is right. Some of those details are proprietary.

MEMBER KIRCHNER: Now, just a moment. We're looking at a phase diagram that's public information.

DR. KRUIZENGA: That's correct.

MEMBER KIRCHNER: And secondly, we're asking whether you're going to operate in the solid and liquid zone, or a liquid zone. That's simply my question.

DR. KRUIZENGA: We are fully in liquid zone.

MEMBER KIRCHNER: Okay. So we should be looking at -- you will be in the white space of the diagram?

DR. KRUIZENGA: Correct.

MEMBER KIRCHNER: And control operating

conditions to remain comfortably above the -- I'll describe as the lines there that delineate the different phases.

DR. KRUIZENGA: That's correct.

MEMBER KIRCHNER: Okay, thank you.

DR. KRUIZENGA: No problem.

MEMBER BALLINGER: This is Ron Ballinger again. With respect to that phase diagram, if you were to have an unusual event, which caused the temperature to drop -- if you're actually on that line, when you get down to 458.9 -- plus or minus .2 degrees centigrade -- something weird is likely to happen which is very dependent on the exact mole fraction of beryllium fluoride. Have you folks thought about what likely would happen? I mean, you know, these lines are -- who knows what the range is on these -- on that vertical line. But you could end up with a case where you had instant conversion to solid. Or in a solid-plus-liquid range where you have to go through.

DR. KRUIZENGA: That's true. So, these light blue areas are solid plus liquid?

MEMBER BALLINGER: Yes, that makes me feel good. It's the purple area for which you're exactly on the boundary.

DR. KRUIZENGA: Yes.

MEMBER BALLINGER: And that means to me that if you go to the left a little bit, you're in a different regime and that is a -- if it's a puff system, which it is, when you get there, things are likely to get exciting.

MEMBER PETTI: Alan, is there any data available on the kinetics of that transformation? Do you know?

DR. KRUIZENGA: I'd have to go back and look. I didn't see anything specifically in the MSRE with regards to the specific kinetics. It's something that we can look into, though.

MEMBER BALLINGER: I'm just curious as to why you wouldn't want to be -- like, maybe there's a reactor physics concern slightly to the right.

MEMBER KIRCHNER: Yes, that's where I was going, Ron.

MEMBER BALLINGER: Because, you know, bad things can happen if all of a sudden the thing locks up.

MEMBER KIRCHNER: That's right, Ron. That's where I was going. So maybe in the closed session we can explore this further. But the question I'll ask, you don't have to answer right now, is why

are you not at a higher mole fraction so that you have much more margin in ensuring that you remain in the liquid phase?

MR. GARDNER: So, this is Darrell Gardner again. Just want to be careful of -- so I think if you went back and looked at the subcommittee presentation, you would see a proprietary slide that does define the operating range, which is to the right in the area where the asterisk is. But again, cautioning everyone. We are not prepared to get into that detail on the bottom axis in this open session. But there is a figure that has been submitted to the ACRS. It does show the specific operating ranges.

MEMBER BALLINGER: Thank you.

MEMBER BLEY: This is Dennis Bley. You sense this as something we haven't seen before in looking at reactors and how you will deal with this in the safety analysis and are jumping the gun?

MR. GARDNER: So again, this is Darrell Gardner. These are all great discussions that I would expect us to have as we move into that discussion -- the transient and accident analysis. But we're a bit ahead of that. This is more about the properties. So we can then conduct those transients and accident analysis in the future. Which would be, by the way,

a subject of a -- we anticipate that being its own topical report.

MEMBER PETTI: Are there any other questions from the members?

MEMBER MARCH-LEUBA: This is Jose. I wanted to confirm, I went to this committee slide -- from slide number 9. One of them, the one that's -- the report has the range we're talking about, and it is proprietary.

MEMBER PETTI: Yes, I remember.

MEMBER MARCH-LEUBA: Yes. So if you would like -- it's on Sharepoint if you can find the slides from the subcommittee in February.

(Pause.)

MEMBER MARCH-LEUBA: Over and out.

MEMBER PETTI: Okay. Hearing no questions, NRC staff, please?

MR. CHERESKIN: Good morning, this is Alex Chereskin. Can everybody hear me?

(Pause.)

PARTICIPANT: Yes, we can.

MR. CHERESKIN: Thank you. Stu, are you going to share the slides for the presentation?

Okay, so good morning everyone. Again, my name is Alex Chereskin. I am a chemical engineer in

the Office of Nuclear Reactor Regulation. And this morning I will be presenting to the ACRS full committee the high level results of the staff's review of the Kairos Reactor Coolant Topical Report. So next slide, please.

So we are now on Slide 2. And this slide covers a general introduction in the staff's review approach for this topical report. Any submittal with this topical report, Kairos had requested approval of the thermal physical properties and reactor coolant characteristics described in Tables 1 and 4 of the topical report. And therefore, the staff only provided conclusions for these portions of the topical and information needed to support anything found in these tables. And this is reinforced in some of the staff's limitations and conditions. And I would like to ask for -- if there are any questions before I move on to the next slide.

Okay, so hearing none, this next slide provides the regulatory basis for the review of this topical report. And part of the regulatory basis are 10 CFR Sections 50.34(a) and 52.79. And these regulations contain the requirements for an applicant to provide information related to safety analyses and also for reactor design characteristics. In addition

to these regulations in 10 CFR, in the Kairos topical report there were several principal design criteria that were referenced. These are described in a separate topical report that was submitted by Kairos, and that topical report contains a more thorough discussion of the principal design criteria. And there is some of them that are related to the molten salt characteristics that were reviewed in this topical report. And this is also discussed back at the subcommittee meeting in a bit more detail. So again, I would like to ask if there are any questions on this slide?

(Pause.)

MR. CHERESKIN: So, hearing no questions, I would like to move on to the next slide please. Okay, so this slide covers the staff review of Table 1, which are the thermal physical properties of the Kairos reactor coolant. And, sorry, I lost the visual briefly. Sorry about that. So this table -- Table 1 contains the thermal physical properties of the Kairos reactor coolant. And as Kairos had noted in its report and in their presentation earlier, these are derived from the Oak Ridge -- the molten salt reactor experiment.

And so the staff reviewed the thermal

physical properties that were provided by Kairos, and the overall finding was that these values were reasonable for salt with the nominal composition as the same as what was proposed by Kairos. And then in addition to that, there were some limitations and conditions in the topical report that would also need to be satisfied for these properties to be found acceptable. Some of this is described in section 3.2 of the topical report that Kairos submitted. And here I just wanted to take one moment to briefly speak about discussion from earlier in this meeting between Member Rempe and Kairos. I believe that the limitations and conditions that were being discussed do provide some of the flexibility for how and when to close these. And I think that the discussion earlier did accurately capture the intent of the limitations and conditions that were being discussed.

