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UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

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702ND MEETING

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

(ACRS)

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WEDNESDAY

FEBRUARY 1, 2023

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The Advisory Committee met via teleconference at 8:30 a.m., Joy L. Rempe, Chairman, presiding.

COMMITTEE MEMBERS:

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

ACRS CONSULTANT:

DENNIS BLEY

DESIGNATED FEDERAL OFFICIAL:

WEIDONG WANG

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P-R-O-C-E-E-D-I-N-G-S

8:30 a.m.

MEMBER REMPE: Good morning. It's 8:30 on the East Coast, and this meeting will now come to order. This is the first day of the 702nd meeting of the Advisory Committee on Reactor Safeguards. I'm Joy Rempe, Chairman of the ACRS.

Other members in attendance are Ron Ballinger, Vicki Bier, Charles Brown will be here soon, there were some delays on the road, Vesna Dimitrijevic, Greg Halnon, Walt Kirchner, Jose March-Leuba, Dave Petti and Matt Sunseri. So we do have a quorum today.

Today the Committee is meeting in-person and virtually.

The ACRS was established by the Atomic Energy Act and is governed by the Federal Advisory Committee Act. The ACRS Section at the U.S. NRC public website provides information about the history of this Committee and documents such as our charter, bylaws, Federal Register notices for meetings, letter reports and transcripts of all full and subcommittee meetings, including all slides presented at the meetings.

The Committee provides its advice on

safety matters to the Commission through its publicly available letter reports.

The Federal Register notice announcing this meeting was published on December 27, 2022, and this announcement provided a meeting agenda as well as instructions for interested parties to submit written comments or written documents or request opportunities to address the Committee.

The Designated Federal Officer at today's meeting is Mr. Weidong Wang.

The communications channel has been opened to allow members of the public to monitor the open portions of the meeting. The ACRS invites members of the public to use the MS Teams link to view slides and other discussion materials during these open sessions. This link information was placed in the Federal Register notice and the agenda on the ACRS public website.

We've received no written comments or requests to make oral statements from members of the public regarding today's session. Periodically, the meeting will be open to accept comments from participants listening to our meetings.

Written comments may be forwarded to Mr. Weidong Wang, today's Federal Officer.

During today's meeting, the Committee will consider the following two topics, the Kairos Topical Report on Graphite Materials and the Kairos Topical Report on Metallic Materials.

Note that portions of these Kairos topic discussions may be closed as stated in the agenda. A transcript of the open portions of the meeting is being kept, and it is requested that speakers identify themselves and speak with sufficient clarity and volume so they can be readily heard. Additionally, participants should mute themselves when not speaking.

Before we begin today's meeting, I do have one announcement I would like to make. On December 9, 2022, it was publicly announced that President Biden appointed Member Ballinger to the Nuclear Waste Technical Review Board. So please join me in congratulating Member Ballinger for this appointment.

And so at this time, I would like to ask other members if they have any opening remarks. Seeing no one, I would like to ask Dave Petti to lead us in our first topic in today's meeting. Dave?

MEMBER PETTI: Okay. We're going to talk about the draft safety evaluation of graphite material qualification for Kairos fluoride high temperature reactor. To start is Bill Jessup on the line to give opening comments?

MR. JESSUP: Yes, sir. And thank you, Member Petti and thank you, Chairman Rempe, for the opportunity to present to the Committee today.

I am Bill Jessup, Chief of Advanced Reactor Licensing Branch 1 here in the Division of Advanced Reactors in Non-Power Production and Utilization Facilities, or DANU, in the Office of Nuclear Reactor Regulation, or NRR.

Today the staff will be providing brief presentations on our reviews and the safety evaluations for two Topical Reports from Kairos Power.

The first Topical Report on the qualification of graphite materials to be discussed this morning describes the testing required to qualify the structural graphite materials used in the safety related components of Kairos Power's fluoride-cooled high-temperature reactor or KP-FHR designs.

The second Topical Report on the qualification of metallic materials to be discussed this afternoon focuses on the testing and modeling required to qualify the structural alloys that will be used in the safety-related portion of the KP-FHR designs.

The staff presented on these topics to the

ACRS Kairos Subcommittee on January 12, 2023. And today's presentations are going to highlight key areas from the staff's reviews and relevant limitations and conditions associated with the future use of each Topical Report.

As mentioned during last month's subcommittee meeting, the staff is currently reviewing the construction permit application from Kairos for its non-powered Hermes test reactor that would use the KP-FHR technology.

And the two Topical Reports that we're going to be discussing today would apply to both the non-power and power reactors that are currently under development by Kairos. Therefore, the reviews of the Topical Reports we are going to talk about today will need to be finished before we can complete the construction permit application review.

We're looking forward to today's discussions. Always appreciative of the Committee's insights and comments on these topics. And with that, I'll turn it back over to you, Member Petti and Chairman Rempe.

MEMBER PETTI: Okay. Thank you, Bill. With that, Kairos? Margaret, are you ready to get your slides up?

MS. ELLENSON: Yes, I am. Can you hear me all right?

MEMBER PETTI: Perfectly. Thank you.

MS. ELLENSON: Okay. Great. Thanks. I increased the noise reduction so hopefully that will help a little bit.

Hi. I'm Margaret Ellenson. I'm with Kairos Power. And I'm the lead for this graphite material qualification for KP-FHR Topical Report.

We presented to the subcommittee back in January, and we're excited to be able to speak to the full Committee today. Thank you for your time.

Kairos is a mission centered organization. And our mission is to enable the world to transition to clean energy with the ultimate goal of dramatically improving people's quality of life while protecting the environment. Along the path, there will be many steps to bringing this clean technology to the market and qualifying graphite is one of those steps.

This is a general background on the Graphite Topical Report. Our purpose in submitting this report to the NRC is to present the methods for qualifying structural graphite for the use in a KP-FHR. And by structural graphite, we really mean the reflector structure in the core, not the pebbles.

The secondary purpose there is to align with the NRC staff on the methods for qualifying structural graphite. Because this is -- while graphite is not a new material in the nuclear space, it is relatively new in the licensing space. So we were interested in aligning early on what the methods can be to close data gaps.

The scope of the report is applicable to both a test in a power reactor as was previously mentioned. The graphite that we're going to be qualifying is ET-10, which is a super fine grain graphite with nearly isotropic properties.

The reflector structure serves two different safety functions. It provides that physical pathway for maintaining core cooling, and it provides a physical pathway for reactivity control insertions. However, the reflector serves that safety function simply by maintaining its integrity. It's a pretty simple safety function there.

And I wanted to take a moment to take note of our quality assurance program. So the ASME Section III, Division 5, code, which we will talk more about in a minute, states specifically to use an NQA-1 based quality assurance program.

For the power reactor application, we

expect to fully meet the code. So any information that we rely on for a power reactor application would be under an NQA-1 based program.

However, the NRC does not require an NQA-1 based program for test reactors. So for a test reactor application, you're going to take a deviation from the code by using instead the more commonly used code for QA for a non-power reactor, which is the ANSI-15.8-1995.

So I wanted to make sure that point was clear before we move on. And I'll pause here in case there are any questions.

MEMBER PETTI: So let me just be clear. Then any data developed for the test reactor will be not used for the power reactor. There will be two separate data sets because they are under two different quality programs.

MS. ELLENSON: So there are methods -- so the data is the data, right? The NQA program -- or sorry, the quality assurance programs are different methods for being able to evaluate how that data was generated.

So we could use the same data for both. I actually don't think we will be. I think actually all of the data that we will be generating will be either for the test reactor or the power reactor. But just to be clear about, you know, what is involved in an NQA or an ANSI 15.8, the differences are procedural, not necessarily in testing protocol if that makes sense.

And I will, in case Darrell is on the line and would like to weigh in, I'd like to give him that opportunity as well. Darrell, are you on the line?

MR. GARDNER: Sure. So this is Darrell Gardner, Senior Director of Licensing for Kairos Power. And I think it's a good question.

What I would point out is that NQA-1 has provisions for using data from various sources. And so I can't remember the -- it's a non-mandatory appendix. And I just don't recall the number offhand.

But the point we want to make is that we will comply with the NQA-1 revisions in that appendix to evaluate our inputs, one of which would be data. So that allows the use of evaluation of equivalency of QA programs. It evaluates legacy data. There are several pathways in that appendix to NQA-1 for data use.

MEMBER BALLINGER: This is Ron Ballinger. Now to be clear on this, are we to assume or could I assume that if it's NQA-1 qualified it's automatically qualified according to the ANSI?

