

# **Official Transcript of Proceedings**

## **NUCLEAR REGULATORY COMMISSION**

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Kairos Power Licensing Subcommittee  
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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

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1 UNITED STATES OF AMERICA

2 NUCLEAR REGULATORY COMMISSION

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4 ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

5 (ACRS)

6 + + + + +

7 KAIROS POWER LICENSING SUBCOMMITTEE

8 + + + + +

9 FRIDAY

10 FEBRUARY 21, 2020

11 + + + + +

12 ROCKVILLE, MARYLAND

13 + + + + +

14 The Subcommittee met at the Nuclear  
15 Regulatory Commission, Two White Flint North, Room  
16 T2D10, 11545 Rockville Pike, at 8:30 a.m., David  
17 Petti, Chair, presiding.

18  
19 COMMITTEE MEMBERS:

20 DAVID PETTI, Chair

21 RONALD G. BALLINGER, Member

22 DENNIS BLEY, Member

23 CHARLES H. BROWN, JR., Member

24 VESNA B. DIMITRIJEVIC, Member

25 WALTER L. KIRCHNER, Member

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1 JOSE MARCH-LEUBA, Member

2 JOY L. REMPE, Member

3 PETER RICCARDELLA, Member

4 MATTHEW W. SUNSERI, Member

5 ACRS CONSULTANTS:

6 MICHAEL L. CORRADINI

7 STEPHEN SCHULTZ

8 DESIGNATED FEDERAL OFFICIAL:

9 WEIDONG WANG

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

(8:00 a.m.)

MEMBER PETTI: This is a meeting of the Kairos Power Licensing Subcommittee of the Advisory Committee on Reactor Safeguards.

I'm David Petti, chairman of today's subcommittee meeting.

ACRS members in attendance are Vesna Dimitrijevic, Walt Kirchner, Ron Ballinger, Pete Riccardella, Matt Sunseri, Joy Rempe, Jose March-Leuba, and we expect Dennis and Charlie Brown later.

We have consultants, Mike Corradini and Steve Schultz, and Weidong Wang of the ACRS staff as the designated federal official for this meeting.

During today's meeting, the subcommittee will receive a presentation on the design overview of the Kairos Power fluoride salt-cooled high temperature reactor, a new generation for a nuclear reactor, and review two Kairos topical reports on the scaling methodology for the Kairos Power Testing Program, and the reactor coolant for the Kairos power reactor.

The subcommittee will have presentations by and hold discussions with the staff, the Kairos power representatives, and other interested persons.

The rules for participation in all ACRS

1 meetings, including today's, were announced in the  
2 Federal Register on June 13, 2019.

3 The ACRS section of the U.S. NRC public  
4 website provides our charter, our bylaws, agendas,  
5 letter reports, and full transcripts of all full and  
6 subcommittee meetings, including the slides that will  
7 be presented today.

8 The meeting notice and agenda for this  
9 meeting were posted there. We've received no written  
10 statements or request to make an oral statement from  
11 the public.

12 The first part of today's meeting is open  
13 to public attendance.

14 The second part of the meeting will be  
15 closed in order to discuss information that's  
16 proprietary to the licensee and its contractors,  
17 pursuant to 5 U.S.C. 552BC4.

18 Attendance at these portions of the  
19 meeting that deal with such information will be  
20 limited to the NRC staff, and those individuals and  
21 organizations who have entered into an appropriate  
22 confidentiality agreement with them.

23 Consequently, we will need to confirm that  
24 we have only eligible observers and participants in  
25 the room for the closed portions of the meeting.

1           The subcommittee will gather information,  
2           analyze the relevant issues and facts, and formulate  
3           proposed positions and actions as appropriate by  
4           deliberation by the full committee.

5           The rules for participation in today's  
6           meeting have been announced in the Federal Register.  
7           There's a transcript of the meeting being kept, and  
8           again, will be made available.

9           Therefore, we request that participants in  
10          the meeting use the microphones located throughout the  
11          meeting room when speaking.

12          Press on it until you get the green button  
13          light to go on so that the transcribe can hear.

14          Participants should first identify  
15          themselves and speak with sufficient clarity and  
16          volume so that they may be heard.

17          We will now proceed with the meeting, and  
18          I'd like to start by calling on the NRR staff to  
19          introduce our guests.

20                 DR. CORRADINI: Brian, do you want to?

21                 MR. SMITH: Good morning, my name is Brian  
22          Smith, I'm the deputy director of the Division of  
23          Advanced Reactors and Non-Power Production and  
24          Utilization Facilities. It's a long title.

25                 We cover a lot. Not only advanced



1 reactors, but also for the research reactors, as well  
2 as the moly-99 production facilities, so a broad  
3 scope.

4 My staff and I are very pleased to be here  
5 today to meet with you to talk about our review of  
6 these two topical reports. We look forward to  
7 whatever questions you may have, and any feedback you  
8 have on our review.

9 We've been interacting with you over the  
10 last several years on advanced online water reactor  
11 issues, primarily guidance development, so we see this  
12 meeting as a milestone of sorts. No longer talking  
13 about guidance, but talking about specific topical  
14 reports submitted by a reactor developer.

15 So milestones, kind of big day. I want to  
16 thank Kairos in advance for the overview they're going  
17 to do of their design.

18 I looked through the slides. It looks  
19 like it'll be very beneficial to the ACRS, and the  
20 staff, as well.

21 We want to thank the ACRS for assigning  
22 Dr. Petti as the lead for this Kairos review. We look  
23 forward to interacting with him and the rest of the  
24 ACRS on future reviews of topical reports submitted by  
25 Kairos, as well as any future applications that may

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1 reference the Kairos design.

2 In performing these reviews, we used staff  
3 from both NRR, as well as the Office of Research, and  
4 I want to thank them for their efforts in developing  
5 what I thought were high quality documents.

6 Finally, I want to note that the working  
7 relationship between the staff and Kairos was great,  
8 and that we were able to get through these reviews  
9 without having to issue any requests for additional  
10 information. So that's it for me. Thank you.

11 DR. CORRADINI: So can I --

12 MEMBER KIRCHNER: Yeah.

13 DR. CORRADINI: I'm sorry.

14 MEMBER KIRCHNER: Brian, I just want to  
15 ask a question. As you approached this review with  
16 Kairos or other potential applicants, are you now  
17 using as a point of reference the advanced reactor  
18 design criteria?

19 MR. SMITH: Yes.

20 MEMBER KIRCHNER: That's kind of your  
21 substitute for the GDCs, in terms of having some  
22 reference point to look at different aspects of the  
23 design?

24 MR. SMITH: Yes. We developed the ---  
25 obviously that document. I think we coordinated with

1       you guys on that. Recognizing that a lot of the GDC  
2       may not apply to some of these new designs.

3               In fact, Kairos has submitted a topical  
4       report to us that describes their proposed principle  
5       design criteria.

6               DR. CORRADINI: Within that context?

7               MR. SMITH: Yes sir.

8               DR. CORRADINI: So, does that also imply  
9       that the application will use the Licensing  
10      Modernization Program -- I don't know the right name  
11      for this thing, so I'm going to call it the short  
12      name, the LMP, in terms of the process?

13              MR. SMITH: Yes, there's actually another  
14      topical report that we have in house from Kairos that  
15      lays out their approach for utilizing the LMP.

16              MEMBER BLEY: Did I hear you right? You  
17      expect to not have a request for information?

18              MR. SMITH: For these two topical reports  
19      that we reviewed --

20              MEMBER BLEY: You had none?

21              MR. SMITH: We did not issue any.

22              MEMBER BLEY: What led to that?

23              MR. SMITH: The interactions that we had  
24      with their staff directly.

25              MEMBER BLEY: Okay, so you had meetings

1 essentially?

2 MR. SMITH: Yes, we did.

3 DR. CORRADINI: We had a couple other  
4 meetings earlier this week, emphasizing that it's good  
5 the staff has informal discussions ahead of time.

6 Is this part of the reason that you  
7 eliminated the need for RAIs, that you guys had enough  
8 up-front discussions, in terms of --

9 MR. SMITH: Yes.

10 DR. CORRADINI: Okay.

11 MEMBER MARCH-LEUBA: And that's a really  
12 good thing.

13 I mean, I've always been pushing for  
14 audits as opposed to RAIs, where you're having  
15 informal communications, and then you eventually  
16 document it somewhere.