So I had just wanted to mention that. I thought this would probably be an appropriate time to cover that. So just to conclude here, based on the nominal composition of the salt the staff did find the properties in this table reasonable to use in safety evaluation subject to the limitations and conditions that were imposed in the -- in the staff safety evaluation. So I would like to take a pause here to

see if there are any comments or questions?

VICE CHAIR REMPE: So there were some changes in your earlier SE and in the markups that we've received since our subcommittee meeting. Could you talk a little bit about what motivated those changes? And then your thoughts about what additional data -- testing might be needed versus what might be addressed in the other unknown means?

MR. CHERESKIN: Sure, and so I just wanted to note that there was a slide later in the presentation that will deal with the differences. But I think this is also an appropriate time to kind of discuss what you had mentioned there, Member Rempe.

So in terms of motivation, some of the reason for the change was a more clear understanding of how Kairos proposes to bring some of this data into its quality assurance program. And some of the changes to limitations and condition also -- I believe you asked for kind of my view on this -- is that there are multiple ways to be able to do this. You know, whether it be testing or another way. And I think that some of the changes to the limitations and conditions allow for that flexibility, understanding that there may be more than one acceptable way to perform this. And that also did result in some

changes to certain areas of the text that were reflected in the staff's final SE.

VICE CHAIR REMPE: So, today we've heard, and common sense tells us, they're going to go forward with some analysis. And you've heard about scaling and all of that will depend on these properties. And today Kairos said, well, we may wait and submit the updates to this topical report as part of our application for, I guess, the prototype or whatever. The demo. When does the staff really want to see an updated version of this report? Showing how they're going to satisfy your conditions and limitations?

MR. CHERESKIN: So, from my perspective, I am not sure the timeline of when Kairos plans to submit certain reports and when they may submit certain reports that depend on this information. I would think that it makes sense to have some of these items resolved essentially by the time they are needed. But again, I am not familiar with their exact plans on when to submit the certain things. So I don't know how much I could comment on that.

VICE CHAIR REMPE: Well, as one member, I say it makes sense to try to get it resolved.

MR. CHERESKIN: Sure, no problem.

MEMBER PETTI: So I have a question in

terms of the -- bringing this under the QA program and mentioning that there were more than one way to resolve the open item. Are there criteria that the staff uses to decide, yes, the historical data from 1965 was okay. Now, you know, we really need -- even if it's confirmatory, we need measurements today because, you know, of the number of reasons of how, you know -- the pedigree was back there. You can't recreate it completely. Is there something that guides you in that discussion, in that assessment?

MR. CHERESKIN: So I think part of that discussion would be held when Kairos will eventually submit whatever their proposed path forward is on that. However, and I do not recall the exact set of criteria, but depending -- I do believe there is at least some guidance, depending on the way that is chosen to move forward with something like this. And I believe it was done -- there was some data, I believe, from one of the national laboratories on separate licensing realm that used some of these methods. And I think there could be some parallels there.

MR. MAGRUDER: Yes, this is Stu Magruder from the NRC staff. I agree with Alex on that. There are specific requirements in the standard quality

assurance guidance and in Kairos's proposed QA topical report on exactly how to do that, how to bring in legacy data into their program. And as Alex mentioned, we've just done that for the EPRI topical report on the -- or a topical report on fuel data. Actually, not the EPRI one, but the one on the metallic fuel data from Idaho. So the staff is learning, and I would say as we go along, on how to do that. And that the process is pretty well-documented in the QA process.

MEMBER PETTI: I just -- yes, and I was wondering what the timeline is for these things -- and is it, you know, if the answer is it's not acceptable and the -- you need more data, the sooner you can tell the applicant the better, right? So that they have time to react.

MR. MAGRUDER: Yes, absolutely. I think that's a coordinated effort among the developers and the national labs, now, to make sure that whatever is going to be relied on in license application has been approved already.

MEMBER PETTI: Thank you.

MR. CHERESKIN: Okay, are there any further questions on this slide?

Okay, hearing none, I would like to move

to the next slide please.

CHAIRMAN SUNSERI: Just for the public's dialing in, could you state the slide number --

(Simultaneous speaking.)

MR. CHERESKIN: Oh, sorry about that. We are on Slide 5.

CHAIRMAN SUNSERI: Yes, no problem. Thank you.

MR. CHERESKIN: So, this slide covers the staff review of the design specification for the KP-FHR reactor coolant that was provided in Table 4 of the topical report. And as Kairos noted in their earlier presentation, one of the considerations for this table would be limits on allowable impurities. And based on the information provided by Kairos, in addition to the statement in Section 3.2 of the topical that would determine corrosion performance of materials and FliBe -- along with staff limitations and conditions that are described in the staff SE, the staff did find the information provided in Table 4 of the topical report acceptable for use. So are there any questions on this slide?

Hearing none, I would like to move to the next slide, please. So we would be on slide 6. So this slide describes changes to the SER between the

draft SER, which was presented during the ACRS subcommittee meeting back in February, and to the final SER -- which we are discussing now. And so I first wanted to mention that changes made to the SE since the ACRS subcommittee meeting do not impact the staff's overall conclusions. And that some of the discussions that we had earlier regarding Table 1 -- there were some limitations and conditions that were revised based on a clearer understanding of how Kairos plans to do some data gathering activities. And along with that, there were some corresponding changes made to several sections of the text to reflect these changes.

And there is also an opportunity to combine, too, the limitations and conditions while making these changes. Additionally, there was one limitation and condition that was found to already be covered by another. So we had the opportunity to eliminate that to streamline the section a little bit more. And in the text sections itself there were some changes made just to provide additional clarity and some editorial changes as well. Are there any questions on this slide?

Hearing none, I would like to move to the next slide, which would be Slide 7 and the final slide

in this presentation. So this slide presents the staff conclusions on our topical report. And the staff found that Kairos has provided reasonable assurance that the information in Tables 1 and 4 of the topical report satisfy regulatory requirements as described in the staff SE and that this information is accessible to use to begin safety analyses, and that these staff approvals will be subject to limitations and conditions that are specified in Section 4 of the SE. Are there any further questions on my presentation?

Okay. Hearing none, I suppose I will turn it back over to Stu or the ACRS.

MEMBER PETTI: Thank you. Stu, do you have anything else?

MR. MAGRUDER: No, I don't. Thank you.

MEMBER PETTI: Okay, members, any other questions before we complete?

Okay, hearing none, I think this ends the open session now. Chairman, back to you.

CHAIRMAN SUNSERI: Okay, so thank you Dave and thank you Kairos and staff for both presentations. So we are at a point here now where it looks like we're ready to ask for any public comments regarding the presentations you just heard. So, Thomas, if you

can open the public phone line and let me know when that is open.

PARTICIPANT: Public line is open.

CHAIRMAN SUNSERI: Okay, thank you. So any members of the public listening in on the public phone line, if you care to make a comment or a statement, now is the opportunity. State your name and provide your comment. And just for acknowledgment, if there is anybody on the line that just could say something to confirm that the line is open?