MR. GARDNER: One could certainly make that argument, right? If you have data developed under an NQA-1 program, it would bound any expectations under the ANSI/ANS standard.

MEMBER PETTI: So, Darrell, my concern, and again, I'm not a quality expert, but I ran an NQA-1 program of a gas reactor. And I asked my quality experts sort of the same question, like, why can't I just do good science and good quality and publish it and then it becomes legacy data? And I don't need all the extra costs from NQA-1.

And they told me that's not the intent, you know, of what's meant, you know, that part of NQA-1 when one is allowed to bring in legacy data.

So it's probably a gray point, right? If 95 percent of your data was sitting out there not under an NQA-1 program, that's a different situation than if 95 percent is in the NQA-1 program then I got to bring in 5 percent. So that's how I mentally rationalize it.

(Simultaneous speaking.)

MEMBER BALLINGER: I'm a little bit confused. You were saying -- I always assumed that if you had an NQA-1 program for which the data qualified, then it was automatically qualified for ANSI.

MEMBER PETTI: Yes, I'm talking about the opposite --

MEMBER BALLINGER: Okay, okay. That's what --

MEMBER PETTI: -- the opposite situation where they use --

MEMBER BALLINGER: If you use NQA-1, you're good.

MEMBER PETTI: Yes, you're good, the best.

MEMBER BALLINGER: Yes.

MEMBER PETTI: But if you use ANSI -- so it's a matter of, I think, how much of the data will be under ANSI and potentially be brought in.

CHAIRMAN REMPE: Have you talked about this with the staff and said, hey, we may be bringing in some data for the test reactor in trying to qualify it under NQA-1?

MR. GARDNER: So to be -- this is Darrell Gardner again. To be clear, we're jumping ahead into a particular license application question as opposed to the methodology.

But we have not yet discussed what I would argue is -- the question you're asking is about an FSAR application in the actual qualification program that was used for the graphite we're going to install. With that in mind, we do have plans to discuss many things about the actual FSAR application when we start pre-application engagements with the staff.

CHAIRMAN REMPE: So for this application, we are to assume what Margaret said. You're going to use the ANS methodology for the test reactor and then you'll have a separate set of data for the power reactor and that's what we should assume that is being proposed.

MR. GARDNER: I don't think we're saying that. I think what we're saying is we will comply with NQA-1 and all the provisions that it has for processing data. That's a different question from whether it's the exact same data set.

My point is I think, you know, we don't want to leave a conclusion that use of these two programs automatically requires independent data sets. We don't believe that's the case for NQA-1.

MEMBER PETTI: I think this is a question we can get back to when the staff talks because I recall reading a limitation condition around this issue, but we'll wait for the staff so.

MS. ELLENSON: And it might be helpful also I'll just kind of quickly walk through what are these data sets that we're talking about. Like the historical data that's out there that we would be using that would be non-NQA-1 for the test reactor would be things like the historical data from Ibiden about lot-to-lot variation, the historical data about a variation in material properties over time, that kind of thing.

That would be -- the new data that we would generate for the test reactor would be under the 15.8 for those types of data. The data that we would be using for irradiation properties was originally generated under an NQA-1 program so it's kind of moot for that.

So really when we're talking about future data being collected, we're talking about power reactor application data. And in that case, you're talking about again the data that we would be generating for the material properties of unirradiated graphite, the lot-to-lot variation data that, again, is historical.

So we would be using the NQA-1 program to look at that historical data but then also the irradiation data. And our intent there for something that would be under the power reactor would be pulled under that NQA-1 based program. That would be the new data.

So when we're talking about what is the actual data that is being talked about? Like Darrell said the important part is if NQA-1 doesn't necessarily require a new set of data. However, I think that will actually end up being the case because the only difference would be that irradiation data for the power reactor.

Okay. All right. So the next slide here, the code that we're going to use to qualify the graphite is ASME BPV Section III, Division 5. We have a couple of exceptions that we talked through in more detail at the subcommittee. And we can revisit those if you would like here.

Basically, that Division 5 code divides qualification into three different elements, characterization of as-manufactured graphite. That is mechanical and thermal properties and property variation.

Characterization of properties under irradiation, we call that basic irradiation properties and irradiation creep and then evaluation of environmental compatibility.

So qualification of unirradiated and irradiated graphite, tackling the first part of that, unirradiated graphite, we will conduct testing from mechanical properties, thermal properties, impurity. We have a few limited departures from the code where, for example, taking measurements at room temperature as opposed to a variety of temperatures is actually conservative from a modeling perspective.

We will be taking data both with grain and against grain. And the final design of the reflector will take into account uncertainty in property values due to any anisotropy that we note. And I think we noted at the subcommittee meeting that the difference in anisotropy is not huge. We said it was something on that order, 10 percent.

And we will be combining new testing data and historical data like I mentioned. The data that Ibiden has for property variation over time, that would be the historical data and then the new testing data that we would have for properties would be comparing back to that historical data.

We will also use the Division 5 code, the articles that are listed here for irradiated graphite properties.

Applicable data exists for the operating conditions for KP-FHR for basic irradiation properties. And the data that's available is applicable to both the power and the test reactor application.

We will generate new test data for irradiation creep for a power reactor application. And also applicable data already exists for the irradiation creep coefficients for the non-power reactor application.

For environmental compatibility between Flibe and ET-10, Kairos evaluated the available Phenomena Identification Studies through technical literature and identified these four items that are listed in this chart.

First off, infiltration, we plan to conduct testing that graphite mechanicals are not degraded by infiltration itself. I would also note here that freeze-thaw cycles are outside the design basis for a KP-FHR. So that is really the only mechanism that we expect would change physical properties. So we don't expect to see any difference in mechanical properties from infiltration alone.

I would also note that the test reactor will be designed in such a way that the maximum pressure in the vessel is going to be below the threshold infiltration pressure so we don't expect to see infiltration for a non-power reactor.

DR. BLEY: Excuse me. This is Dennis Bley. May I ask you a question here?

MS. ELLENSON: Sure.

DR. BLEY: That was well-qualified. You don't expect to see any changes by infiltration alone. Would infiltration compound or affect other mechanisms that you're going to talk about next?

MS. ELLENSON: That's not what I intended to imply. I was merely speaking to the effective freeze-thaw cycles. That's all I meant by that.

DR. BLEY: Okay.

MS. ELLENSON: That there is literature data that suggests that Flibe that has infiltrated and gone through a freeze-thaw cycle could change physical properties, but that is outside the design basis for a KP-FHR.

Okay. Okay. So abrasion and erosion, we have testing underway to demonstrate that there is no significant abrasion or erosion under prototypical operating conditions.

We are conducting those tests on structural graphite in Flibe. And again this is another thing that is more of a confirmatory test because we don't expect to see a great deal of abrasion or erosion effect.

And one of the reasons that we have confidence in that expectation is that the MSRE operating data, which we spoke about at the subcommittee, there was at least one full power equivalent operating time, and there was no observed abrasion or erosion on the graphite in that test.

We also looked at chemical compatibility. We looked at the applicable literature. And intercalation was the one phenomenon that was of interest to ET-10 and Flibe. And the literature studies indicate that intercalation in this environment is thermodynamically unfavorable. So we do not intend to do any further testing on that.

The last one on the list here is oxidation. Oxidation is an interesting one. As you can imagine with an inert environment like KP-FHR will have, during normal operation, the oxidation would be extremely low, if any. So what we're really talking about are during postulated event conditions for oxidation.

So Kairos will be measuring oxidation kinetic parameters. We'll be determining relationships between weight loss and strength. And then we'll be assessing oxidation depth profiles. And that really is scenario dependent so we'll be giving more information at a specific application time.

And then lastly we're going to do a confirmatory test that submerged graphite doesn't occur in a KP-FHR environment to a degree that would affect its strength.

MEMBER HALNON: This is Greg. I have a quick question on abrasion and erosion.

MS. ELLENSON: Great.

MEMBER HALNON: The surface roughness does affect -- degrade infiltration to some extent based on, well, surface roughness. If you see in your confirmatory testing, is part of that testing that if you see something that you didn't expect you would go back and check for infiltration again or are they mutually exclusive in that testing?

MS. ELLENSON: I think I might ask Chong and Gabriel to weigh in. Are either of you on the line that would like to answer that question?

MR. CHEN: Yeah, this is Chong Chen, and I can answer some of the question. And the roughness will impact infiltration in the way it may change the contact angle of -- graphite slightly but not in a huge amount.