17 A lesson learned from all the reactor  
18 we're reviewing now, and since you're in the process,  
19 that particularly reactor has then the SER, a lot of  
20 areas where all the or the existing regulations don't  
21 apply to me because all the safety features I have  
22 that make my reactor more safe, which is great.

23 But they tend to forget what are the  
24 special characteristics of my reactor that make it  
25 less safe?

1           And they don't really focus on that, and  
2           they don't have a table on -- at least it says none.  
3           They really didn't focus on the special  
4           characteristics of the reactor.

5           And this is something I'm just giving you  
6           notice, like are you start sending description or  
7           anything, I want to be looking for what's missing, and  
8           I'm hoping that you have, too. Okay?

9           MR. SMITH: Okay.

10          MEMBER MARCH-LEUBA: Because I mean,  
11          honestly, if you look at it from that lens, you will  
12          see a lot of that doesn't apply to me, that doesn't  
13          apply to me, that doesn't apply to me, and nowhere  
14          they say ah, but this should apply to me and you never  
15          thought of it.

16          MR. SMITH: Right. For these new advanced  
17          non-light water reactor designs --

18          MEMBER MARCH-LEUBA: It clearly --

19          MR. SMITH: There's a lot of requirements  
20          in Part 50 that are specific to light water reactor  
21          designs, so there will be a good number of exemptions,  
22          we expect, from if not, probably all of that.

23          MEMBER MARCH-LEUBA: But I would expect  
24          that just one or two requests to add requirements  
25          because of the special characteristics of my reactor,

1 right?

2 MR. SMITH: Sure.

3 MEMBER MARCH-LEUBA: So at least a good  
4 condition of why there wasn't any.

5 DR. CORRADINI: Can I just follow up? You  
6 said something that maybe I should have assumed. Is  
7 the applicant in a process of defining they're going  
8 with a Part 50 versus a Part 52?

9 MR. HASTINGS: Yes, and we're going to  
10 talk about that.

11 DR. CORRADINI: Is this an appropriate --  
12 later today?

13 MR. HASTINGS: Okay, fine.

14 MEMBER PETTI: All right. So, just one  
15 more thing before we get started.

16 Because you guys are trying to catch a  
17 flight later today -- many of you -- we were thinking  
18 of making lunch just 30 minutes.

19 Go downstairs, you can bring something  
20 back and eat here, but to try to compress that time to  
21 make sure you guys have a margin to catch your  
22 airplane. Okay.

23 DR. CORRADINI: All right. Thank you.

24 MEMBER PETTI: Yep, no problem.

25 DR. CORRADINI: Go ahead.

1 MR. HASTINGS: Good morning. I'm Peter  
2 Hastings, I'm the vice president of Regulatory Affairs  
3 and Quality for Kairos Power.

4 On behalf of our entire team, thanks to  
5 the subcommittee for the invitation to introduce  
6 Kairos, our plans for developing, deploying the  
7 fluoride salt-cooled high temperature reactor.

8 You'll see it referred to in these  
9 presentations as the KP-FHR. And our first two  
10 topical reports that are before you for review.

11 Joining me today are our chief technology  
12 officer, Ed Blandford, our chief nuclear officer, Per  
13 Peterson.

14 They're cofounders of Kairos Power, along with  
15 our CEO, Mike Laufer, who was unable to join us this  
16 morning.

17 Also here are Darrell Gardner, our senior  
18 director of licensing, Alan Kruizenga, director of  
19 salt chemistry, and Nico Zweibaum, senior manager of  
20 the engineering testing, all of whom will be  
21 presenting later today.

22 And we're also joined by Drew Peebles, our  
23 manager of safety integration, and senior licensing  
24 engineers, John Price and Margaret Ellenson.

25 Next slide.

1 Kairos Power is a mission-driven company,  
2 and we begin every substantive interaction that we  
3 have with a reiteration of that mission, which is to  
4 enable the world's transition to clean energy, with  
5 the ultimate goal of dramatically improving people's  
6 quality of life while protecting the environment.

7 This is very important to us.

8 To put this meeting into context of that  
9 mission, NRC approval of our design is a key component  
10 of meeting the mission, and the ACRS participation in  
11 that process is obviously an important aspect of the  
12 approval.

13 Next slide.

14 This morning's public session will consist  
15 of a relatively brief overview of our design and  
16 development efforts, an overview of our two topical  
17 reports, scale and methodology, and reactor coolant,  
18 salt.

19 This portion is scheduled for about an  
20 hour.

21 We may try to accelerate that in the  
22 interest of getting to the more meaty parts of the  
23 presentation.

24 Then we'll go into closed session and  
25 drill down the proprietary details on each of these



1 topics.

2 Next slide. Our design is a hybrid that  
3 borrows attributes from other designs.

4 We use remarkably robust coated particle  
5 TRISO fuel -- it's historically used in gas reactors  
6 -- demonstrated to withstand extreme temperatures that  
7 are well beyond the threshold of current nuclear  
8 fuels.

9 Unlike gas reactors, we use molten salt  
10 coolant with a very high potential for absorbing and  
11 retaining radionuclides.

12 Our coolant is also chemically inert and  
13 not reactive with water or air.

14 We combine these attributes with a low  
15 pressure primary system into a design with substantial  
16 safety margins, which enables us to think differently  
17 about the size of our safety footprint.

18 Because cost of new nuclear builds is one  
19 of the primary barriers to deployment, the small  
20 safety footprint supports aggressive cost targets that  
21 allows us to think seriously about competing with  
22 natural gas, which is our primary initial market in  
23 the United States.

24 Cautionary tale about the design details  
25 you'll see here, they're intended to provide context

1 for the review of the topical reports.

2 The design is currently in the conceptual  
3 phase, and so a lot will change over the course of the  
4 next several months, but this is sort of a snapshot in  
5 time of where we are.

6 Next slide.

7 Kairos Power is a privately funded company  
8 focused on the commercialization of the FHR.

9 We were founded in 2016, emerging from a  
10 UC Berkeley concept that was part of a DOE sponsored  
11 integrative research project.

12 We're based in the San Francisco Bay Area,  
13 and have doubled our staff in the past couple of years  
14 to about 120 full-time staff currently.

15 As I mentioned, our primary market is U.S.  
16 electricity, with an expectation to deploy broadly in  
17 the 2030s, or sooner.

18 We're pursuing our mission by way of a  
19 determined and intentional approach to designing a  
20 reactor with a combination of remarkable safety  
21 margins and economic performance that enables direct  
22 competition with natural gas.

23 Next slide.

24 MEMBER MARCH-LEUBA: Well, you mentioned  
25 that -- you said U.S. energy. Have you been affected

1 at all by tariffs and export control? Do you have any  
2 partners outside the U.S.?

3 MR. HASTINGS: We're not affected by that  
4 at this time.

5 MEMBER MARCH-LEUBA: Okay.

6 MR. HASTINGS: We'll turn now to a very  
7 high-level overview of the design and development of  
8 the KP-FHR.

9 Next slide.

10 As I mentioned earlier, our primary  
11 initial target is competition with natural gas.

12 Competing with gas requires that we think  
13 differently, and cost of the plant is an important  
14 aspect of our deployment plan.

15 We expect to take advantage of the FHR's  
16 robust inherent safety resulting from large  
17 temperature margins in the fuel, the large retention  
18 capacity of FliBe coolant for fission products, the  
19 lack of a high pressure primary system, and passive  
20 decay heat removal, which eliminates the need for  
21 safety-related power.

22 All combine to reduce capital cost and  
23 enable broader use of conventional components,  
24 conventional materials, and fabrication and  
25 construction techniques, in lieu of higher cost

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1 nuclear-grade versions.

2 Next slide.

3 Our baseline licensing strategy for our  
4 first deployment includes substantial pre-application  
5 engagement, which Brian mentioned we've been very  
6 active with the NRC staff in the last little over a  
7 year.

8 Followed by a two-step Part 50  
9 construction permit and operating license.

10 In pre-application space, we've been  
11 highly engaged with the staff with submittal of  
12 several topical reports, the first two of which are  
13 before you today, and the balance of which are all  
14 about questions you asked.

15 Our principle design criteria, a  
16 regulatory gap analysis, and so forth.

17 During the pre-application phase, we also  
18 plan to submit a preliminary safety information  
19 document, or PSID, which is a platform that's been  
20 used a handful of times in the past for substantive  
21 non-topical pre-app review.