PARTICIPANT: The line is open.

CHAIRMAN SUNSERI: Okay, thank you. Any public comments?

(No response.)

CHAIRMAN SUNSERI: Okay, appreciate that. Thomas, you can close the line now. And so next we will go into report preparation, it looks like. And so members, we have a crossroad here and I ask for your preference on this. We can pick up with NuScale report that we started yesterday, or we can go into the Kairos. I think NuScale, just from a big picture priority perspective, it is a higher priority and it would be beneficial for us to finish those first. But I am open to committing to finishing here. Anybody

want to comment?

MEMBER BALLINGER: This is Ron. When are we -- there's a proprietary session with Kairos. That's in the letter writing part?

CHAIRMAN SUNSERI: That's my understanding.

(Simultaneous speaking.)

MEMBER BALLINGER: So there's really no -- I mean, is that an appropriate venue for us to ask questions to Kairos which they would consider proprietary?

CHAIRMAN SUNSERI: Let me ask Dave for guidance on that. Dave Petti?

MEMBER PETTI: I believe that the letter and draft requires us to be in closed session. If members have questions, which may be developed from the reading of the letter. I think it will be much along the lines of some of the questions that we heard in the open session that they couldn't respond to. So I think we're in a conundrum, frankly, in terms of how we, you know, set out on finalities, the next step.

VICE CHAIRMAN REMPE: Well, could I make a suggestion that I believe the letter on scaling has no proprietary information and a quick read through of it could be done while we're all still here without

having to connect and disconnect and all that to the other line. And then perhaps it would be good to go to the proprietary session and let Dave read the draft letter on the coolant topicals to fully understand where the concerns are. And at that point, stop and go back to NuScale because it is a higher priority and make sure we get through all of the letters that have to be done? It's just a suggestion from one member.

MEMBER PETTI: I don't have a problem with just doing a read through because that doesn't take long.

MEMBER BLEY: It would seem, because we've got the Kairos people here, that if we went to the closed session, did a read through of that letter but also let people ask proprietary questions and get that out of the way for now, I am not sure you've got all the right people if you wait until some arbitrary time in the future.

(Simultaneous speaking.)

MEMBER BROWN: Can I make a -- this is Charlie. While we were going through the other presentation, all of the sudden a join a closed meeting popped up and I was already in this other session.

(Laughter.)

MEMBER BROWN: And Steve Schultz is now in that session also. So I -- we got to figure out -- I -- because I didn't close it because I didn't know if I could get back in or not. So --

(Simultaneous speaking.)

MR. MOORE: Mr. Chairman, this is Scott Moore. I think when the public line got closed, it got closed all the way. In fact, it needed to be muted but not closed. So, Thomas, could you bring the public line back on and just mute it, please?

PARTICIPANT: Copy that.

MEMBER PETTI: So, Matt, I think Joy's idea is a good one. So I only want to say, we'll start with a read through of the scaling topical. And since Jose led that, he can do the read through.

MEMBER BROWN: Is that the one that has to be closed?

MEMBER PETTI: No. That's the one that's open.

MEMBER BLEY: Matt?

CHAIRMAN SUNSERI: Yes.

MEMBER BLEY: I think we're off the record for the meeting, are we not?

CHAIRMAN SUNSERI: You mean as far as the transcriber goes?

MEMBER BLEY: Exactly.

CHAIRMAN SUNSERI: I believe that is true.

(Simultaneous speaking.)

COURT REPORTER: Can anyone hear me?

MEMBER BLEY: Is P&P on the record?

CHAIRMAN SUNSERI: No, it's not transcribed. It's public, but it's not transcribed. So we can -- yes, Scott, so we're going to -- we can release the transcriber -- he doesn't have to do report preparation.

MR. MOORE: I believe that's correct.

(Simultaneous speaking.)

MR. MOORE: I think all the rest of the sessions are letter writing or are P&P and none of those are transcribed. Alicia, are you here?

PARTICIPANT: Yes, I am here.

MR. MOORE: And is my analysis correct that everything is either letter writing or P&P and none of those are transcribed?

PARTICIPANT: Correct.

(Simultaneous speaking.)

PARTICIPANT: Scott, this is Chris, just wanted to chime in that I see here some of the questions for Kairos that might have to be addressed in the closed session. If that were the case, then I

would recommend that you keep the court reporter for that Q&A session before we release the court reporter when we switch into the letter writing session.

MR. MOORE: And split it up into Q&A and then letter writing?

PARTICIPANT: Correct. Assuming that the members would like to have Q&A portion being captured on record.

MR. MOORE: That's a good point --

VICE CHAIR REMPE: I think some of the questions are going to be about what is proprietary and not proprietary in the draft coolant letter?

MR. MOORE: Well, Member Rempe, that's fine. The transcriber can have a proprietary portion of the transcription. We checked all that before this.

MEMBER BROWN: Well, why doesn't it make sense to do that proprietary session now? Read the proprietary letter, ask the questions, and then we can close that out?

MEMBER PETTI: Yes, in light of the fact that the transcriber has to be here, with that information, I kind of agree with you, Charlie, we probably should flip it around.

VICE CHAIR REMPE: Do we really need a

transcriber for questions about what's proprietary and not proprietary in a draft letter?

CHAIRMAN SUNSERI: Well, there were other questions regarding the operating envelope and stuff like that that I think might come up, too, so it's not just administrative stuff.

MEMBER BROWN: I mean, we've got the open -- we've got the closed session. It's there. It's already opened. I know I'm in it, and Steve Schultz is in it and there's somebody else in it. So I don't know how it opened, but I've got it.

CHAIRMAN SUNSERI: Okay, so I've asked for everybody's input. Thank you for all that. The direction that we're going to move into is we're going to break off of this open session. We're going to go into closed session. And the order will be we'll have a closed session, proprietary Kairos discussion follow-up, and then we'll release the court reporter. And then we'll go into the proprietary report preparation. Dave can do the read-through. We can get the major comments and then we can close that session and come back into the public without the court reporter after that. So --

VICE CHAIR REMPE: Do we need to tell the public when we'll be back? Or do we just -- or expect

to hold on?

MR. MOORE: So, Member Rempe and Chairman Sunseri, my understanding from Larry, who is on the public line is that right now, he's the only member on the public line. Larry, is that correct?

MR. BURKHART: Yes, that's correct.

CHAIRMAN SUNSERI: Well, I mean, that's fine. But it's not all that material. We maintain a public line no matter who is on it or not. And according to our agenda, which was published on the Federal Register, I don't think we need to make any further announcements. It's clear that we're going to be in and out of proprietary sessions. They can call in as long as we keep the line open at the right time, then we're covered. Okay, so at this point in time, we are going off the public record.