I think the erosion and infiltration could be two different mechanisms to impact the graphite.

Abrasion/erosions stay on the surface. Infiltration is really needed to generate damage once the flap goes into the graphite, and it goes through a free cell cycle.

Does this answer your question?

MEMBER HALNON: I guess to some extent. When you do confirmatory testing, you look and see. And if you don't have any further questions, you move on. I guess the question more is if you saw something you didn't expect, like, you know, more erosion or abrasion than you expected, would you go back -- if you had already done the infiltration confirmatory test, would you go back and redo the confirmatory test on that sample for infiltration as well just to make sure that that contact angle didn't go -- you know, make a huge, bigger weathered surface and cause additional issues that you weren't actually looking for at the time.

MR. CHEN: Infiltration actually covers the weight, and the pressure ranges cover weight above and in the regular operation condition. So if we see something not usual in abrasion/erosion pass, I think it is looking into more aware of graphite and that leads to -- wear of a graphite, does not lead to change of infiltration. And the pressure has more impact.

MEMBER HALNON: Right, right. So are those two confirmatory tests done on the same sample then?

MR. CHEN: Would you restate again, please?

MEMBER HALNON: Are those confirmatory tests for infiltration and abrasion/erosion done on the same sample?

MR. CHEN: No, it's not -- the same material, but not same sample set.

MEMBER HALNON: Okay. I understand it's not a real issue for the test reactor, but the power reactor coolant infiltration is a potential -- I would hope that the confirmatory test procedures would have a brain in it that if you don't see anything -- if you see something you're not expecting to see that you would at least go back and see if the other confirmatory tests are valid or not. That's just my comment. You know, I understand the margin.

MR. CHEN: Yes, I agree. So if we see something unusual, we will dive into it. I guess it depends on what kind of things would work there.

MEMBER HALNON: Right. Okay. Thanks.

MR. CHEN: Thank you.

MS. ELLENSON: Okay. Any other questions there? Okay. Great. So in summary the Graphite Material Qualification Topical Report describes how we're going to qualify ET-10 for structure-related graphite -- I'm sorry, for structural graphite for use in a KP-FHR specifically.

The qualification plan conforms with that Section III, Division 5, code. We have a few limited departures that are described in the report. And we'll use both existing data and data from new tests. And then just a last note there, a reminder that seismic qualification is outside the scope of this particular Topical Report.

And that's all the prepared comments that we had. Any last questions?

MEMBER PETTI: Yeah, I had a question on the oxidation testing. It is your anticipation that it's going to look like other graphite grades that have similar veracity in grain size? I know you said you have to do it because every grade is a little different. But you're not anticipating something different from the closest twin to ET-10?

MS. ELLENSON: Yes. No, we're not expecting any --

MEMBER PETTI: All right.

MS. ELLENSON: -- differences. But Chong, do you want to weigh in? Are there any reasons to think ET-10 would behave any differently?

MR. CHEN: No, I do not expect a huge difference. The trend will be similar.

MEMBER PETTI: All right. Thanks.

MR. CHEN: Thank you.

MEMBER PETTI: Members, any other questions? Okay, if not, staff? I'll give them a minute to get to the table.

PARTICIPANT: Can everybody see the presentation?

MEMBER REMPE: Yes. But we need you to go presentation mode, please?

PARTICIPANT: Yup. There you go.

MEMBER REMPE: All right. Thank you.

MR. CHERESKIN: Good morning, everyone. This is Alex Chereskin from the NRC staff. I'm here in the room today, but I am joined by my colleagues Rich Rivera, Matt Gordon and Meg Audrain. So I will be giving the presentation for the NRC staff's evaluation of the Kairos Power Graphite Material Qualification Topical Report.

And can I have the next slide, please? So for the introduction, Kairos had requested the staff review and approve this Topical Report. And this Topical Report provides the methodology of Kairos to qualify their ET-10 graphite for use in either the KP-FHR non-power or power reactor designs.

In general, the methodology proposes to --

MEMBER PETTI: Alex, could you move the mic closer to you?

MR. CHERESKIN: Sorry about that.

MEMBER PETTI: I think everybody else can hear, but in the room it's a little hard.

MR. CHERESKIN: Oh, sorry. Is that better?

MEMBER PETTI: That's better, yeah.

MR. CHERESKIN: Okay. I'll find somewhere else to put my notes, I guess.

Okay. So in general the qualification methodology follows the ASME Code Section III, Division 5, requirements, with certain deviations that were reviewed and approved by the staff as we discussed in the subcommittee meeting.

The NRC's staff's review focused on the overall qualification framework. And this includes the use of existing data, unirradiated testing together with graphite properties or radiation testing, oxidation testing and environmental testing.

That includes testing in molten sale that Kairos described in their presentation.

Next slide, please. So the regulatory basis for this review includes portions of 10 CFR 50 and 54 that are related to information that is required to be submitted in licensing applications and information related to graphite material properties will need to be supplied as part of a license application.

And so the staff also evaluated the Topical Report against several Kairos PDC that were previously reviewed and approved by the NRC staff in the referenced Topical Report.

The principal design criteria include PDC 1, quality standards and records, which requires that system structures and components that are safety significant be designed to quality standards commensurate with safety significance.

PDC's 34 and 35, which are similar, contain removal requirements. And the graphite components will be needed to maintain structural integrity and maintain physical geometry at the core in order to support adequate heat removal.

And PDC 74, which requires the design of the reactor vessel system to support the integrity of the graphite during postulated accidents to ensure geometry for passive heat removal and allow sufficient insertion of neutron absorbers, and the graphite will be required to maintain its integrity in order to achieve these functions.

Next slide, please. This slide is a condensed version of what was discussed previously over the course of several slides at the ACRS subcommittee meeting. The staff's evaluation focuses on a couple of specific areas, the first one being the qualification of unirradiated graphite properties.

And the staff had found that the proposed testing plan will satisfy the requirements of Section III, Division 5, specifically the article listed here for properties of as-manufactured graphite. In addition, the Kairos Power Topic Report proposed to evaluate the intra-billet and lot-to-lot property variations of graphite.

The staff also evaluated the method to qualify the irradiated properties of the ET-10 graphite. And, again, this is consistent with code requirements for irradiated material properties for graphite, which requires measurements of certain irradiated properties.

As Kairos mentioned during their

presentation, this includes the basic irradiated properties and the irradiation creep properties that will require additional irradiation testing for the power reactor design.

Finally, the NRC staff reviewed the environmental effects testing proposed by Kairos Power. This includes the molten salt infiltration testing, oxidation testing and the testing for abrasion and erosion. And the staff had reviewed these and found them acceptable as noted in the staff safety evaluation.

Next slide, please. So in conclusion, the staff had reviewed the Topical Report and concludes that the graphite material qualification program is acceptable for the ET-10 graphite to be used in the non-power or power reactor designs of KP-FHR as described in the Topical Report and subject to NRC staff limitations and conditions.

This Topical Report will in part meet the applicable PDCs. For example with principal design criteria number one, the graphite components will be qualified to the ASME Code, which is, you know, commensurate with the safety function of the graphite components.

And additionally, the qualification plan will help to ensure that graphite components maintain their integrity, need to achieve the heat removal functions of PDC 34 and 35 as well as the functions of PDC 74 related to maintaining geometry, permit sufficient insertion of neutron absorbers and also to maintain adequate core cooling in a postulated accident.

The NRC staff also includes certain limitations and conditions on the use of this Topical Report. They fall into a few broad categories. The conditions are there to ensure that the data collected by Kairos bounds the anticipated qualification envelope for their reactor, ensure that certain future actions stated in the Topical Report are reviewed and approved by staff, ensure that as certain design aspects change, they are appropriately addressed, for example, the use of potentially an incompatible intermediate coolant. That's just one example of what I mean here.

And as Member Petti noted before, there is a condition related to the use of quality insurance requirements. That one was geared specifically to the power reactor as stated in the condition. And that was to show that the data meets code requirements for the power reactor design. So there is a condition there for the power reactor as you noted earlier.

Are there additional questions?

MEMBER MARCH-LEUBA: Yes, a qualification. You just said the data must meet the Code, the ASME Code requirement. Have you guys considered the discussion we had earlier, is that one data is developed, and there isn't quality assurance program level. Have you considered the implications?

MR. CHERESKIN: Yes. So this is how I think we've considered the implications in that the way that everything is structured that this will have to be reviewed as part of a license application.