22 The PSID will look somewhat like an early  
23 application, and will result in a preliminary non-  
24 binding review by the staff in a preliminary safety  
25 evaluation.

1           This vehicle's intended to provide early  
2 feedback on key technical issues, not dissimilar from  
3 the Canadian Vendor Design Review, but with additional  
4 flexibility in terms of content.

5           DR. CORRADINI: Has --

6           MR. HASTINGS: Mm-hmm?

7           DR. CORRADINI: Not to slow you down much.  
8 What's an example most recently the NRC has had this,  
9 and has exercised this so they're aware of how to  
10 respond?

11          MR. HASTINGS: It has been some time. There was  
12 one for the MHTGR, there was one for PRISM, and there  
13 was a third one that I always forget.

14          DR. CORRADINI: So we're talking the '80s?

15          MR. HASTINGS: Yeah.

16          PARTICIPANT: Eighties, yes.

17          DR. CORRADINI: Okay, well the only reason  
18 I ask is personally, this is a very logical approach,  
19 but I'm just making sure the staff is aware and ready  
20 for your first blue box.

21          MR. HASTINGS: They are. We've discussed  
22 it.

23                You may recall a couple of years ago,  
24 there was a lot of discussion about the development of  
25 a VDR-type process by the staff.

1 (Simultaneous speaking.)

2 DR. CORRADINI: I remember you were here  
3 talking about it.

4 MR. HASTINGS: And the staff were off to  
5 develop such a program, and we sort of collectively  
6 all came to the conclusion at about the same time that  
7 if we use the PSID format, it really provided  
8 everything we needed with actually more flexibility  
9 than the VDR process because it has a very fixed  
10 format around 19 topics.

11 The PSID can sort of be whatever you want  
12 it to be.

13 DR. CORRADINI: Okay.

14 MR. HASTINGS: And so, we're working with  
15 the staff now to narrow down what the topics are going  
16 to be --

17 DR. CORRADINI: Within it?

18 MR. HASTINGS: Within the PSID.

19 MEMBER BLEY: Okay. And you said it's a  
20 non-binding document?

21 MR. HASTINGS: Correct. So --

22 MEMBER BLEY: But it means you get some  
23 advanced review, but if what comes out next isn't the  
24 same, you might be starting over?

25 MR. HASTINGS: Exactly.

1 MEMBER BLEY: Okay.

2 DR. CORRADINI: Yeah, but to follow up  
3 Dennis' question, I assume the whole purpose of this  
4 is to identify things that are issues early and --

5 MR. HASTINGS: To address them. It's all  
6 about de-risking the programmatic portion of the  
7 process.

8 MEMBER REMPE: Do you have a schedule in  
9 mind of how long you'll take for the pre-application  
10 phase versus the construction permit application?

11 MR. HASTINGS: We do. That schedule is a  
12 work in progress.

13 Our current plan is for a PSID early 2021,  
14 with a CPA a couple of years after that. Those  
15 numbers are moving around a bit, frankly.

16 MEMBER REMPE: Thanks.

17 DR. CORRADINI: Okay. Thank you.

18 MEMBER BROWN: Non-binding doesn't  
19 necessarily mean you all might make changes, but NRC,  
20 even though they provide feedback, they could change  
21 their minds --

22 MR. HASTINGS: It's --

23 MEMBER BROWN: Based on a subsequent  
24 thing, that oh, we've thought about this some more.

25 So I mean, it's a two-way street when it

1 comes to non-binding? I just wanted to make sure I  
2 understood that.

3 MR. HASTINGS: Right. Yeah, that's  
4 correct.

5 MEMBER BROWN: Since I haven't seen one of  
6 these.

7 MR. HASTINGS: Yeah. And we understand  
8 that risk, but it is all about de-risking the program.

9 MEMBER BROWN: No, no objection to the ---  
10 (Simultaneous speaking.)

11 MR. HASTINGS: So the more we can get, the  
12 better, obviously then.

13 MEMBER BROWN: Okay, thank you.

14 MEMBER KIRCHNER: Could I ask a question  
15 of the staff just to -- a little quick digression.  
16 What would you do if you get a PSID?

17 Would you do what was done in the '80s and  
18 do like a preliminary SER kind of document? And then  
19 how would you review that?

20 MEMBER BLEY: I seem to remember they did  
21 a new reg as that part was done.

22 (Simultaneous speaking.)

23 MEMBER KIRCHNER: Yeah, but I was --

24 MR. MAGRUDER: Right, yeah. This is Stu  
25 Magruder, I'm the lead project manager in NRR for the



1 project.

2 And what we're planning to do is similar  
3 to what we did for PRISM and MHTGR is to write what we  
4 call a draft or preliminary safety evaluation report.

5 It would be published.

6 We would hope to brief you and get a  
7 letter from the ACRS on that before we issued it, but  
8 as Dr. Brian said, this would be all based on  
9 preliminary information.

10 It's not a final answer, but it would  
11 serve to kind of identify if there are any  
12 showstoppers or significant issues that Kairos would  
13 need to pursue in different areas.

14 MEMBER MARCH-LEUBA: But the topical  
15 reports each will have a safety evaluation report with  
16 it, and those are binding, right?

17 Once you issue the SER, they can use it.

18 MR. MAGRUDER: Yes. We'll talk about that  
19 obviously later today, but you're absolutely right.  
20 There's more regulatory certainty with topical report  
21 SERs and --

22 (Simultaneous speaking.)

23 MEMBER MARCH-LEUBA: It has more --

24 MR. MAGRUDER: So this is all part of  
25 their plan.

1 MEMBER MARCH-LEUBA: It has more value in  
2 a sense. I mean, it's final.

3 MR. MAGRUDER: Yes.

4 MEMBER MARCH-LEUBA: And once the position  
5 --

6 (Simultaneous speaking.)

7 MR. MAGRUDER: Although, there are, of  
8 course, as you'll see, there are limitations and  
9 conditions in our SERs --

10 (Simultaneous speaking.)

11 MEMBER MARCH-LEUBA: Which are actually --  
12 - are also final. Right?

13 (Simultaneous speaking.)

14 MEMBER BROWN: How does that affect the  
15 non-binding nature of the PSID if there's topical  
16 reports that have a formal locked-in SER?

17 DR. CORRADINI: I guess it would be  
18 similar to other examples, which is they've committed  
19 to doing it a certain way within the limitation and  
20 conditions, and that's holes, however the design moves  
21 around.

22 MEMBER MARCH-LEUBA: Unless they want to  
23 change --

24 MEMBER BROWN: I'm saying just yeah, the  
25 non-binding nature is a little bit -- it's not totally

1 non-binding if you have a topical report SER.

2 MR. HASTINGS: Right, so it's a continuum,  
3 right? From a PSID to a topical to another  
4 application.

5 (Simultaneous speaking.)

6 MEMBER BROWN: That's fine, I just wanted  
7 to --- it's another thing that got thrown into the  
8 hopper.

9 MEMBER MARCH-LEUBA: They always have the  
10 possibility of issuing Revision 1 of the topical  
11 report.

12 MEMBER BROWN: Yeah, I got it.

13 MEMBER BLEY: Or issue a technical report  
14 that adapts that one --

15 DR. SCHULTZ: And the limitations and  
16 conditions will be very important for both parties.

17 MR. HASTINGS: All true. And if there's  
18 a topic that rises to the level of a topical report in  
19 terms of maturity and readiness to receive a formal  
20 review, you wouldn't see much discussion of that in  
21 the PSID, other than pointing to it.

22 MEMBER MARCH-LEUBA: Given the fact that  
23 this is new technology for some of us, I mean, we are  
24 too young to remember molten salt reactors --

25 MR. HASTINGS: Speak for yourself.

1 PARTICIPANT: No, we're not.

2 MEMBER BLEY: We have a couple people of  
3 that sort.

4 MR. HASTINGS: Speak for yourself.

5 MEMBER MARCH-LEUBA: Yeah, well I was  
6 making a joke.

7 The methodology of topical reports, how  
8 you analyze it and what correlations, you use and  
9 everything. I assume you're waiting for the results  
10 from the experiments to finalize those. Is that  
11 correct, or are you working already on those?

12 MR. HASTINGS: Both. So many of our  
13 topicals are in two phases where the initial topical  
14 is methodological or phenomenological, and the  
15 revision later would be with supporting qualified  
16 data.