MEMBER BLEY: Sorry, this is Dennis. Do we have any problem -- I am going to shut this session down and go to the other one. If some members leave it open, is there cross-talk from one to the other? Because we have trouble with proprietary unless we all shut this other one down?

CHAIRMAN SUNSERI: Yes, I think the only way to avoid these duplicate sessions is we're just -- everyone is going to have to sign out of this current

session, sign in to the new one. And then when we're ready to go forward with, you know, a more open session then we will close out of the private one, the proprietary one, and then sign back in to this one.

MEMBER MARCH-LEUBA: I might have missed it. What time do we join the proprietary? Do we have a break?

CHAIRMAN SUNSERI: Yes, we're going to take a 15-minute break here. We will resume at 10:30 --

MEMBER KIRCHNER: Matt?

CHAIRMAN SUNSERI: I'm sorry, go ahead.

MEMBER KIRCHNER: Could we take a little bit longer break this time?

CHAIRMAN SUNSERI: Longer than 15 minutes?

MEMBER KIRCHNER: Yes.

CHAIRMAN SUNSERI: How long do you suggest, Walt?

MEMBER KIRCHNER: So, quarter of the hour?

CHAIRMAN SUNSERI: Thirty-minute break? Okay. We'll take a 30-minute break. We'll resume at a quarter till the hour.

MEMBER MARCH-LEUBA: And I think we should all be planning to work late. I don't know about you all guys, but I don't have anything better to do. I

am here -- I have been at home and I am not going anywhere. So --

MEMBER BLEY: Speak for yourself.

MEMBER MARCH-LEUBA: Okay.

CHAIRMAN SUNSERI: Jose, we'll see what -- we'll work as, you know, whatever is prudent and practical. I mean, I don't want to spend our time here after all the hours yesterday, I physically can't do anything anyway, it was exhausting. But we'll see how it goes.

MR. WIDMAYER: Hey, Matt?

CHAIRMAN SUNSERI: Yes.

MR. WIDMAYER: This is Derek. There's a question on the IM from NuScale people that joined the Skype session and would like to understand what they should do.

MR. MOORE: Weidong, this is Scott. Does NuScale have the bridge line?

MR. SNODDERLY: This is Mike Snodderly. Let me speak. So I just was communicating with Mark Chitty of NuScale. That should not be a problem. This Skype session, they don't have access to the Kairos Skype session. They could stay here until we come back to here to do letter writing. I think it would benefit NuScale if we could give them some idea

when that might occur so that they could go off and do other things. But there's not a problem with -- I don't see a problem to have a separate Skype session for closed. I don't believe there's a problem.

MR. WONG: Yes, let's go to Skype for closed session. It was sent out this morning -- it's all to the members in this email.

MR. SNODDERLY: Yes, please do not share that or put that on the instant message. Just go to that NRC email to get it --

MR. WONG: I sent it out to email, yes.

MR. MOORE: Thank you, I misunderstood the question. So for anybody on this we would --

(Simultaneous speaking.)

MR. MOORE: -- we will definitely be back at 1:00. We may be back before 12:00.

MEMBER BROWN: Now, to be clear, we're supposed to hang up from this session and we'll just log back in later?

MR. MOORE: We'll log back in at 10:45.

MEMBER BROWN: Yes, we're going to do the closed meeting at 10:45.

MR. MOORE: That's correct.

MR. NGUYEN: I think what Charles is asking is that -- if you are an ACRS member, you

should hang up on this call and so --

MEMBER BROWN: Exactly.

MR. NGUYEN: -- go to a closed Kairos session at 10:45.

CHAIRMAN SUNSERI: That is correct.

MEMBER BROWN: Right, that's what I wanted to confirm. Thank you.

CHAIRMAN SUNSERI: And as far as the NuScale folks, I don't see any way we're going to get to them before 1:00 Eastern Time. So --

MR. SNODDERLY: Thank you very much, Chairman Sunseri. I will let NuScale know and we'll look forward to starting letter writing with you guys at 1:00.

CHAIRMAN SUNSERI: Okay. So just to summarize, ACRS members are going to hang up from this current session. We are going to sign into the proprietary session that Weidong has sent out the note to our NRC email at a quarter till the hour. So that would be 10:45. We will have the court reporter transcribing for that part of the meeting, and then we will release the transcriber and go into a proprietary report writing or preparation. And then, when Dave Petti is satisfied we are sufficiently progressed through that, we will sign out of the proprietary

session. And I am not going to say what's going to happen after that. We will decide when we get to that point in the proprietary session. All right? Everybody clear?

MR. MOORE: Yes.

CHAIRMAN SUNSERI: Thank you all for a good open session. And we are recessed out of this. See you on the proprietary line.

(Whereupon, the above-entitled matter went off the record at 10:21 a.m.)

Kairos Power

KP-NRC-2004-001

April 1, 2020

Project No. 99902069

US Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, DC 20555-0001

Subject: Kairos Power LLC
Presentation Materials for Kairos Power Briefing to the Advisory Committee on Reactor Safeguards on Reactor Coolant and Scaling Methodology Topical Reports

This letter transmits presentation materials for the April 9, 2020, briefing for the Advisory Committee for Reactor Safeguards (ACRS) full committee meeting. At the meeting, participants will discuss two topical reports that were submitted to the Nuclear Regulatory Commission staff for review and approval: (1) Reactor Coolant for the Kairos Power Fluoride Salt-Cooled High Temperature Reactor (KP-TR-005-P); and (2) Scaling Methodology for the Kairos Power Testing Program (KP-TR-006-P).

Enclosure 1 provides the non-proprietary presentation materials for the open session.

If you have any questions or need any additional information, please contact Drew Peebles at peebles@kairospower.com or (704) 275-5388 or Darrell Gardner at gardner@kairospower.com or (704) 769-1226.

Sincerely,

Peter Hastings, PE
Vice President, Regulatory Affairs and Quality

Enclosures:

1) Open Session Presentation Materials for the April 9, 2020, ACRS Briefing (Non-Proprietary)

xc (w/enclosure):

Benjamin Beasley, Chief, Advanced Reactor and Licensing Branch
Stewart Magruder, Project Manager, Advanced Reactor and Licensing Branch
Weidong Wang, Senior Staff Engineer, Advisory Committee for Reactor Safeguards

Enclosure 1

Open Session Presentation Materials for the April 9, 2020, ACRS Briefing (Non-Proprietary)

Kairos Power

OVERVIEW OF SCALING METHODOLOGY TOPICAL REPORT

ACRS FULL COMMITTEE MEETING, APRIL 8, 2020

Kairos Power's mission is to enable the world's transition to clean energy, with the ultimate goal of dramatically improving people's quality of life while protecting the environment.