And for a power reactor, we would have to ensure that it meets NQA-1 requirements and for the non-power reactor the applicable ANSI requirements. And if Kairos develops separate data sets, it would clearly be more work. However, in the end as part of a licensing action, we would still need to make sure the applicable quality requirements are met for non-power or power reactor design.

And so I think, I guess, from what I'll call a licensing standpoint, we still perform that review as part of a license application.

MEMBER MARCH-LEUBA: You can think at a high level that the reason we are doing a test reactor is to do an internal test of everything else, and therefore all those results from the test reactor would be available to a quality assurance level at this load and not required for the power reactor.

So, I mean, it helps to think a little bit before the power reactor comes for licensing, and we know what to say.

MR. CHERESKIN: That makes sense.

MEMBER HALNON: This is Greg. Just real quick, I mean, the data set which you use and how you use it and what you are using it for and what you are crediting makes all the difference in the world in this. I mean, data to inform a design is one thing, but data to credit a design is a different story. So that's where my understanding of a quality program data set is in play is, what are you using it for?

So, I mean, just like the MSRE, they are using data from MSRE to inform their testing and their design and their data collection. The same thing is going to happen. They are going to use the test reactor data to inform what they are doing with the power reactor, but they are going to credit the data from a safety perspective. And then they're going to have to meet NQA-1 data collection and integrity and all that stuff.

So to me it looks like it's a question of what am I using the data for not necessarily can I use the data or not?

MEMBER PETTI: My only concern is, you know, you gather the data on the test reactor QA and somehow when you get to the power reactor you need to credit it. And there is something you find out that is missing in the QA pedigree that NQA-1 requires that isn't required in ANSI.

I mean, they act different, you know. And there is a process to dedicate ANSI. I understand all that. But just make sure that it is thought through because this data is not insignificant from a cost perspective to gather, you know? And you don't want to, you know, find out at the end.

MEMBER HALNON: But like what you're saying, the bottom line is when you credit it, it's going to have to meet NQA-1 standards --

MEMBER PETTI: Correct.

MEMBER HALNON: -- for a power reactor.

MEMBER PETTI: Correct.

MEMBER HALNON: Right.

MEMBER PETTI: And most of the data that we talk about, you know, the irradiation, that stuff is all going to be in NQA-1. That's not what I'm talking about. And the historical data is the historical data, you know.

MEMBER HALNON: Right.

MEMBER PETTI: And that sort of information but, yeah. Any other questions, members?

MEMBER KIRCHNER: And Dave, this is Walt.

MEMBER PETTI: Yeah.

MEMBER KIRCHNER: May I make an observation?

MEMBER PETTI: Sure.

MEMBER KIRCHNER: It's along the lines of Greg's earlier questions about cause and effect between different test regimes. I just would observe -- I don't think -- well, first I'll make this observation. This is not part of a qualification of materials per se. It's more of a design consideration.

From what we note to date about the Hermes design, it appears that the irradiation of the graphite will not be significant for the lifetime of that test reactor and probably not, you know, anything close to what may be seen in the actual power reactor.

But with dimensional changes of graphite under temperature and irradiation, then the fastening structural support for this reflector system becomes a design issue because you worry about the potential with dimensional change of flow-induced vibrations. Using Flibe as a coolant, there is a certain amount of levitation of the graphite blocks. And any resulting loose fit then could exacerbate abrasion and wear, which then becomes a source for infiltration and oxidation and other deleterious effects.

So I'm just making an observation that as long as things are within the prototypical operating conditions, fine. But if it turns out that the dimensional changes with the graphite lead to other effects, then as Greg was suggesting for example, if you do see abrasion, do you go back then and look at the considerations of infiltration and oxidation and such?

So this is an observation beyond the materials qualification methodology ATR to design considerations for probably more so for the power reactor than for the Hermes test reactor. Thank you.

MEMBER PETTI: Okay. No other questions then I think we thank our speakers.

CHAIRMAN REMPE: We need to open the line to public comments --

MEMBER PETTI: Oh, yes.

CHAIRMAN REMPE: -- at this time.

MEMBER PETTI: Any member of the public, unmute yourself, state who you are and your comment. Okay. I'm not hearing any. We're ready.

CHAIRMAN REMPE: Okay. At this time then, we're going to go off the record.

(Whereupon, the above-entitled matter went off the record at 9:14 a.m. and resumed at 1:01 p.m.)

CHAIRMAN REMPE: So it's 1:01 p.m., and we're back in session. And I'm going to ask Member Ballinger to lead us through our next topic.

MEMBER BALLINGER: Thank you. Thank you, Madam Chairman. We're going to cover the second Topical Report, this one on metallic materials, this afternoon. And we've had a pretty much very good introduction this morning, which basically covered both so we don't need to do that, I don't think unless there is staff that wants to say something initially. Is that correct? No. Okay.

So we'll start off with Kairos and then finish with the staff. And so who at Kairos goes? Is it Margaret?

MR. PRICE: No. This is John Price. Can you hear me okay?

MEMBER BALLINGER: We can hear you fine.

MR. PRICE: Okay. Hello.

MEMBER BALLINGER: Take it away.

MR. PRICE: Okay. Thank you very much. Hello, my name is John Price. I'm a senior licensing engineer for Kairos Power. And I'll be presenting with Dr. George Young the slides for the Metallic Materials Qualification Licensing Topical Report Rev. 4.

First of all, I'd like to thank the full committee for this opportunity to make this presentation. This is a summary of the presentation given to the ACRS Subcommittee on January 12.

Slide 2. As we always start off, our company'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.

What this means as we go through this meeting is that if the Licensing Topical Report gets approval, we are one step closer to transitioning to a cleaner energy and improving people's quality of life while protecting the environment.

Slide 3. Dr. Young and I would like to present the Metallic Materials Qualification Topical Report and our methods used to qualify these materials for use in the KP-FHR, specifically addressing the environmental effects on materials.

MEMBER BALLINGER: Excuse me. This is Ron Ballinger. Somebody is crinkling paper, doing something in the background. So whoever it is, could you mute your microphone, please, unless it's the speaker, in which case, stop crinkling it.

MR. PRICE: You got it.

CHAIRMAN REMPE: It's a technical term, right?

MEMBER BALLINGER: Okay. Thanks.

MR. PRICE: Yeah. Today Dr. Young and I would like to present the Metallic Materials Qualification Topical Report and our methods used to qualify these materials for use in the KP-FHRs, specifically addressing the environmental effects on materials.

The testing plan is for metallic materials used in Flibe-wetted areas for safety-related, high temperature components in non-power test reactors, which we will call Hermes, and for the commercial power reactor, which we will call KPX.

The materials, 316H and the associated Weld Filler Metal 16-8-2, were chosen because of existing qualification in high temperature applications and because they are provided by the ASME

Code Section III, Div. 5, and endorsed by Reg. Guide 1.87.

The materials used to exhibit desirable mechanical properties have demonstrated compatibility with Flibe salt and have extensive experience based in nuclear applications.

MEMBER BALLINGER: This is Ron Ballinger. I'm told by our staff that 1.18 -- Reg. Guide 1.87 is now on the street.

MR. PRICE: Great. The metals are used in other industry applications, near time and temperature with the KP-FHR.

Qualified materials provide assurance that components can be designed for extremely low probability of abnormal leakage, resistance to rapidly propagating failure and resistance to gross rupture.

As this is a methodology document, the demonstration of qualification will be documented in the safety analysis reports as part of our future licensing actions, provided the limitations specified in the staff safety evaluation are met.

Slide 4. The Alloy 316H is qualified by ASME Code Section III, Div. 5, for 816°C. The associated Weld Filler Metal 16-8-2 is current qualified for only 650°C.

The ASME qualification of the weld filler metal will be extended by testing to match the base metal temperature for Alloy 316H. This will be provided by elevated temperature tensile testing, creep-fatigue testing and by creep-rupture testing.

The qualification for the power reactor will satisfy NQA-1 based QA program and the qualification for the non-power test reactor will satisfy ANS-15.8 1995-based program.

There is a limitation stated in the draft SC that Kairos Power plans on complying with. At this time, I'm going to turn it over to Dr. George Young, if there are no other questions, to complete the open session presentation.

Dr. Young is a fellow scientist at Kairos Power. Dr. Young has a BS in materials engineering from Rensselaer Polytechnic Institute and an MS and PhD degrees in material science from the University of Virginia.

He has over 30 years of experience in the nuclear power industry and is an expert with material selection and performance for both conventional and advanced nuclear power systems.