17 MEMBER MARCH-LEUBA: So you're moving  
18 ahead and doing Part A, and then just leaving the  
19 appendices to be done?

20 MR. HASTINGS: In many cases, that's  
21 correct.

22 MEMBER MARCH-LEUBA: That's good, because  
23 for other reactors, which shall not be named, we're  
24 reviewing methodology now after this here has been  
25 issued. So, that's not desirable. You're doing much

1 better. Thank you.

2 MR. MAGRUDER: Let me just add one more  
3 thing. Brian reminded me that I should point out that  
4 with regard to issue finality or kind of staff's  
5 conclusions, this is different from Part 52, where you  
6 have a design certification document and the staff is  
7 actually bound by what we write in our SE for that.  
8 This is under Part 50 space, there's no issue finality  
9 for these types of issues.

10 I mean, obviously when we issue an  
11 operating license eventually, there will be, but up to  
12 that point, there's no issue finality like there is in  
13 Part 52.

14 MEMBER REMPE: So, your comment about  
15 well, yeah, maybe there's more finality, but we've got  
16 some limitations and conditions that might come into  
17 play.

18 And when I was looking through your SERs,  
19 there are some interesting limitations and conditions  
20 regarding -- like, because this is new -- well, it's  
21 not new technology, but we've not been using it for a  
22 lot of years -- if you see something different, we may  
23 have some additional changes.

24 And have you ever done that in a topical  
25 report review before, or in recent years?

1           Because I thought in some ways it's like  
2           a get out of jail free card that you've put in,  
3           there's a limitation and condition. Have you done  
4           that before? Because I don't recall something as  
5           different as that in past reviews.

6           MR. MAGRUDER: So, I'll let the technical  
7           reviewers talk specifically about that, but I think  
8           these topicalals did present some challenges because  
9           there were so many new features and so many things  
10          that we're waiting on.

11          MEMBER REMPE: Right.

12          MR. MAGRUDER: And so, there was a lot of  
13          good discussion among the staff about how to write it.

14          MEMBER REMPE: But you have examples where  
15          you've done that in -- I hadn't seen that before, and  
16          it's a little -- I mean, maybe back in the MHTGR and  
17          PRISM days, they did that too, but I didn't recall it.

18          MR. MAGRUDER: I don't know of any  
19          specific examples, but we can talk more later about  
20          that.

21          MEMBER PETTI: Certainly in the MHTGR  
22          days, there were a long list of things that drove that  
23          program for the next decade.

24          MEMBER REMPE: But this one, it's just  
25          like, eh, if you see some new phenomena, we answer

1 questions.

2 I mean, they had specific items of where  
3 they were looking into.

4 MEMBER PETTI: Right. Well, because the  
5 technologies were a little more mature.

6 MEMBER REMPE: Right.

7 MEMBER PETTI: Right. Keep on going.

8 MR. HASTINGS: All right, next slide.

9 The goals of a licensing strategy are  
10 straightforward.

11 The chairman has said in several public  
12 forums that if we can't find a way to take advantage  
13 of increased safety in advanced designs, we all will  
14 have failed, and we certainly agree with that.

15 Kairos' intents to take advantage of the  
16 significant safety margins of the FHR design, not only  
17 to compete with natural gas as a way to accomplish our  
18 mission of enabling the world's transition to clean  
19 energy, but also to achieve the enabling goals that  
20 you see here.

21 First, to get early acceptance of the FHR  
22 safety case in order to retire programmatic risk as  
23 early as possible, which is most of what we've been  
24 talking about already this morning.

25 Second, to minimize the safety footprint,

1 enabling both economic competitiveness and true focus  
2 on safety significant aspects of the plan.

3 And third, to build flexibility into the  
4 process invigorating the design so that every tweak in  
5 the design going forward doesn't constitute another  
6 significance licensing action, to the extent we can  
7 achieve that.

8 So with that, I'll turn things over to Dr.  
9 Ed Blandford, who will discuss Kairos' testing and  
10 development overview.

11 DR. CORRADINI: Ah, there we go.

12 DR. BLANDFORD: Excellent, good morning.  
13 Thank you. As Peter mentioned, my name is Ed  
14 Blandford. I am the cofounder and chief technology  
15 officer of Kairos Power. I'm going to provide a quick  
16 overview of our testing and development program.

17 Next slide.

18 So, this slide we present in a number of  
19 public forums. It pretty much encapsulates everything  
20 that we do at Kairos.

21 At the top, it outlines what we would  
22 consider a conventional development cycle, where we  
23 have a plan, design, build, test sequence.

24 And I think many people would agree one of  
25 the challenges in the civilian nuclear community is



1 really trying to break down the cycles and really  
2 accelerate development.

3 But Kairos' focus is really on the bottom  
4 part of that slide that shows how we go through that  
5 process through an iterative development effort, and  
6 so this really encapsulates a lot of the activities  
7 that we're doing today.

8 Peter had talked through our licensing  
9 approach.

10 That's an example of that sort of  
11 iterative, putting the early topical reports in front  
12 of the staff, and walking through our technology.

13 So this really encapsulates a lot of our  
14 development program.

15 Next slide.

16 We recognize the importance of  
17 demonstrating our technology.

18 This is a very, very big part of our DNA,  
19 it's a very big part of who we are and what we're  
20 focused on.

21 We recognize that this is a new  
22 technology, but it's an area that we see a lot of  
23 opportunities.

24 We also recognize that there's a need for  
25 testing facilities to support our development program.

1           So in this slide, it shows the progression  
2 of a series of test facilities that Kairos is  
3 currently invested in.

4           It's already stood up, or is in the  
5 process of standing up.

6           And it really starts with the first two  
7 letters. It's a little bit of a QRSTU.

8           It starts with what we call our Rapid Lab,  
9 which is a rapid analysis prototype and iterative  
10 design lab.

11          This is located in our headquarters in  
12 Alameda.

13          It's a part of our facility where we're  
14 able to iterate quickly, so we use rapid prototyping  
15 technologies to produce components, iterate the  
16 surrogate fluids, and really inform elements of the  
17 design that are important.

18          It allows us to move quickly.

19          In parallel, we understand the importance  
20 of working at the high temperature and working with  
21 the prototypical fluids, and so we also have what we  
22 call our Salt Lab, which is a facility that we're  
23 standing up in our Alameda lab.

24          We're about, I think, two weeks away from  
25 actually operating our first salt experiment utilizing

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1 the beryllium salts. Slide. In parallel, we also  
2 have what's called our Testing Facility or our T-  
3 Facility.

4 This is actually a location that we're  
5 about to open up in the state of New Mexico, in  
6 Albuquerque, and this is an area where we plan on  
7 doing larger scale qualification testing.

8 And so, we're very hard at work trying to  
9 stand up that facility and those capabilities.

10 DR. CORRADINI: If this is an appropriate  
11 time to ask, where's that in New Mexico within the  
12 laboratory structure?

13 DR. BLANDFORD: It's in Albuquerque.

14 DR. CORRADINI: Okay, but --

15 DR. BLANDFORD: So it's a  
16 private facility, so there's been a little bit of  
17 press, so it's in the public domain.

18 DR. CORRADINI: Okay, fine.

19 DR. BLANDFORD: But it's at -- it's called  
20 the Mesa Del Sol development site.

21 DR. CORRADINI: Okay, thank you.

22 DR. BLANDFORD: And then lastly, there's  
23 a user facility, and this is an area where we would  
24 anticipate training end users in terms of operations  
25 and maintenance.

1                   That's the one facility that we're working  
2                   towards today that doesn't physically exist right now.

3                   Next slide.

4                   MEMBER KIRCHNER: Before you go on?

5                   DR. BLANDFORD: Uh-huh?

6                   MEMBER KIRCHNER: So, your slide says non-  
7                   nuclear.

8                   DR. BLANDFORD: Correct.

9                   MEMBER KIRCHNER: So, have you a shortlist  
10                  or development and test plan for those aspects that  
11                  actually have a nuclear component?

12                  DR. BLANDFORD: Good question. So, we've  
13                  committed to both a nuclear and a non-nuclear test  
14                  program, and we'll get into a little bit more of the  
15                  details later on today.

16                  It's difficult for us to go in those  
17                  nuclear facilities today, and so we believe a  
18                  combination of our nuclear testing, where we leverage  
19                  a lot of the DOE complex to deal with radiations and  
20                  do the type of work that we need to do compliments the  
21                  non-nuclear test program. So it's a combination of  
22                  both.