Outline

- Purpose of the Scaling Methodology Topical Report
- Hierarchical Two-Tiered Scaling (H2TS) Methodology
- Use of Surrogate Fluids in Scaled Experiments
- Application of Scaling Methodology to Integral Effects Tests (IETs)
- Application of Scaling Methodology to Separate Effects Tests (SETs)
- Conclusions

Kairos Power

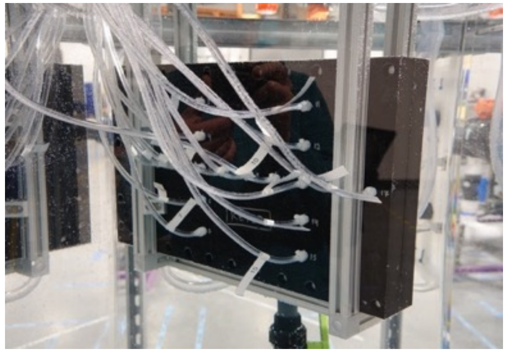
Purpose of the Scaling Methodology Topical Report

- The methodology is used to scale integral effects tests (IETs) and separate effects tests (SETs) supporting the KP-FHR evaluation model assessment base
- The methodology is limited to single-phase Flibe systems and phenomena
- Surrogate fluids enable direct and comprehensive, local measurements of the phenomena under investigation due to higher compatibility of high-accuracy instrumentation (e.g., temperature and flow velocity)
- Kairos Power is requesting NRC review and approval to:
  - Use the scaling methodology with surrogate fluids described in the report (heat transfer oil and water) for testing included in the assessment base of evaluation models supporting KP-FHR safety analysis

Scaling Methods Support Acceleration of Kairos Power's Validation Testing Roadmap

KP-SETs

R-Lab
2020



Fluid dynamics tests
Room-temperature water
40% geometric scale

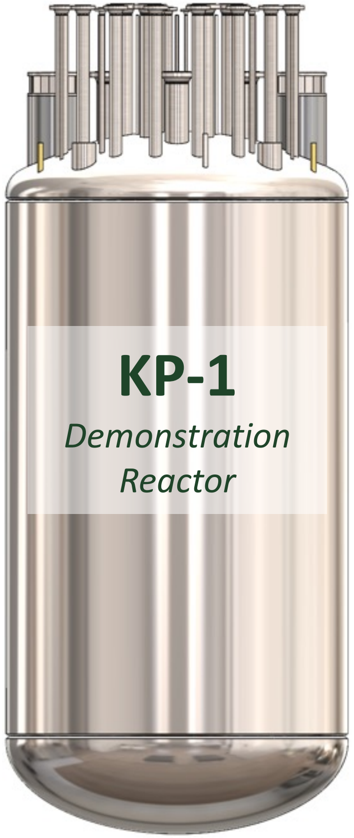
Heat transfer tests
Heat transfer oil (72°C)
Reduced geometric scale

+

KP-IETs

R-Lab
2020
½ Height

Validation of KP-FHR Evaluation Models



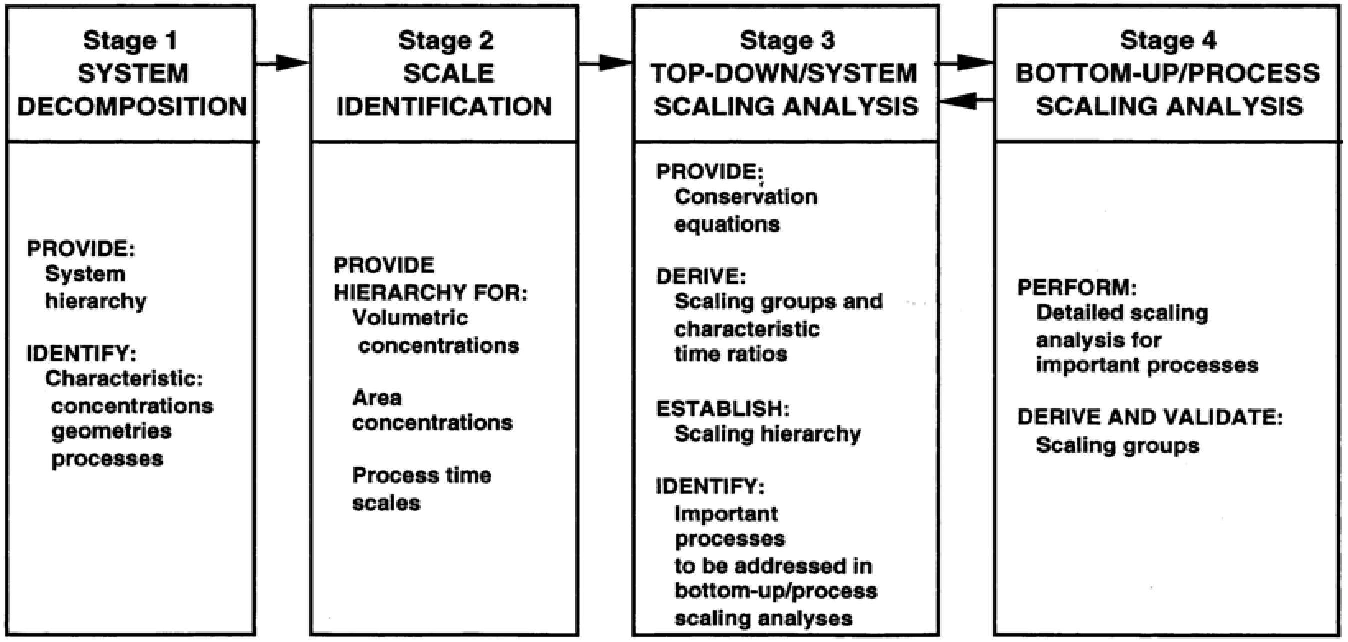
Reduced scale (size, power, temperature)
Surrogate fluids
Surrogate materials

Full scale
Flibe coolant (550-650°C)
TRISO fuel pebbles

Kairos Power

Hierarchical Two-Tiered Scaling (H2TS) Methodology

- Generic scaling method previously developed for and approved by the NRC
- Used for development of previous and current experimental programs for LWRs and non-LWRs
- Selected by Kairos Power for scaling of thermal fluids IETs and SETs as part of the Evaluation Model Development and Assessment Process described in Regulatory Guide 1.203



Source: Zuber, N. et al. (1998). An Integrated Structure and Scaling Methodology for Severe Accident Technical Issue Resolution: Development of Methodology. Nuclear Engineering and Design, 186 (1), 1-21.