At Kairos Power, Dr. Young leads structural materials qualification efforts in environmental degradation testing. Dr. Young has authored over 50 peer-reviewed articles and book chapters in the research areas of environmental assisted cracking, welding metallurgy and physical metallurgy. So, Dr. Young, take it away.

DR. YOUNG: Thanks, John. Hopefully, you can hear me okay.

MEMBER BALLINGER: We can hear you fine.

DR. YOUNG: Great. Thank you. If we go to the next slide. All right. We used the Phenomena Importance and Ranking Table, the PIRT, approach for the Metallic Materials Testing Program. We convened the panel of experts about four years ago now, three, four years ago.

And this PIRT review identified and ranked the appropriate environmental degradation phenomena that are applicable to the Flibe-wetted safety-related components of our KP-FHR reactor technology.

From that review, we highlight that the reactor vessel is the only safety-related structural metallic component which serves the function of retaining the coolant around the fuel and that the PIRT -- and again, this PIRT was for the power reactor -- identified two potential accident scenarios that could affect the structural integrity of these Flibe-wetted safety-related components.

I note that these effects are mitigated by design features. Those are air ingress into the reactor and the potential for intermediate cooling ingress into the primary coolant Flibe that only pertains to the power reactor.

For the demonstration reactor, Hermes, we a have a Flibe to air heat exchanger so there is no intermediate coolant.

So that testing program that was informed by the PIRT consists of kind of two major efforts, testing and high temperature air to support ASME design and then testing in molten Flibe salt to account for any potential environmental degradation.

Next slide. So for the test in high temperature air on Alloy 316H, these tests that support the ASME model calibration and validation include tensile testing, stress relaxation testing, strain rate change, sometimes called stress dip tests, uniaxial creep testing, notch bar creep-testing and creep-fatigue testing so quite an extensive high temperature air testing program to validate our high temperature design.

Next slide. So as far as environmental degradation, we grouped these in kind of four categories. So these are the phenomena that were assessed in detail based on the PIRT ranking. And these form the basis for our testing plans.

So corrosion testing in Flibe, we intend to perform, and are performing, corrosion tests in Flibe. Those use compositional analysis of the salt and also electrochemical potential monitoring to monitor the test conditions there.

We identified environmentally assisted cracking now where there may be some interaction of the Flibe environment with applied stress on the material. And we intend to assess the well-accepted slow strain rate methodology, a very severe tensile test in Flibe salt, and also fracture mechanics-based testing where now we're using pre-crack samples to look at corrosion fatigue and the potential for stress corrosion cracking.

Then additionally, we'll use both our slow strain rate test for the power reactor dedicated test to look at the potential interaction of pre-bloating in the Flibe environment.

The next topic on the upper right here is kind of a catch-all we call metallurgical effects or kind of other phenomena. Here we're going to look at potential degradation modes like stress relaxation cracking, phase formation, embrittlement. And we did consider thermal cycling and thermal striping quite a bit. I want to note that last bullet is mitigated by design and don't require any additional testing.

Lastly, we assessed irradiation effects or potential effects. These include just irradiation induced embrittlement and then potential interactions with the Flibe, irradiation affected corrosion and irradiation assisted stress corrosion crack. So that's an overview.

Next slide. So in summary, we have two major efforts here. We are doing metallic materials qualification testing to support the design and licensing of both the non-power reactor Hermes and the commercial power generation reactor, what we call KPX.

The scope of the testing is limited to the structural alloys, the Base Metal 316H, and the Weld Filler Metal 16-8-2. Those were used for construction of the reactor vessel and, again, that's with determining the primary safety related component of interest.

The reactor vessel maintains the inventory of Flibe coolant around the fuel pebbles and that's the safety function so that we can credit the Flibe salt as another barrier to the fission products.

And by using qualified materials like these, we are providing assurance that the reactor vessel can be designed for extremely low probability of abnormal leakage, resistance to reactor leak propagating failure and resistance to gross rupture.

So materials testing then consists of two major efforts. That's in the tests we discussed in high temperature air that support ASME design as well as extension of the ASME Code for the weld filler metal up to 816C and then the testing of the molten Flibe salt to assess the potential environmental degradation modes.

Any questions on that?

MEMBER KIRCHNER: George, this is Walt Kirchner, just a clarification. You're limiting the scope of testing for the reactor vessel, but I presume you intend to use these same alloys for the primary coolant boundary?

DR. YOUNG: That's right. All our piping or hot leg and cold leg piping is 3/16th inch.

MEMBER KIRCHNER: Thank you.

MEMBER BALLINGER: Any questions from the members, consultants? Okay. I should have mentioned we have the possibility of a closed session if we need it for this, but so far we haven't needed one. But if we need one, we have that opportunity. So if there aren't any questions from the members and consultants, we can thank you very much for your presentation and then is the staff ready to go?

MR. RIVERA: Hi. This is Richard Rivera, and yes, I have the presentation on my screen as soon as you are available to share my screen.

CHAIRMAN REMPE: Would the folks from Kairos please quit sharing?

DR. YOUNG: Will do.

CHAIRMAN REMPE: Thank you.

MEMBER BALLINGER: Well, we'll get there. We'll get there.

CHAIRMAN REMPE: Okay. Time for the staff to share.

MR. RIVERA: Let me know if you can see the screen.

MEMBER BALLINGER: Yes, we can. Thank you.

MR. RIVERA: All right. Thank you. And John Honcharik was the lead reviewer for this Topical Report and will lead the presentation.

MR. HONCHARIK: Thanks, Rich. I'll turn my microphone.

MEMBER BALLINGER: Yeah, turn your mic so you can -- have it pretty close to you if you can.

MR. HONCHARIK: Thank you. Is this good? Good afternoon. I'm John Honcharik, Senior Materials Engineer in the Division of New Licenses.

Alex Chereskin in the Division of Advanced Reactors also reviewed this Topical Report with me. I will present to you our evaluation and conclusion of the Metallic Materials Qualification Topical Report for use in the Kairos fluoride salt-cooled reactor.

Next slide. The NRC staff reviewed the Topical Report, which provides the qualification plan for metallic structural materials used in Flibe-wetted areas for safety-related high temperature components of the KP-FHR power and non-power test reactors.

The planned material testing includes analysis and monitoring programs that will be used to address the materials reliability and compatibility of the metallic material in an environment of the KP-FHR designs in order to partially satisfy PDC 14 and 31 of the Kairos principal design criteria that was approved by the staff in Topical Report KPR-003.

These PDCs are applicable to the qualification of the metallic components for the Kairos designs on which the staff based this review. And the results of these planned tests and analysis will be provided in future licensing applications that references Topical Report along with the detailed description of the design, inspection and surveillance programs for the KP-FHR designs in order to demonstrate the materials reliability.

Next slide. The staff's review focused on the overall testing framework to conclude there is reasonable assurance that the testing for environmental effects of Flibe on metallic structural materials provided in Section 4 of the Topical Report will partially satisfy PDCs 14 and 31.

The specific topics reviewed include the materials, which are 316H and ER16-8-2 stainless steel weld metal. The test environment and the four degradation categories, which were corrosion, environmentally-assisted cracking, effects on metallurgical properties and irradiation.

Next slide. First, we'll discuss the material to be used. The metallic structural materials proposed for KP-FHR designs are 316H, also known as stainless steel, and the associated ER16-8-2 stainless steel weld fill metal.

These materials are qualified for use in ASME Code, Section III, Division 5, for high temperature applications with respect to mechanical properties. Division 5 of Section III, as someone pointed out, is endorsed in Regulatory Guide 1.87, Rev. 2, which was just published, I believe, yesterday.

There is a Limitation and Condition 4 related to the weld material mechanical properties since the fill metal is not currently qualified to the higher temperatures necessary to support the accident scenarios of the KP-FHR designs. Therefore, NRC imposed the condition that the fill metal must be qualified to the temperature in accordance with the ASME Code Section III, Division 5, requirements that bound postulated accident conditions and are approved by the staff.

Next slide. Next, we will discuss the test environments used for the proposed material testing. The staff found that the material testing environment duplicates the operating environment for the Kairos designs for both normal operating and postulated accident conditions.

There is a Limitation and Condition 3 which requires that if the time and temperature for both normal and postulated accident conditions change for the Kairos designs, they must still be bound by the NRC-endorsed ranges found in Table 2 of Reg. Guide

1.87 for the 316H and fill metal.

NRC staff also finds the impurity test acceptable since it will be conducted for the commercial power reactor similarly intermediate salt ingress and air ingress into the Flibe salt while the non-power test reactor testing will similarly air ingress into the Flibe.