23                  MEMBER MARCH-LEUBA: Can you speak up  
24                  louder? They cannot hear you.

25                  DR. BLANDFORD: Oh, I'm sorry.

1 MEMBER MARCH-LEUBA: Can we ask them to  
2 increase the volume?

3 DR. CORRADINI: Yeah, that might be a  
4 crappy microphone. Try the one next to you.

5 (Simultaneous speaking.)

6 DR. BLANDFORD: All right. Is this  
7 better?

8 DR. CORRADINI: Yes.

9 DR. BLANDFORD: Okay. Sorry, apologies.

10 DR. CORRADINI: Just get closer to Peter.  
11 You're colleagues. However much you feel like you  
12 have to.

13 MEMBER REMPE: What about the fuel  
14 fabrication capability, because it's not exactly what  
15 we've seen even in our national communities.

16 There's some differences in the fuel, and  
17 where will that be made?

18 DR. BLANDFORD: That's a good question.  
19 I believe we're going to be submitting our fuel  
20 qualification topical report.

21 I'm not sure the exact schedule for when  
22 we're submitting that, but that'll be a time for us to  
23 really jump into the details of that.

24 So right now, some of that information is  
25 actually proprietary, so.

1 DR. SCHULTZ: Yeah, excuse me, the  
2 operations and training, the user facility, how is  
3 that -- are you going to talk about that today?  
4 Conceptually, it sounds like a great idea.

5 DR. BLANDFORD: Sure.

6 DR. SCHULTZ: But, how far have you gone  
7 with identifying the details of that?

8 DR. BLANDFORD: The details of it we don't  
9 have fully fleshed out yet.

10 Conceptually, I can speak we're at a high  
11 level.

12 So it's basically a full scale version of  
13 the primary side of the plant, and it's an opportunity  
14 for us to train operators with the real equipment,  
15 from the whole spectrum of effectively inservice  
16 inspections, component replacements, and getting  
17 familiar with the technology.

18 The concept is at a high level.

19 DR. SCHULTZ: Great idea, thank you.

20 MEMBER MARCH-LEUBA: And are you thinking  
21 of a single module in a remote location, or are you  
22 thinking of a multi-module with a single control room  
23 and 25 units?

24 DR. BLANDFORD: I think that's to be determined,  
25 and it's an area that we'll check --

1 (Simultaneous speaking.)

2 MEMBER MARCH-LEUBA: But you're staying  
3 open -- that would affect a lot of the training and  
4 the design of the control room obviously.

5 DR. BLANDFORD: Sure. And just to  
6 clarify, the U-Facility and concept goes well beyond  
7 control room, you know, training simulator.

8 This was really working on the hardware,  
9 so that would be a singular module that we would be  
10 looking at.

11 DR. CORRADINI: Ah, thanks. This might be  
12 for the closed session.

13 So from the standpoint of using this, I'll  
14 call it challenging coolant, which has its own  
15 chemical safety issues, where is there experience in  
16 the United States of this in the past?

17 DR. BLANDFORD: So, and this is something  
18 that we can probably talk about in private session.

19 DR. CORRADINI: Okay, then we can wait.  
20 Okay, fine.

21 DR. BLANDFORD: But we recognize that, and  
22 it's important to have the right partnerships and work  
23 with the right people that have the prior experiences.

24 DR. CORRADINI: Okay, fine.

25 MEMBER BLEY: You mentioned the training.

1 Do you have people on the staff as you work in that  
2 area who have actual operating experience?

3 DR. BLANDFORD: We do.

4 MEMBER BLEY: You know, engineers think  
5 they're best at this, but they often get surprised.

6 PARTICIPANT: Very much so.

7 DR. BLANDFORD: I would be remiss to that.  
8 So, our vice president of engineering, Mark Peres, was  
9 a former operator at FFTF.

10 We do have people on staff that do have  
11 operational experience, and that's very valuable for  
12 us. So I'm going to go ahead and pass this off to Dr.  
13 Nico Zweibaum.

14 DR. ZWEIBAUM: Good morning, everyone. Is  
15 this mic better? Okay. Very good.

16 As Ed said, my name is Nico Zweibaum. I  
17 am the senior manager of engineering testing at Kairos  
18 Power, and I was also one of the preparers for scaling  
19 methodology topical report, which I'm going to give a  
20 brief overview of right now.

21 Next slide, please.

22 So, what was the purpose of that topical  
23 report? We are describing the methodology we intend  
24 to use to scale both integral effects tests, referred  
25 to as IETs, and separate effects tests, or SETs, that



1 will support the KP-FHR evaluation model assessment  
2 base.

3 The report goes through the justification  
4 for the use of surrogate fluids that enable direct and  
5 comprehensive local measurements of the phenomena that  
6 are under investigation, and the use of surrogate  
7 fluids is due to their higher compatibility for high  
8 accuracy instrumentation that is readily available,  
9 for instance, to measure temperature and flow  
10 velocities.

11 The intent of that report was to  
12 communicate and request the NRC review and approval to  
13 use our scaling methodology with surrogate fluids  
14 described in the report, namely, heat transfer oils  
15 and water for testing, including in the assessment  
16 base of evaluation models that support our safety  
17 analysis.

18 Next.

19 So what is the scope of that report?  
20 First off, we are basing our scaling methodology on  
21 the well-known hierarchy called two-tiered scaling  
22 methodology, or H2TS.

23 This generic scaling methodology was  
24 previously developed for and approved by the NRC. We  
25 selected it for scaling of our thermal fluids, IETs

1 and SETs, and the methodology includes quantification  
2 of distortions in the scaling.

3 The report addresses scaling of our  
4 primary heat transport system, thermal fluids, IETs  
5 for the KP-FHR plant at normal operating conditions  
6 with forced flow, as well as transients that involve  
7 natural circulation.

8 And it describes the use of specific  
9 classes of heat transfer oils that are deemed  
10 acceptable surrogate fluids for these integral effects  
11 tests.

12 In addition, the report also addresses scaling  
13 of specific phenomena in component level separate  
14 effects tests that would also use a specific class of  
15 heat transfer oil or water as acceptable surrogate  
16 fluids.

17 The figure to the right is mainly provided  
18 for illustration, but is from the NRC's Regulatory  
19 Guide 1.203 on evaluation methods, development, and  
20 assessment process.

21 And I apologize for the very small font,  
22 but the element 2 of that process includes scaling  
23 efforts and identification of integral effects tests  
24 and separate effects tests that are supposed to  
25 support our safety analysis methodology, and this is

1 really what that scaling report is about, is  
2 addressing those parts of element 2 of the EMDAP  
3 process.

4 DR. CORRADINI: This makes perfect sense.  
5 The one thing though about your two surrogates are  
6 that they don't freeze and they don't get gooey.

7 So, is it your job to worry about that, or  
8 the next person down the line's job to worry about  
9 that?

10 DR. ZWEIBAUM: Well, so the report really  
11 addresses what happens outside of that range.

12 DR. CORRADINI: Okay.

13 DR. ZWEIBAUM: It --

14 DR. CORRADINI: Okay, that's fine.

15 DR. ZWEIBAUM: Yeah.

16 DR. CORRADINI: Okay.

17 MEMBER PETTI: So, I have a question just  
18 to help me understand. As I understand H2TS, I mean,  
19 it was really focused on the coolant, right, in the  
20 light water reactor, right?

21 So I've got a heat flux with a -- from the  
22 fuel rods that don't move that's static. Here, your  
23 fuel is moving.

24 This does not really apply to the movement  
25 of the fuel in the core. Is that a fair statement?

1 DR. ZWEIBAUM: So, our scaling approach  
2 does.

3 It is true that H2TS doesn't touch this  
4 specific topic, but the scaling that we've developed  
5 includes pebble movement in the coolant, and this will  
6 be one of the types of separate effects tests that we  
7 will talk about today.

8 MEMBER PETTI: Not heated?

9 DR. ZWEIBAUM: That is right.

10 The movement of the fuel in the core is  
11 largely decoupled from the heat transfer aspects  
12 because the fuel moves at a very slow pace in the core  
13 ---

14 (Simultaneous speaking.)

15 DR. CORRADINI: So it's basically just a  
16 density ---- it's just basically a buoyancy density?

17 MEMBER PETTI: Okay, did I misread  
18 something? I read that the pebbles are really  
19 cruising.

20 (Simultaneous speaking.)