Kairos Power

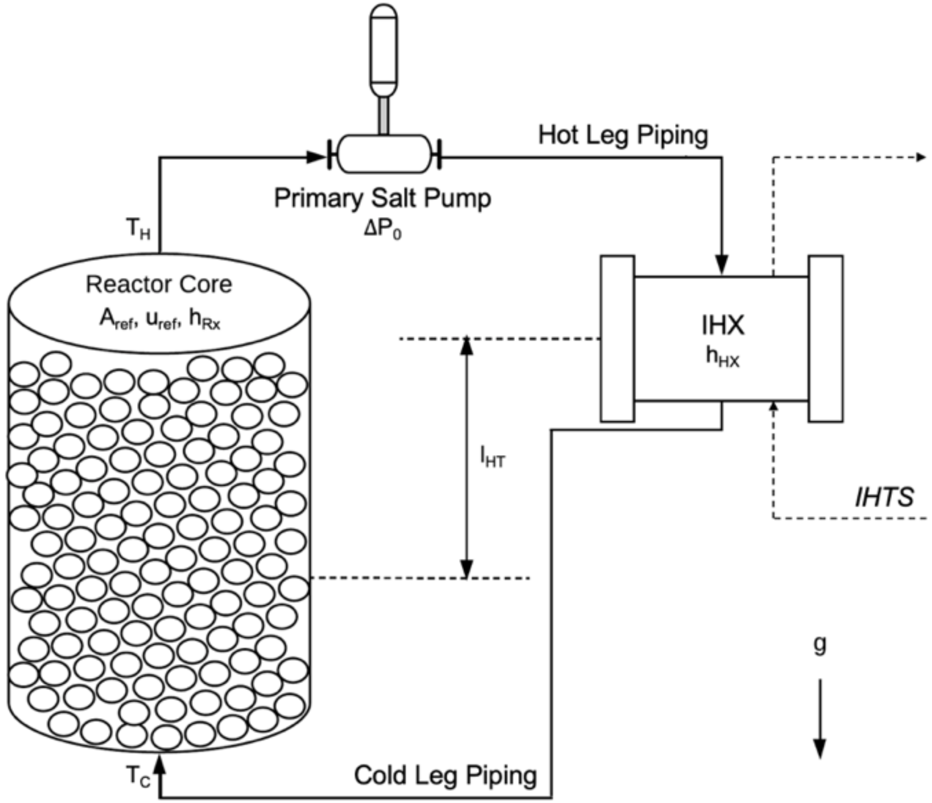
Use of Surrogate Fluids in Scaled Experiments

- Surrogate fluids allow the investigation of fluid flow and heat transfer phenomena relevant to the KP-FHR design at significantly smaller scale and required resources (e.g., power and temperature)
  - Heat transfer oil at room temperature may simultaneously match Reynolds, Prandtl, Grashof and Froude numbers for Flibe at average operating temperatures in the KP-FHR primary heat transport system
  - Water may be used for simultaneous matching of Reynolds and Froude numbers
- Surrogate fluids enable direct and comprehensive, local measurements of the phenomena under investigation due to higher compatibility of high-accuracy instrumentation (e.g., temperature and flow velocity) with low-temperature environment
- As a result, extensive, high-accuracy local data may be collected from scaled IETs and SETs to support the assessment base of KP-FHR safety analysis evaluation models, and transparent surfaces may be used for direct visual access
- Surrogate fluids have been used extensively in past and current experimental efforts for nuclear reactor development in both single- and multi-phase flow systems

Kairos Power

Application of Scaling Methodology to IETs

- Scaling analysis for a surrogate fluid (heat transfer oil) IET of the KP-FHR primary heat transport system
- Classes of licensing basis events illustrated in the topical report:
  - Steady-state, normal forced-circulation operations
  - Transients involving loss of forced flow and transition to natural circulation (e.g., pump trip, loss of heat sink)
- Illustrated using an idealized model of the KP-FHR primary heat transport system and scaled IET



Kairos Power

Application of Scaling Methodology to SETs

- SETs are used to develop closure models and correlations for module/component-level phenomena
- Topical report covers generic fluid dynamics and heat transfer phenomena, and KP-FHR design specific phenomena:
  - Forced circulation fluid dynamics
  - Convective heat transfer
  - Conjugate heat transfer with solid structures
  - Twisted elliptical tube experiments
  - Pebble bed granular flow dynamics experiments
  - Porous media and packed bed heat transfer experiments

Conclusions

- Kairos Power has adopted the H2TS methodology for scaling of IET and SET experiments in support of KP-FHR evaluation models
- The report details the scaling methodology used for thermal fluid IETs that will model the KP-FHR primary heat transport system under normal operations and transients that involve transition to natural circulation
- The report details the scaling methodology used for thermal fluid SETs relevant to specific KP-FHR components and phenomena
- The report describes the motivations and rationales for using specific classes of surrogate fluids in scaled KP-FHR IET and SET experiments
- **Kairos Power is requesting NRC review and approval to:**
  - Use the scaling methodology with surrogate fluids (heat transfer oil and water) described in the report for testing included in the assessment base of evaluation models supporting KP-FHR safety analysis

Kairos Power

Questions

Kairos Power

OVERVIEW OF REACTOR COOLANT TOPICAL REPORT

ACRS FULL COMMITTEE MEETING, APRIL 8, 2020

Kairos Power's mission is to enable the world's transition to clean energy, with the ultimate goal of dramatically improving people's quality of life while protecting the environment.

Outline

- Purpose of Reactor Coolant Topical Report
- Coolant Selection Criterion for MSRE
- KP-FHR Flibe Specification
  - Corrosion allowances
  - Neutronic Considerations

Purpose of the Reactor Coolant Topical Report

Kairos Power requested the NRC review and approval of the reactor coolant design specification limits and thermophysical properties for the Kairos Power Fluoride Salt-Cooled, High Temperature Reactor (KP-FHR).

Compilation of Coolant Data and Information

Williams ORNL-2006

ORNL/TM-2006/12

Assessment of Candidate Molten Salt Coolants for the Advanced High-Temperature Reactor (AHTR)

March 2006

Prepared by

D. F. Williams
L. M. Toth
K. T. Clarno

Reference leveraged heavily for basis of Flibe due to excellent compilation of broad information.

CONTENTS

Kairos Power

Coolant Selection Criterion for MSRE

Criteria	Flibe Information
1. Stability at high temperatures (>800°C)	Vapor pressure is low over operational temperatures
2. Stability under radiation	Minimal degradation if using ^{7}Li
3. Melting point below 500°C	The melting point of Flibe is 459°C
4. Materials compatible	Clean Flibe has low corrosion rates. Additions of elemental beryllium control corrosion to less than 30 micron/year
5. Effective solvent for fissile material and fission products	Flibe was solvent for MSRE fuel salt; able to dissolve fuel and most fission products
6. Negative coolant reactivity	Coolant density Coefficient: -$0.01 per 100°C Coolant Void Ratio: -$0.11*
7. Low short-term activation and no long-life activation	Short-term activation is small.
8. Low relative neutron capture	8x neutron capture relative to graphite.
9. Thermophysical properties	

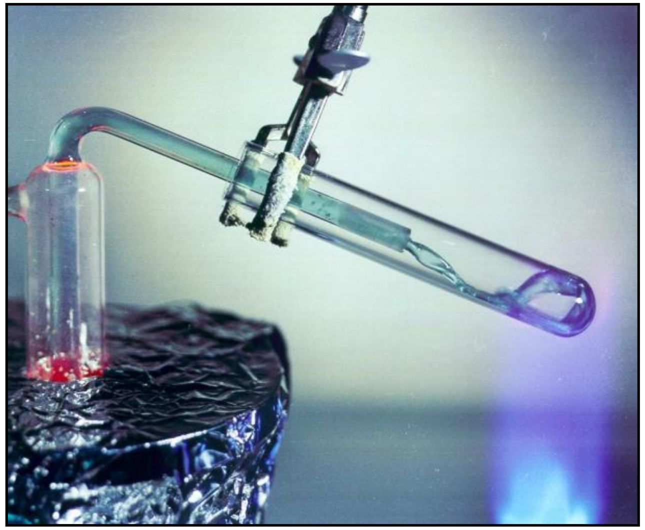
* Analysis performed using prismatic VHTR geometry.