In addition, Limitation and Condition 8 applies since the details of impurity testing, that is the concentration of the contaminants have not been determined. Therefore, the condition states that the specific concentration of each contaminant used in impurity effects testing shall bound accident scenarios postulated in the transient analysis for the KP-FHR designs.

MEMBER BALLINGER: This is Ron Ballinger. I have a question about since 1.87 endorses Division 5, aren't these limitations and conditions in effect redundant because assuming that they satisfy both 1.87 and the ASME Code, don't those documents require you to do these tests in effect to meet those limitations and conditions?

MR. HONCHARIK: No. The ASME Code for metallics does not provide what you need to do for testing for environmental compatibility.

MEMBER BALLINGER: I'm not talking about the environmental part. I'm talking about the mechanical part.

MR. HONCHARIK: The mechanical part, yes.

MEMBER BALLINGER: Yes.

MR. HONCHARIK: Mm-hmm. Right. Yeah. I think what we're saying here is the limitation and condition is that you have to do it. You have to have it qualified so that your accident temperature, whatever that will be, that they are postulated by the transient air.

MEMBER HALNON: Okay. So this is Greg. That answers I think a question I had about this. Like the filler material qualification, it is not qualified to the higher temperature because it just wasn't tested that high. It's not the technical issue where something happens to the grain structure or something, is it?

MR. HONCHARIK: Right.

MEMBER HALNON: Okay.

MEMBER BALLINGER: But again, not to beat a dead horse, but the point is if the filler gets the material in Section II so then you can use it in Section V, it has to be qualified for a temperature that is at least, I think 25 degrees or so higher than the operating temperature.

So the limitation and condition is redundant because just the application applying to the Code means you're going to have to do that testing to get in Section II.

MEMBER HALNON: Is operating temperature the same as accident temperature?

MEMBER BALLINGER: Well, they don't call it operating or maximum. They just call it maximum temperature.

MEMBER HALNON: Maximum temperature. Okay.

MEMBER BALLINGER: Corrosion is a different story.

MR. HONCHARIK: All right. Next slide. The next topic is the degradation mechanisms. The first is corrosion. This includes the various types of corrosion, such as general corrosion, crevice corrosion, thermal aging, erosion and wear.

So the NRC staff found the proposed testing acceptable to determine the impacts Flibe has on the corrosion rates of materials based on several variables including temperature, microstructure, salt composition, which would include the nominal redox and impurity ingress chemistries, geometry, erosion/corrosion, thermal aging, presence of graphite and redox control. The corrosion rates of 316H and its fill metal can be determined from these proposed tests.

The next degradation category is environmentally-assisted cracking. For stress corrosion cracking and corrosion fatigue, the NRC found the proposed testing plan provides reasonable assurance in determining the crack growth rates for fatigue and stress corrosion cracking relative to the environment of the Kairos designs.

For environmental creep degradation, the NRC staff found the proposed testing plan acceptable because creep testing in both nominal Flibe and in air would be conducted to determine if the Flibe contributes additional degradation beyond those determined in the creep test performed on the air. Also additional testing will be required to quantify any increase in degradation caused by the Flibe.

Next slide. Next is metallurgical effects degradation as designated in the Topical Report.

For stress relaxation cracking, the NRC staff found the proposed testing acceptable because testing air is acceptable since the triaxial stresses are the major contributors to stress relaxation cracking not the environment. And the tests will be used to conduct failure future analysis and design requirements of the Kairos designs.

For phase formation embrittlement, the NRC staff found the proposed testing plan acceptable because the testing will determine whether the material picks up any element during its exposure to Flibe and form a deleterious second phase.

As part of this testing, Condition 11 is applicable, which states that, if intermetallic formation occurs, an applicant will need to perform testing to quantify the effects on the mechanical properties of 316H and the associated weld metal.

For thermal cycling, the NRC found that the thermal stresses will be addressed by conducting analysis through refined design and operation of the Kairos designs.

As part of this testing analysis, Condition 12 applies in that the applicant will assess the thermal cycling and striping in future licensing submittals by minimizing the thermal gradients via appropriate design and operating conditions.

Next slide. The next degradation mechanism is irradiation-induced effects. The NRC staff found the testing acceptable for irradiation-induced embrittlement because the degradation factors will be based on existing data and supplemented by irradiation tests conducted on material to quantify design margins at the irradiation levels for the non-power test reactor and the commercial power reactor.

As part of this testing, Limitation and Condition 13 would apply and that the test environment shall bound the Kairos designs, including expected irradiation damage and healing content.

For irradiation-affected corrosion, the NRC found the proposed testing plan acceptable because existing data will be used to develop degradation factors and be monitored by a materials surveillance program and in addition an inspection program.

As part of this surveillance and inspection program, Condition 14 applies in that the material surveillance program and inspection and monitoring program must be implemented for the non-power test reactors and commercial power reactors.

And finally for irradiation-assisted stress corrosion cracking, the NRC found the proposed testing plan acceptable because stress corrosion cracking testing program specified in Section 4 will determine if stress corrosion cracking is a credible degradation mechanism and a materials surveillance program will be used to monitor the irradiation stress corrosion cracking for the non-power reactor and commercial power reactor systems. In addition, Condition 14 also applies.

Next slide. So in conclusion, the staff finds that there is reasonable assurance that the material testing plan, including analysis, surveillance and monitoring for 316H and ER16-8-2, with the limitations and conditions noted in the safety evaluation can be used to provide the necessary information to address the materials reliability and compatibility in the environment of the Kairos designs. And that is because testing duplicates the material operation and accident condition environments that the material will experience in these designs.

The material test samples are representative of actual weldments. Analysis will be performed to mitigate stress relaxation cracking and thermal cycling through design and operations.

The material surveillance program will be used to monitor for irradiation effects on corrosion and stress corrosion cracking.

And, as I stated before, the results of these planned tests and analysis will be used for future licensing applications to ensure the components perform its safety function and that there will be an extremely low probability of normal leakage or rapidly propagating failure, which would partially satisfy PDCs 14 and 31.

And that concludes my presentation.

MEMBER BALLINGER: Thank you. I have one last -- well, I have a question. How does the document compare with the ESG?

MR. HONCHARIK: Oh, are you talking about the ISG Report?

MEMBER BALLINGER: The ISG.

MR. HONCHARIK: Yes. It is very similar to it. I think we basically were reviewing this --

MEMBER BALLINGER: Similar?

MR. HONCHARIK: -- at the same time.

MEMBER BALLINGER: Yeah.

MR. HONCHARIK: So we kind of, you know --

MEMBER BALLINGER: Okay.

MR. HONCHARIK: -- used this as a --

MEMBER BALLINGER: For the record --

MR. HONCHARIK: -- template.

MEMBER BALLINGER: -- very, very close.

MR. HONCHARIK: Yes.

MEMBER BALLINGER: Questions from the members?

MEMBER HALNON: Were any of the limitations and conditions, were any of those controversial in any way? Did the applicant accept all of those as a good thing?

MR. HONCHARIK: Yeah, from what I know, yeah, there was no really confrontational report --

MEMBER HALNON: Okay.

MR. HONCHARIK: -- of those conditions.

MEMBER HALNON: So technically everybody agrees that this is good stuff?

MEMBER BALLINGER: It's hard not to agree. It's very extensive. Other questions? I don't think we need a closed session then. So we need to go out and ask the public for comments. So if you're a member of the public and you would like to make a comment, please do whatever it takes to unmute yourself and make your comment. Thank you.

Hearing no comments, thank you very much. And I'll turn it back over to you, Madam Chairman.

CHAIRMAN REMPE: Thank you. So at this point, we're going to go off the record. And that will be going off the record for the rest of this meeting, so thank you, Mr. Court Reporter.

(Whereupon, the above-entitled matter went off the record at 1:34 p.m.)

Kairos Power

Metallic Materials Qualification Topical Report

ACRS Kairos Power Full Committee Meeting

February 1, 2023

Background

- Purpose: This report presents a materials testing plan methodology, including analysis and monitoring, for metallic structural materials used in Flibe-wetted safety-related high temperature components.
  - The materials include Alloy 316H and Weld Filler Metal 16-8-2. These materials were chosen because of existing qualification in high temperature applications and because they are provided by ASME Code, Section III, Division 5 and endorsed by Regulatory Guide 1.87.
  - Alloy 316H and its weld metals exhibit desirable mechanical properties, have demonstrated compatibility with Flibe salt, and have an extensive experience base in nuclear applications.
  - Alloy 316H and its weld metals are used in other industry applications near the time and temperature of the KP-FHR.
  - Qualified materials provide assurance that components can be designed for extremely low probability of abnormal leakage, resistance to rapidly propagating failure, and resistance to gross rupture.
- Scope: The report is applicable to both the KP-FHR test reactor and power reactor designs, provided the limitations specified in the report are met.
  - The material qualification test results generated by this methodology will be used as a basis in future licensing actions to address materials reliability and environmental compatibility in KP-FHR reactor designs.