21 MEMBER PETTI: Yes. We'll put that on the  
22 list when we get into the closed session.

23 DR. ZWEIBAUM: Sure.

24 MEMBER PETTI: Maybe I misread it, but I  
25 thought that the fluids were a lot more than, say, a

1 gas reactor pebble bed.

2 DR. ZWEIBAUM: Yeah, we can talk about  
3 that in the closed session.

4 MEMBER PETTI: Okay.

5 MEMBER KIRCHNER: But for the scaling  
6 purposes, you're just assuming the pebbles are static?

7 DR. ZWEIBAUM: As far as the heat transfer  
8 separate effects tests, that's right.

9 MEMBER REMPE: So, what about the fact  
10 that in the real reactor that there is nuclear heat  
11 coming out of the pebbles, or decay heat, if you're  
12 doing some sort of transient?

13 How do you simulate that, because I didn't  
14 see that in the scaling report.

15 DR. ZWEIBAUM: So that would be the heat  
16 source that we would have to scale, whatever the heat  
17 generation levels are.

18 So, the level of either full power or  
19 decay heat power would come from our neutronic  
20 simulations. Is that --

21 MEMBER REMPE: But you're looking at fluid  
22 flow, and it seems like that would be an effect on the  
23 fluid flow, and so you're separating that out?

24 DR. ZWEIBAUM: No, we are treating the  
25 heat source as a -- well, simulated heat source,

1 obviously, in our scale tests, but scaled from the  
2 heat generation that would happen from nuclear fission  
3 in the core.

4 MEMBER REMPE: So I guess I didn't see how  
5 you're going to heat them in the scale tests, and so  
6 when you get -- you can wait until the closed session,  
7 but I did not see how you were going to introduce that  
8 into the --

9 DR. ZWEIBAUM: Yeah, we can talk --

10 MEMBER REMPE: Whatever you're simulating.

11 DR. ZWEIBAUM: We can talk about it more  
12 in the closed session, but one thing to note is that  
13 this report is really about the methodology, and not  
14 necessarily about the engineering that would allow us  
15 to meet that methodology.

16 But, I'd be happy to talk about it a  
17 little bit more in the closed session.

18 MEMBER PETTI: Yeah, you see members  
19 jumping to the details, right, because this is kind of  
20 theoretical, and so.

21 DR. ZWEIBAUM: Sure. So, this is really  
22 the meat of our validation testing program right now.

23 We are using those scaling methods to  
24 support acceleration of our validation testing road  
25 map.

1           And we talked about the combination of  
2           separate effects tests and integral effects tests all  
3           use reduced scale in terms of size, power,  
4           temperature, surrogate fluids, and surrogate  
5           materials.

6           Both are under development in our Rapid  
7           Lab facility in Alameda that Dr. Blandford talked  
8           about.

9           We already have a number of separate effects  
10          tests that are up and running as of now.

11          For illustration here, you have pictures  
12          of a few of our fluid dynamics tests using room  
13          temperature water and 40 percent geometric scale, as  
14          well as heat transfer tests that use a surrogate heat  
15          transfer oil to 72 degrees Celsius matches the  
16          properties of our FLiBe coolant at 600 C, also at  
17          reduced geometric scale.

18          And coming up towards the end of this year  
19          would be our first integral effects tests facility,  
20          which would be a half height roughly facility scaled  
21          to our primary heat transport system.

22                 MEMBER MARCH-LEUBA: I'm curious. It's  
23          relatively easy to heat up a rod because you can  
24          connect from the top and the bottom.

25                 How do you heat up your balls?

1 DR. ZWEIBAUM: I guess we can talk about  
2 that in the closed session.

3 (Simultaneous speaking.)

4 MEMBER REMPE: And keep them heated, is  
5 the question too.

6 DR. ZWEIBAUM: Huh?

7 MEMBER REMPE: And keep them heated. You  
8 could start with them hot, but yeah.

9 MEMBER MARCH-LEUBA: Okay, we'll talk in  
10 the closed session.

11 DR. ZWEIBAUM: Yes.

12 MEMBER MARCH-LEUBA: Obviously, you had  
13 some patents in that? You should.

14 DR. ZWEIBAUM: And so this combination of  
15 the separate effects test and integral effects test is  
16 really the basis for validation of our evaluation  
17 models, which would lead us to the KP-1 demonstration  
18 and reactor full scale FLiBe coolant, and TRISO fuel  
19 pebbles.

20 Next, please. So first, about IETs.

21 At a high level, the scaling methodology  
22 we use, this is the analysis for using the surrogate  
23 fluid, mainly heat transfer oil, for the KP-FHR  
24 primary heat transport system.

25 The classes of licensing basis events that



1 are illustrated in the topical report include steady-  
2 state normal operation, which is forced circulation  
3 operation, as well as transients that involve the loss  
4 of force flow in a transition to natural circulation.

5 This would include pump trips, losses of  
6 heat sink, station blackouts, and so on.

7 The methodology in the report is  
8 illustrated using an idealized version of our primary  
9 heat transport system and scaled IET.

10 You have this very simplified schematic  
11 here that shows this configuration with the pebble bed  
12 reactor core, primary salt pump, hot leg piping going  
13 into an intermediate heat exchanger, then cold leg  
14 returning to the core.

15 Although this is a simplified model that's  
16 illustrated in the methodology, the methodology can be  
17 extrapolated to a number of different branches in  
18 several loops, as would be the case in the current KP-  
19 FHR design.

20 Next.

21 Also in the report is our scaling  
22 methodology for a number of separate effects tests.

23 These are used to develop closure models  
24 and correlations for phenomena that happen at the  
25 module or component level, and the topical report

1 covers generic fluid dynamics and heat transfer  
2 phenomena, as well as some KP-FHR design specific  
3 phenomena.

4 And those six types of phenomena are  
5 examples of what's covered in the report, namely  
6 forced circulation fluid dynamics, convective heat  
7 transfer, conjugate heat transfer with solid  
8 structures, twisted elliptical tube experiments,  
9 pebble bed granular flow dynamics experiments, and  
10 forced median impact bed heat transfer experiments  
11 that are relevant to our core.

12 MEMBER PETTI: Can I ask a question? You  
13 know, there's lots of literature out there for packed  
14 beds and correlations.

15 I mean, do you think that they'll end up  
16 working and you'll spend just a lot of time, you know,  
17 providing some data to show that for your situation,  
18 that they'll be one close from the chemical  
19 engineering industry?

20 DR. ZWEIBAUM: So the existing experience  
21 with those packed bed correlations don't directly  
22 apply to the ranges we're operating at.

23 Namely, the Prandtl number of our fluid is  
24 much higher than what's being reported in the  
25 literature for both gas-cooled reactors, obviously,

1 and also outside of the nuclear industry for other  
2 experiments.

3 So this is the reason why we need to run  
4 our own tests --

5 (Simultaneous speaking.)

6 MEMBER PETTI: Okay, so it's for the  
7 Prandtl number?

8 DR. ZWEIBAUM: To get out of that.

9 MEMBER PETTI: Great, thanks.

10 DR. CORRADINI: So, neither your first  
11 bullet in forced circulation fluid dynamics, nor your  
12 fifth bullet on, I'll call it pebble bed movement,  
13 have historical or past literature basis?

14 Do you guys have to do it from scratch?  
15 That's what I was gathering from Dave's question that  
16 you can rely on past --

17 (Simultaneous speaking.)

18 DR. ZWEIBAUM: So yeah, a lot of this is  
19 not breaking new ground. Obviously, for circulation  
20 fluid dynamics, it's a pretty well-known topic for  
21 several centuries.

22 The idea was really to compile all of this  
23 in our own methodology to make sure that the staff  
24 agrees that this is indeed the right approach in our  
25 case.

1 DR. CORRADINI: All right, thank you.

2 MEMBER RICCARDELLA: So, I assume that the  
3 primary purpose of these tests and scaling is the  
4 qualified computer codes that you're going to use to  
5 analyze it, right?

6 And then --

7 DR. ZWEIBAUM: Yes, this is the purpose of  
8 the EMDAP process.

9 MEMBER RICCARDELLA: And then if it works  
10 on the test, then presumably it works when you apply  
11 these codes to the reactor, right?