From Williams ORNL-2006

Kairos Power

KP-FHR uses Flibe ($2LiF:BeF_2$) as a coolant

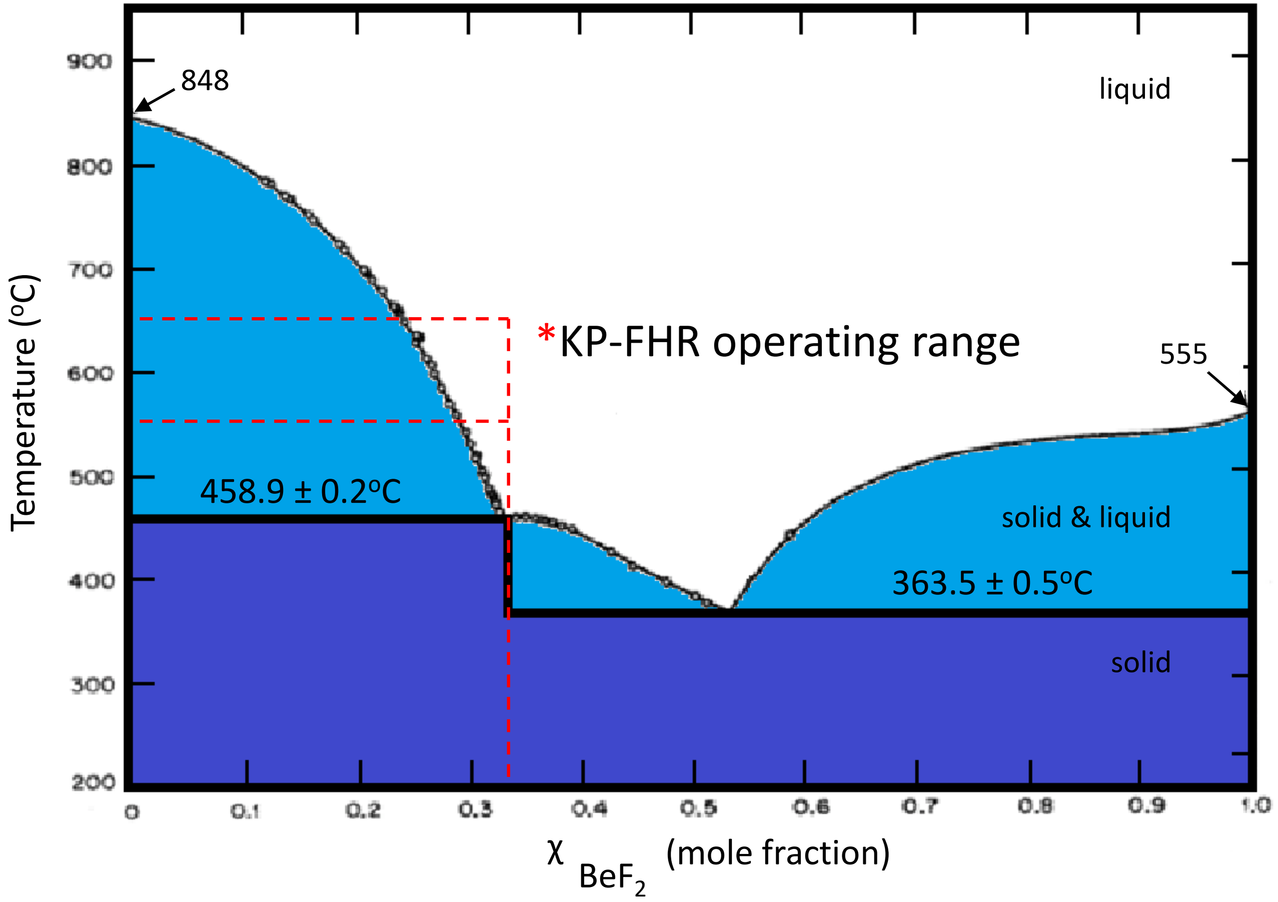
- Flibe coolant provides enhanced safety features relative to LWR designs.
  - Large thermal inertia minimizes rapid temperature transients
  - Negative temperature coefficient of reactivity supports reactivity control
  - Minimal short-term and long-term activation
- Flibe is an optimization for nuclear reactor operation
  - High density and heat capacity (i.e. thermal inertia)
  - Viscosity comparable to water
  - Stable under radiation and at high temperatures
- Flibe supports safety basis as a barrier to fission product release.
  - Absorbs fission products that escape the TRISO protective layer, providing additional functional containment protection.



LiF-BeF_2 mixture (Flibe)

Lithium Fluoride, Beryllium Fluoride Phase Diagram

Simplified from ORNL-DWG71-527OR2



Grimes, W.R., Bohlmann, E.G., Meyer, A.S., and Dale, J.M.,"Fuel and Coolant Chemistry," Chapter 5 in Rosenthal, M.W., Haubenreich, P.N., and Briggs, R.B., The Development Status of Molten-Salt Breeder Reactors, Oak Ridge National Laboratory Report ORNL-4812 (1972).