Codes and Standards Applicability

- ASME Code
  - Alloy 316H and Weld Filler Metal 16-8-2 are approved materials for high temperature reactors in ASME Code, Section III, Division 5
    - Alloy 316H is qualified for 816°C
    - Weld Filler Metal 16-8-2 is currently qualified to 650°C
  - The ASME qualification of weld filler metal 16-8-2 will be extended by testing to match the base metal temp for Alloy 316H:
    - Elevated Temperature Tensile Testing
    - Creep-Fatigue Testing
    - Creep-Rupture Testing
- Quality Assurance
  - The qualification for the power reactor will satisfy an NQA-1 based QA program
  - The qualification for the test reactor will satisfy an ANSI/ANS-15.8-1995 based QA program

Testing Program Overview

- A phenomena importance and ranking table (PIRT) was created for the metallic materials testing program
  - The PIRT review identified and ranked the appropriate environmental degradation phenomena that are applicable to the Flibe-wetted safety-related components of the KP-FHR.
    - The reactor vessel is the only safety-related structural metallic component which serves the function of retaining the coolant around the fuel.
  - The PIRT identified two potential accident scenarios that could affect the structural integrity of Flibe-wetted safety-related components (Note that these effects are mitigated via design features):
    - air ingress into the reactor
    - intermediate coolant ingress into the Flibe (power reactor only)
- The testing program is informed by the PIRT results and consists of two major efforts:
  - testing in high temperature air to support ASME design, and
  - testing in molten Flibe salt to account for potential environmental degradation.

Testing Program Overview (continued)

- The following tests are conducted for Alloy 316H stainless steel to support model calibration and validation of ASME design methodologies (all conducted in high temperature air):
  - Tensile Testing
  - Stress Relaxation Testing
  - Strain Rate Change (Stress Dip) Testing
  - Uniaxial Creep Testing
  - Notch Bar Creep Testing
  - Creep-Fatigue Testing

Testing Program Overview (continued)

- The following potential degradation phenomena were assessed in detail and form the basis for the testing plans:
  - Corrosion
    - Corrosion Testing with Use of Compositional Analysis and Electrochemical Potential (ECP) Monitoring
  - Environmentally Assisted Cracking
    - Slow Strain Rate Testing (SSRT)
    - Fracture Mechanics Based Testing – Corrosion Fatigue (CF) and Stress Corrosion Cracking (SCC)
    - Environmental Creep Testing
  - Metallurgical Effects / Other
    - Stress Relaxation Cracking
    - Phase Formation Embrittlement
    - Thermal Cycling / Striping
  - Irradiation Effects
    - Irradiation-Induced Embrittlement
    - Irradiation-Affected Corrosion
    - Irradiation-Assisted Stress Corrosion Cracking (IASCC)

Summary

- Metallic materials qualification testing is being conducted to support the design and licensing of both the non-power test reactor (Hermes) and the commercial power generation reactor (KP-X).
  - The scope of testing is limited to structural alloys 316H and 16-8-2 for the reactor vessel, which was determined to be the primary safety-related component of interest
    - The reactor vessel maintains an inventory of Flibe coolant around the fuel pebbles (fission product barriers).
  - Qualified materials provide assurance that the reactor vessel can be designed for extremely low probability of abnormal leakage, resistance to rapidly propagating failure, and resistance to gross rupture.
- The materials testing consists of two major efforts:
  - testing in high temperature air to support ASME design, ASME qualification extension, and
  - testing in molten Flibe salt to account for potential environmental degradation.

Kairos Power

Graphite Material Qualification Topical Report

ACRS Full Committee Meeting

February 1, 2023

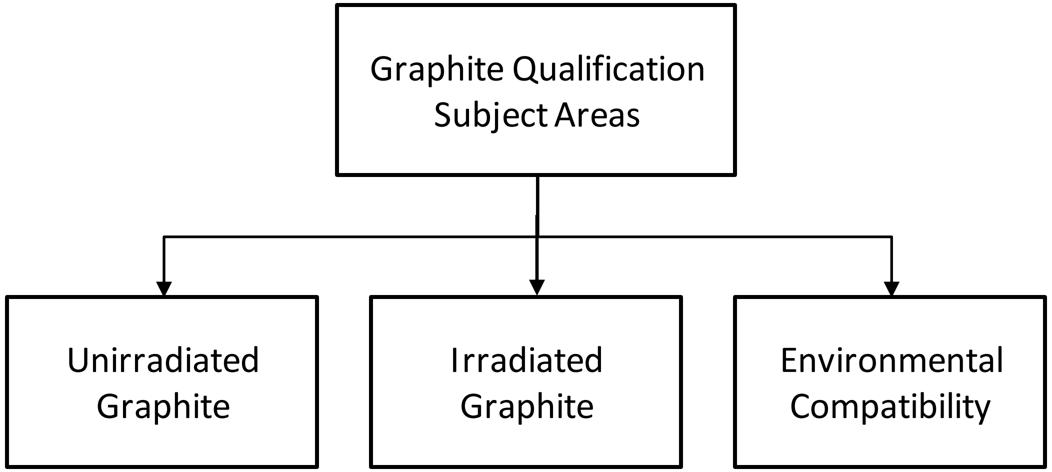
Background

- Purpose: This report presents the methods for qualifying structural graphite for use in KP-FHRs
  - Qualification is subject to the conditions specified in topical report
- Scope: This report is applicable to a KP-FHR test or power reactor provided that the report conditions are met
- Graphite to be Qualified: ET-10 is a superfine grain graphite with nearly isotropic properties

- Safety Functions
  - The graphite reflector provides a physical pathway for maintaining core cooling and a physical pathway for reactivity control element insertions
  - Structural integrity ensures the safety functions can be met
- Quality Assurance
  - The qualification for the power reactor will satisfy an NQA-1 based QA program
  - The qualification for the test reactor will satisfy an ANSI/ANS-15.8-1995 based QA program

ASME Code Application

- The qualification plan follows the ASME BPV, Section III, Division 5, code with a few exceptions.
  - A portion of the code specifically addresses graphite materials
- The code and the topical report organize qualification into three elements:
  - Characterization of as-manufactured graphite mechanical and thermal properties
  - Characterization of graphite properties under irradiation
  - Environmental compatibility


Graphite Qualification Subject Areas

Unirradiated Graphite

Irradiated Graphite

Environmental Compatibility

Qualification of Unirradiated and Irradiated Graphite

- Qualification for unirradiated ET-10 would follow ASME Code III (5), *As-Manufactured Graphite*:
  - Kairos Power will conduct testing for mechanical properties, thermal properties, and purity with limited departures from the code.
  - Both with grain and against the grain properties will be measured. The final design of the reflector structure will take into account uncertainty in property values due to anisotropy.
  - A combination of testing data and historical data will be used to assess property variation.
- Qualification will apply ASME Code III (5) HHA-2200, *Material Properties for Design and HA-III-3000 Properties to be Determined*, for irradiated graphite properties.
  - Applicable data exists for basic irradiation properties for use in either a power and test reactor application.
  - Kairos Power will generate new test data to characterize irradiation creep for a power reactor application.
  - Applicable data exists for irradiation creep coefficients for use in a test reactor application.

Environmental Compatibility Between Flibe and ET-10

- Phenomena relevant to qualification were identified through review of applicable phenomena identification studies and other technical literature

Phenomenon	Qualification Plan	Purpose
Infiltration	Confirmatory testing (applicable to power reactor conditions only)	Confirm that graphite mechanical properties are not degraded by Flibe infiltration.
Abrasion and Erosion	Confirmatory testing	Demonstrate no significant abrasion or erosion under prototypical operating conditions.
Chemical Compatibility	No testing planned	Applicable literature indicates that intercalation is thermodynamically unfavorable in Flibe.
Oxidation	Testing (applicable to test and power reactors)	Measure ET-10 oxidation kinetic parameters; determine weight loss vs strength; determine oxidation depth profile; confirm that oxidation of submerged graphite does not occur to a degree that would affect strength.