12 DR. ZWEIBAUM: That is right.

13 MEMBER MARCH-LEUBA: And have you  
14 considered the fact that we have so much margin on the  
15 fuel pellets that if you miss your heat risk  
16 coefficient by a factor of two, who cares? You just  
17 raise the temperature of the fuel and keep cranking.

18 DR. ZWEIBAUM: That is very beneficial to  
19 us, obviously, and you'll see in the --

20 MEMBER MARCH-LEUBA: And you probably  
21 would take advantage of that?

22 DR. ZWEIBAUM: Yes, we would be in the --  
23 (Simultaneous speaking.)

24 MEMBER MARCH-LEUBA: Because that would be  
25 a hard sell, a very logical sell, and I will support

1 you in it, but it is going to be a hard sell.

2 Pressure drop, obviously you need to know,  
3 did you want to have amount of circulation, but not  
4 easy to measure. The heat risk coefficient you can  
5 have four or a factor of two and nothing happens.

6 DR. ZWEIBAUM: Okay.

7 MEMBER MARCH-LEUBA: Just put it in there.  
8 It's going to be a hard sell.

9 DR. KRUIZENGA: I'm Alan Kruizennga. I'm  
10 the director of salt chemistry at Kairos Power, and  
11 I'm the primary preparer of the reactor coolant  
12 topical report, and then we'll just go over just a  
13 couple of slides so you have a little bit of an idea  
14 of what we're looking at, and what the purpose of --

15 MEMBER MARCH-LEUBA: Alan, is that  
16 microphone working? Because you don't sound as good  
17 as me.

18 DR. KRUIZENGA: I mean you've got a really  
19 nice voice.

20 (Laughter.)

21 DR. CORRADINI: Move closer.

22 DR. KRUIZENGA: He sounds really good, so  
23 I -- how about now, is that better?

24 DR. CORRADINI: That's much better.

25 DR. KRUIZENGA: Okay, great, excellent.

1 All right, perfect.

2 So, as has been said already this morning,  
3 we're using FLiBe as a coolant for our reactor.

4 There's a few reasons, and they've been  
5 covered a little bit already, but really it's the fact  
6 that it's a coolant that helps provide enhanced safety  
7 properties, it has a high boiling point, it has high  
8 thermal inertia, minimal short-term, long-term  
9 activation products in the salt itself.

10 And it's been optimized over time through  
11 use during the molten salt reactor experiment back in  
12 Oak Ridge.

13 The high density fluid has good heat  
14 capacity, again with that thermal inertia, pace, the  
15 viscosity is comparable to water in a factor of 5, and  
16 it's stable under radiation at high temperatures.

17 And then lastly, from a safety  
18 perspective, it's a good solvent for fission products.  
19 So that's one of the reasons it was viewed as favored.

20 MEMBER BLEY: How about worker safety?

21 DR. KRUIZENGA: That's a great question.

22 MEMBER BLEY: Thank you.

23 DR. KRUIZENGA: I mean I think you're more  
24 referring from a chemical perspective?

25 MEMBER BLEY: Yeah.

1 DR. KRUIZENGA: So certainly, we're aware  
2 of that.

3 That's something -- like, I have  
4 personally, along with many others in the company,  
5 have spent a lot of time trying to work with the right  
6 partners to develop good procedures and practices that  
7 are compliant, and keep our workers safe, so it's  
8 extremely important.

9 DR. CORRADINI: Alan, where is the  
10 industrial experience in the United States in terms of  
11 using beryllium compound fluids?

12 Because that's I think what Dennis is  
13 getting at.

14 MEMBER BLEY: Yeah.

15 DR. SCHULTZ: And developing safety  
16 programs --

17 DR. CORRADINI: And developing safety  
18 programs.

19 DR. SCHULTZ: Related to that.

20 DR. KRUIZENGA: So, as far as chemical  
21 processing -- so we could talk a little bit more in  
22 the closed section, but I'll give you just kind of a  
23 quick snippet.

24 Just even from the extraction, beryllium  
25 ore has to go through a series of aqueous processing

1 to get in a state that it can ultimately be made into  
2 beryllium metal.

3 So there is some precedent, at least in  
4 the chemical manufacturing industry, that beryllium is  
5 in a liquid state and has to be taken precautions  
6 appropriately for that.

7 I don't know if that's helpful, but there  
8 is some precedence, and this isn't at a high  
9 temperature, again, which is different for our  
10 application.

11 MEMBER KIRCHNER: This is in the category  
12 that Jose was mentioning. You know, full disclosure  
13 would say up front that beryllium is a hazard.

14 DR. KRUIZENGA: Beryllium is a chemical  
15 hazard.

16 MEMBER KIRCHNER: Then you're going to have  
17 to take counter measures or whatever to deal with it.

18 DR. KRUIZENGA: Yes.

19 MEMBER KIRCHNER: Because the industry by  
20 and large has shunned working with beryllium. I mean,  
21 other than in a metal form.

22 MEMBER BLEY: Well, even in a metal form.  
23 I mean --

24 MEMBER KIRCHNER: Even in a metal form.

25 MEMBER BLEY: In electronics it was used



1 a lot, but there are a lot of --

2 MEMBER KIRCHNER: I know one business that  
3 used a lot of beryllium.

4 MEMBER BLEY: Sick and dead people around,  
5 in my experience.

6 MEMBER MARCH-LEUBA: And ordinarily it is  
7 actually forbidden to even mention the name.

8 MEMBER PETTI: Does the flowing activate?  
9 I remember --

10 DR. KRUIZENGA: It does, but it's got a  
11 quite short half-life. I think it's less than a minute  
12 or so.

13 MEMBER PETTI: Yeah, so it's like sort of  
14 N16 in a water reactor sort of, right? Okay. So --

15 DR. CORRADINI: What activates it?

16 MEMBER PETTI: Flowing 19 I think, right?

17 DR. KRUIZENGA: I think so. I think  
18 that's right.

19 DR. CORRADINI: And it's about a minute  
20 and a half long?

21 DR. KRUIZENGA: Yeah, about a minute.

22 MEMBER RICCARDELLA: Okay. Would you  
23 briefly describe the process how it achieves a  
24 negative temperature coefficient?

25 DR. KRUIZENGA: Yeah, so the density

1 decreases as it goes up in temperature.

2 MEMBER MARCH-LEUBA: Yeah so, say again?

3 DR. KRUIZENGA: As you go up in  
4 temperature, the change in density reduces the  
5 moderation.

6 MEMBER RICCARDELLA: And it is a moderator?  
7 I thought the graphite was the moderator, no?

8 DR. KRUIZENGA: The graphite is the  
9 primary moderator.

10 MEMBER KIRCHNER: The graphite is the  
11 primary moderator.

12 DR. KRUIZENGA: Beryllium does have some  
13 moderation capability, though.

14 (Simultaneous speaking.)

15 MEMBER KIRCHNER: It becomes a second  
16 order effect on reactivity transients and such.

17 MEMBER RICCARDELLA: Okay.

18 DR. CORRADINI: Go ahead.

19 MEMBER MARCH-LEUBA: You can hear from the  
20 questions that everybody's going to complain about  
21 beryllium, so can you give us a short 30 second answer  
22 unclassified why you chose beryllium?

23 Is it for neutron efficiency, or is it for  
24 chemical viscosity, transparency? Is there a  
25 particular reason that you didn't use regular salt?

1 And just put it to rest so we keep asking  
2 you --

3 DR. KRUIZENGA: Yeah. So I have more  
4 information in the closed session, but --

5 MEMBER MARCH-LEUBA: Wait.

6 DR. KRUIZENGA: Okay, great.

7 MEMBER BLEY: Well, let me ask one other.

8 DR. KRUIZENGA: Sure.

9 MEMBER BLEY: I don't know the chemistry,  
10 but if you get water near the fluoride salt, can you  
11 get HF coming out?

12 DR. KRUIZENGA: You can get some trace  
13 amounts of HF.

14 MEMBER BLEY: Only trace amounts?

15 DR. KRUIZENGA: We haven't fully  
16 quantified --

17 (Simultaneous speaking.)

18 MEMBER BLEY: Now you keep the water away  
19 from it?

20 DR. KRUIZENGA: We do keep the water away  
21 from it, and we're aware of it, and that's part of our  
22 ongoing work.

23 MEMBER BLEY: Because that's pretty  
24 dangerous stuff too.

25 MEMBER MARCH-LEUBA: What's your

1 intermediate salt?