Kairos Power

Reactor Coolant Topical Report Scope

Reactor Coolant Topical Report Defines

- Thermophysical properties of Flibe
  - Density, viscosity, heat capacity, thermal conductivity, melting temperature, etc.
- Chemical Specification used in KP-FHR
  - Corrosion allowances; impurities known to cause corrosion have limits on concentration
  - Neutronics considerations; impurities important for neutronics have limits on concentration

Questions

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Presentation to the ACRS Full Committee

Staff Review of Kairos Topical Reports

KP-TR-006, REV 1,
"SCALING METHODOLOGY FOR THE KAIROS POWER TESTING PROGRAM"

Presenters:

Stu Magruder - Project Manager, Office of Nuclear Reactor Regulation (NRR)
Antonio Barrett, Reactor Systems Engineer, NRR

April 9, 2020

(Open Session)

“Scaling Methodology for the Kairos Power Testing Program” Overview

- Review scope and approach
- Integral effects tests (IETs)
- Separate effects tests (SETs)
- Surrogate fluids
- Conclusions/Limitation and conditions

Regulatory Basis

- An approved scaling methodology is used to design test facilities that provide data for analytical tool assessment and demonstrate safety features of a design.
- Applicable regulations:
  - 10 CFR 50.43(e) requires that sufficient test data exist on the safety features of the design to assess the analytical tools used for safety analyses over a sufficient range of normal operating conditions, transient conditions, and specified accident scenarios
  - 10 CFR 50.34, 10 CFR 52.47, and 10 CFR 52.79 "Contents of Applications" require a safety analysis report to analyze the design and performance of structure, systems, and components
    - Analyses are typically performed with evaluation models (i.e., analytical tools)

Review Scope and Approach

- IET Review
  - Top-down
    - Control volume approach consistent with top-down evaluation from Hierarchical Two-Tier Scaling Analysis (H2TS)
    - Review transport equations and associated assumptions
    - Perform independent non-dimensional analysis
  - Bottom-up
    - Compare scaling groups against results from traditional non-dimensional analyses
- SET Review
  - Compare against standard practice where applicable
  - Identify unique design features and access scaling approach experience base
- Surrogate Fluid Review
  - Perform independent calculations to compare thermophysical properties
  - Investigate sources of distortion
  - Identify limitations to the use of surrogate fluids

Changes to SER

- Minor changes to the SER following the Subcommittee meeting
  - Updated the applicant's motivation for the use of surrogate fluids to include fewer required resources, and to enable the use of available and accurate instrumentation.

    the TR clarifies the motivation for the use of surrogate fluids is to allow for the investigation of relevant fluid and heat transfer phenomena at significantly smaller scale, reduced temperatures, ~~and~~fewer required resources, and to enable the use of available and accurate instrumentation.

  - Updated the conclusion discussion to include the regulatory basis to develop assessment data as required by EMDAP and in partial fulfillment of 10 CFR 50.43(e).

    of the SE, for scaling momentum and heat transfer phenomena for the KP-FHR PHTS under normal operations and transient conditions~~.~~ to develop assessment data as required by EMDAP and in partial fulfillment of 10 CFR 50.43(e) . In particular, the NRC staff finds that (1) the

- Open Items from Subcommittee meeting
  - No follow-up questions or activity identified during Subcommittee meeting

Conclusions

- The NRC staff approves the KP-TR-006 topical report methodology for scaling momentum and heat transfer phenomena for the KP-FHR PHTS under normal operations and transient conditions, subject to 3 Limitations and 5 Conditions
  - The application of the scaling methodology to IETs identifies the appropriate scaling groups to capture the relevant physical phenomena subject to the applicable Limitation and Conditions
  - The application of the scaling methodology to SETs identifies the appropriate scaling groups to capture the relevant physical phenomena subject to the applicable Limitations and Conditions.
  - The use of surrogate fluids as described in KP-TR-006 is capable of preserving the appropriate scaling groups, with acceptable distortions

Backup Slides

Limitations and Conditions

- **Limitation 1:** NRC staff's approval on the identified scaling groups is limited to the KP-FHR Primary Heat Transport System for 1-D flow for the 3 scenarios identified in the TR
- **Limitation 2:** Modeling of specified flow behavior requires justification outside the scope of the scaling TR
- **Limitation 3:** The use of surrogate fluids cannot be used for scenarios involving a change of phase
- **Condition 1:** An evaluation model that references the TR will include a summary of a distortion analysis that evaluates the as-built and completed test distortions.
- **Condition 2:** An evaluation model that references the TR will assess the impact of the distortion attributed to parasitic heat loss differences between the KP-FHR prototype and the scaled facility.
- **Condition 3:** An evaluation model that references this TR for the scaling of twisted tube heat exchangers needs to assess the potential for unidentified scaling distortions, due to uncertainties in the adequacy of the geometric scaling presented for twisted tube heat exchangers, in the evaluation model assessment and uncertainty quantification.
- **Condition 4:** An evaluation model that references this TR for the scaling of heat transfer phenomena in packed beds, and the associated development of heat transfer correlations, needs to assess the potential for unidentified scaling distortions, due to uncertainties in the adequacy of the geometric scaling presented for porous media or packed beds, in the evaluation model assessment and uncertainty quantification.
- **Condition 5:** Distortion report will quantify the impact of thermal radiation heat transfer

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

Presentation to the ACRS Full Committee Regarding NRC Staff Review of

KP-TR-005, Revision 1
Reactor Coolant for the Kairos Power Fluoride Salt-Cooled High Temperature Reactor Topical Report, Revision 1

ACRS Full Committee Meeting
April 9th, 2020

Presenters:
Alexander Chereskin
Stewart Magruder

April 9, 2020
Open Session

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

Introduction and Review Approach

- Kairos requested approval of the thermophysical properties in Table 1 of the TR and the reactor coolant characteristics in Table 4 of the TR.
- The staff only provided conclusions for these portions of the TR and any information needed to support the values and parameters found in these tables.
- Limitation and Condition 1 states that an applicant referencing this TR may only use information provided in Tables 1 and 4 (subject to other relevant Limitations and Conditions).

Regulatory Basis

- Title 10 of the *Code of Federal Regulations* (10 CFR) Sections 50.34(a) and 52.79 contain requirements regarding reactor design characteristics and preliminary safety analyses.
- Principal Design Criteria (PDC) as described in the Kairos PDC Topical Report.

Staff Review of Table 1

- Kairos stated that the thermophysical properties are predominately derived from the Oak Ridge National Laboratories Molten Salt Reactor Experiment.
- Staff reviewed the thermophysical property correlations and expected uncertainties provided in Table 1 of the Reactor Coolant Topical Report.
- The staff found the thermophysical properties and associated uncertainties in Table 1 acceptable for use subject to Limitations and Conditions.
  - An 'Open Item' in Section 3.2 of the TR states that Kairos will bring this data under its QA program.

Staff Review of Table 4

- Table 4 provides the design specification for the KP-FHR reactor coolant.
- The staff found the design specification acceptable subject to Limitations and Conditions.
  - Additionally, Kairos stated in Section 3.2 of the TR that corrosion performance of 316H in Flibe (consistent with specified impurity limits) will be addressed.

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

Changes to SER

- Changes made to the SER since the ACRS sub-committee meeting do not impact overall conclusions.
- Two Limitations and Conditions were consolidated based on clearer understanding of planned Kairos data gathering activities described in Section 3.2 of the TR.
  - Corresponding changes to several text sections to reflect this.
- Eliminated one redundant Limitation and Condition.
- Additional clarity and editorial changes.

Staff Conclusions

- Kairos has provided reasonable assurance that the information in Tables 1 and 4 of the Reactor Coolant TR will satisfy regulatory requirements as described in the staff SER.
- Information is acceptable to use in safety analyses.
- The Staff approvals are subject to the Limitations and Conditions in Section 4.0 of the SER.