Summary

- The qualification plan in the Graphite Material Qualification Topical Report describes the plan to qualify ET-10 for safety-related structural graphite component design for use in a KP-FHR.
- The qualification plan conforms with the ASME BPV, Section III, Division 5, code with limited departures.
- The qualification plan will use existing data and data from new tests.
- Seismic qualification of the reflector structure is outside the scope of the topical report.

NRC Evaluation of KP-TR-014-P, "Graphite Material Qualification for the Kairos Power Fluoride Salt-Cooled High Temperature Reactor (KP-FHR)", Rev. 4

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Introduction

- Kairos Power, LLC requested staff review and approval of KP-TR-014-P, Rev. 4, “Graphite Material Qualification for the Kairos Power Fluoride Salt-Cooled High Temperature Reactor (KP-FHR)”
- KP-TR-014-P, Rev 4 provides a methodology by which the Kairos ET-10 graphite will be qualified for use in either a KP-FHR non-power or KP-FHR power reactor
- The staff’s review focused on the overall qualification framework including:
  - Evaluation against ASME Code Section III Division 5 requirements (Regulatory Guide 1.87, Revision 2)
  - Use of existing data
  - Unirradiated testing
  - Irradiation testing
  - Oxidation testing
  - Molten salt testing

Regulatory Basis

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

The following Kairos PDC are applicable to this topical report and were previously approved by the NRC staff (KP-TR-003-NP-A):

KP-FHR PDC 1, “Quality standards and records”
KP-FHR PDC 34, “Residual heat removal”
KP-FHR PDC 35, “Passive residual heat removal”
KP-FHR PDC 74, “Reactor vessel and reactor system structural design basis”

Staff Evaluation

- <u>Qualification of Unirradiated Graphite</u>
  - The NRC staff found that the proposed testing plan will satisfy the requirements of ASME Code Section III Division 5 (Section III Division 5) Article HHA-III-3100, “As-Manufactured Graphite“
  - Intra-billet and lot-to-lot property variation
- <u>Irradiated Properties</u>
  - HHA-2220, "Irradiated Material Properties" requires measurements for irradiated properties
  - ORNL data is used for basic properties
  - Additional irradiation testing for irradiation creep for the power reactor design
- <u>Environmental Effects</u>
  - Infiltration, oxidation, abrasion and erosion

Conclusions

- The staff reviewed the topical report KP-TR-014-P, Rev. 4 and concludes that the graphite material qualification program is acceptable for ET-10 graphite to be used in either non-power or power designs of the KP-FHR.
- Will meet applicable PDCs, in part
  - Graphite components will be qualified to ASME Code consistent with PDC 1
  - Graphite component integrity is needed to achieve PDCs 34, 35, and 74
- Subject to NRC staff limitations and conditions
  - Needed to ensure data bounds anticipated conditions
  - Ensures certain future actions stated in the topical report are reviewed
  - Ensure that if certain design aspects change, they are appropriately addressed

Questions?

BACK-UP SLIDES

Limitations and Conditions

1. The NRC staff finds that it is necessary to limit applicability of the topical report consistent with the limitations listed by Kairos in Section 7.2, “Limitations,” of the topical report. An applicant referencing this topical report will need to demonstrate that these limitations are met at the time of a license application, subject to NRC staff review and approval.

2. In the topical report, KP described several action items to be performed in the future. These action items, as described below, are subject to NRC staff review and approval once submitted with an application:
    1. Section 3.1.1 states that KP will perform low cycle fatigue testing to demonstrate that ET-10 follows the same fatigue trends as H-451 and PGX.
    2. Section 3.2 states that in order to use historical data, KP will verify that the historical data is applicable as per the process described in Appendix B of the topical report.
    3. Section 4.3 states that the qualification envelope from the irradiation data will be shown to envelope the operating conditions of the reactor.
    4. Section 4.3 states that the ORNL irradiation data will be used to estimate the turnaround fluence with confidence intervals.
    5. Section 4.3.1.2 states that irradiation creep target test temperatures are selected to bound operating conditions, and that the power reactor lifetime is bounded by irradiation creep testing conditions.
    6. Section 4.3.1.2 states that tertiary creep will be identified if it occurs.
    7. Section 4.3.2.2 states that a conservative turnaround fluence limit will be calculated, and that it will be shown that the non-power reactor does not exceed this limit.
    8. Section 5.2 states that KP will quantify wear rates of the graphite via tribological testing with the carbon pebbles, and confirm that no significant loss of volume occurs due to erosion via visual inspection of graphite exposed to moving Flibe.
    9. Section 7.2 states that the design will preclude the coincident effects of oxidation and irradiation that may inhibit the reflector from performing its safety function.

Limitations and Conditions

3. The NRC staff’s review and approval of this topical report was conducted against the 2017 Edition of Section III Division 5 and the associated staff endorsement, and associated conditions. Therefore, approval of this topical report is only applicable for the 2017 Edition and any deviations not described in this topical report or use of updated BPVC versions would require separate review and approval.

4. The approval of this qualification methodology is only applicable to the Kairos’ power and non-power test reactor designs. Graphite will experience different changes to its properties as a function of its operating environment (e.g., temperature, fluence, coolant). Additionally, graphite components may have different safety functions and damage tolerance depending on the specific reactor design. Therefore, the specifics of this methodology may not be applicable to other designs.

5. If a salt other than the Flibe used as the primary coolant (e.g. nitrate) salt is used in the intermediate loop for either the power or non-power reactor designs, an applicant referencing this topical report must demonstrate that no adverse effects of graphite exposure to the intermediate salt will occur and quantify these effects to demonstrate that the graphite components can perform their safety functions.

Limitations and Conditions

6. The approval of this topical report is limited to the qualification testing methodology for ET-10 graphite. The NRC staff did not review topics such as the reflector design, margins, monitoring, surveillance, or inspection programs. The approval of this topical report does not include a determination of an acceptable operating life for the graphite components. An applicant will need to demonstrate an acceptable graphite component lifetime based on intended function of the graphite blocks, damage tolerance, reflector design, margins, monitoring, surveillance, and/or inspection programs.

7. An applicant referencing this topical report must describe how flaw acceptance will occur without using fracture toughness.

8. The NRC staff does not currently accept the use of any known documented creep model in literature for modeling tertiary creep of graphite. The staff does not accept the use of the United Kingdom Atomic Energy Authority (UKAEA) creep model, as it was developed on the irradiation response of Gilsonite. Therefore, an applicant referencing this topical report will need to develop its own creep model and demonstrate that it adequately models creep behavior for ET-10 graphite. This includes identification of tertiary creep if it occurs and determination of creep coefficients.

9. An applicant referencing this topical report must demonstrate that the irradiated test data for both basic properties and creep properties bounds the temperature and fluence profiles for the qualification envelope without extrapolation of the data. If this cannot be demonstrated, then the applicant will be required to obtain additional irradiated test data to bound anticipated operating conditions (i.e., temperature and fluence combinations).

Limitations and Conditions

10. An applicant referencing this topical report must demonstrate how the data (irradiated and unirradiated) meet the quality assurance requirements in Section III Division 5 (e.g., HAB-3125, 3127, 3800, and 4000) for graphite qualification for the power reactor design.

11. Dimensional changes of creep samples must be measured and recorded in both the with grain (WG) and against grain (AG) directions, as required by HHA-II-4000, Detailed Requirements for Derivation of the Material Datasheet – Irradiated Material Properties.

12. The following Limitations and Conditions apply to creep modeling for the non-power reactor:
    1. An applicant referencing this topical report must demonstrate that a creep model can be developed for the non-power reactor without using creep data that pre-dates H-451.
    2. Demonstrate that a conservative creep coefficient can be derived from data described in Section 4.3.2.2 of the topical report and show margin to ensure that the graphite components can perform their safety functions.
    3. The proposed creep model is only acceptable because it is limited to applications before turnaround. Additionally, an applicant referencing this topical report must submit the turnaround fluence to the NRC staff for review to confirm that the non-power reactor does not reach turnaround.
    4. Development of a creep model based on the historical data referenced is only acceptable for a non-power reactor.
    5. As stated in Section 4.3.2.2 of the topical report, an applicant must demonstrate that no irradiation-induced stress-driven failure of graphite will occur pre-turnaround.

13. If results of the testing described in Section 5.1.3 of the topical report indicate that there is significant degradation of graphite exposed to the Flibe, then this effect must be accounted for in the design of the graphite reflector.

14. If properties that are not included in this qualification program are needed for the graphite reflector design, an applicant referencing this topical report must perform the necessary testing to obtain properties not included in the qualification program