2 DR. KRUIZENGA: It's a nitrate salt, it's  
3 a solar salt.

4 (Simultaneous speaking.)

5 DR. KRUIZENGA: No.

6 MEMBER REMPE: You almost look like you're  
7 going to go to the next slide, and I know you didn't  
8 get to go through your bullets because we interrupted  
9 you, but before you leave this slide, I was interested  
10 in what data support the fission product retention  
11 claims, and how much it was.

12 And then I'm thinking back about with the  
13 MHTGR and NPR days, and it's not just fission products  
14 one might be wanting to be concerned about, but also  
15 if you have say stainless steel somewhere in your  
16 system, the chromium can migrate through it and attack  
17 the silicon carbide and the TRISO particles.

18 Have you considered those effects in your  
19 testing program?

20 DR. KRUIZENGA: We have, and we've  
21 considered it. We're aware of it.

22 MEMBER REMPE: Okay.

23 DR. KRUIZENGA: So it's come up during  
24 some of our like, internal PIRT processes. So, it's  
25 been identified, but we are aware of it.

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1                   MEMBER REMPE:    Okay, so you'll need to  
2                   have something to add extra protection on that.

3                   MEMBER PETTI:    I'd like to come back to  
4                   this in the closed session to talk about some numbers  
5                   and things.

6                   MEMBER BLEY:    You just caught my ear with  
7                   something, your internal PIRT processes. Do you have  
8                   an external PIRT process too?

9                   Have you brought, you know, outside folks  
10                  in to help you --

11                  DR. KRUIZENGA:   Well, we've --

12                  MEMBER BLEY:    Think about key issues.

13                  DR. KRUIZENGA:   So, can we defer that to  
14                  the closed session?

15                  MEMBER BLEY:    Sure, absolutely.

16                  DR. KRUIZENGA:   We can give a lot more.  
17                  Then we can give some more information about it.

18                  So the purpose really of this coolant  
19                  report is to establish a common basis specifically for  
20                  the chemical specification we have for the fluid, and  
21                  then the thermophysical properties that we're going to  
22                  use as part of the safety analysis.

23                  So, the scope again is the thermophysical  
24                  properties of the fluid, the chemical specification,  
25                  so that we're on a common basis for understanding as

1 we go through some of the future licensing work, what  
2 the properties are.

3 DR. CORRADINI: And as well as the  
4 allowable span that you can tolerate before things  
5 become unacceptable?

6 DR. KRUIZENGA: Right. Yeah, there are  
7 bars, so --

8 MEMBER BLEY: All of you have emphasized  
9 it earlier, and in your reports, you kind of treat the  
10 salt as an extra barrier against fission product  
11 release.

12 Are there any nuclear chemical affects  
13 that can change that ability to hang on to the fission  
14 products?

15 DR. KRUIZENGA: I think this would be  
16 maybe a good one to talk in the closed session, so.

17 MEMBER BLEY: Perfect.

18 MEMBER PETTI: So Alan, in terms of the  
19 specification, do you see this as an initial  
20 specification, and that it might evolve over time?

21 As you do some experiments, you might add  
22 -- I mean, there were just some things that weren't in  
23 there as limits that I could see, potentially in the  
24 future as you do testing and you become more  
25 knowledgeable, you might add more to the

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1 specification?

2 DR. KRUIZENGA: I think that's our basis.  
3 We just need a place to start, and I think Joy kind of  
4 brought it up.

5 We're learning new things, so we expect  
6 that we'll manipulate as we have to.

7 MEMBER PETTI: Right.

8 DR. KRUIZENGA: That is it.

9 PARTICIPANT: Never show a slide like that.

10 (Laughter.)

11 DR. CORRADINI: Or you can just defer the  
12 questions to the closed session.

13 MEMBER BLEY: I guess it'll come up in the  
14 fuel qualification topical, but you're using a  
15 different TRISO or some different properties in your  
16 TRISO fuel than the stuff my colleague over here did  
17 years of testing on.

18 Will that be the time to talk about what  
19 that matters to us, and to you?

20 DR. KRUIZENGA: Yes.

21 MEMBER BLEY: Okay.

22 MEMBER PETTI: Okay. Well, I guess at  
23 this point in the agenda, we're a little ahead of  
24 schedule.

25 DR. CORRADINI: Weidong is checking --

1 MEMBER PETTI: Oh. We're a few minutes  
2 ahead of schedule, but it's time for public comments.  
3 Do we have anybody in the audience to make a comment?

4 DR. CORRADINI: Hold on.

5 MEMBER PETTI: And I assume the phone  
6 line's on?

7 DR. CORRADINI: Weidong is checking out.

8 MEMBER PETTI: Okay, Weidong's checking  
9 out.

10 DR. CORRADINI: You may want to just see  
11 if anybody's out there.

12 MEMBER PETTI: Yes. Anybody on the open  
13 line?

14 DR. CORRADINI: We're right on time.

15 PARTICIPANT: Yes, sir.

16 MEMBER PETTI: Any questions?

17 PARTICIPANT: Comments.

18 MEMBER PETTI: Comments? Sorry.

19 PARTICIPANT: No questions at this time.  
20 Thank you.

21 MEMBER PETTI: Thank you. We can take a  
22 small break. We'll be back here at 9:15. Okay?  
23 Great.

24 PARTICIPANT: No.

25 MEMBER MARCH-LEUBA: Those of us that



1 don't speak Greek fluently, what does Kairos mean? I  
2 do because I checked it out.

3 PARTICIPANT: Dave, you don't have to go  
4 to 9:15, you can accelerate it.

5 MEMBER PETTI: Oh okay. We'll just take  
6 five minutes, and then we'll go into closed session.

7 DR. BLANDFORD: Do you want me to answer  
8 his --

9 MEMBER PETTI: Yes, please go ahead and  
10 answer.

11 DR. BLANDFORD: Sure, so Kairos is an  
12 Ancient Greek term for the right or opportune moment,  
13 and so it ties into our business case about where we  
14 see the market going, so.

15 I've heard it can be pronounced Kairos,  
16 and true Greeks will say it that way, so.

17 DR. CORRADINI: Luckily you have no true  
18 Greeks on the group.

19 DR. BLANDFORD: Not right now, no.

20 PARTICIPANT: You have one at home.

21 DR. BLANDFORD: Yeah.

22 (Off-microphone comments.)

23 MEMBER PETTI: Yeah, a five minute break.


24 (Whereupon, the above-entitled matter went  
25 off the record at 8:58 a.m.)



# Kairos Power

## OVERVIEW OF KAIROS POWER, SCALING METHODOLOGY AND REACTOR COOLANT TOPICAL REPORTS

ACRS SUBCOMMITTEE MEETING, FEBRUARY 21, 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

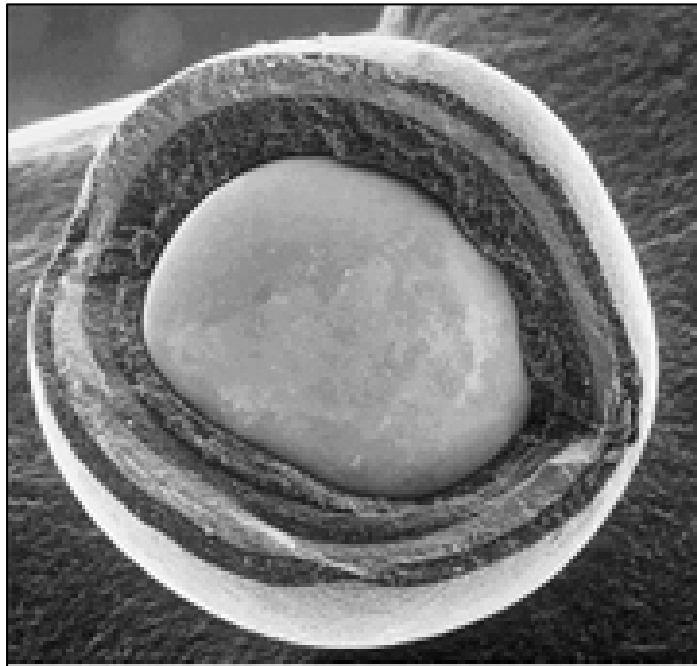
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- Overview of Kairos Power and KP-FHR Design and Development
- Scaling Methodology Topical Report
- Reactor Coolant Topical Report

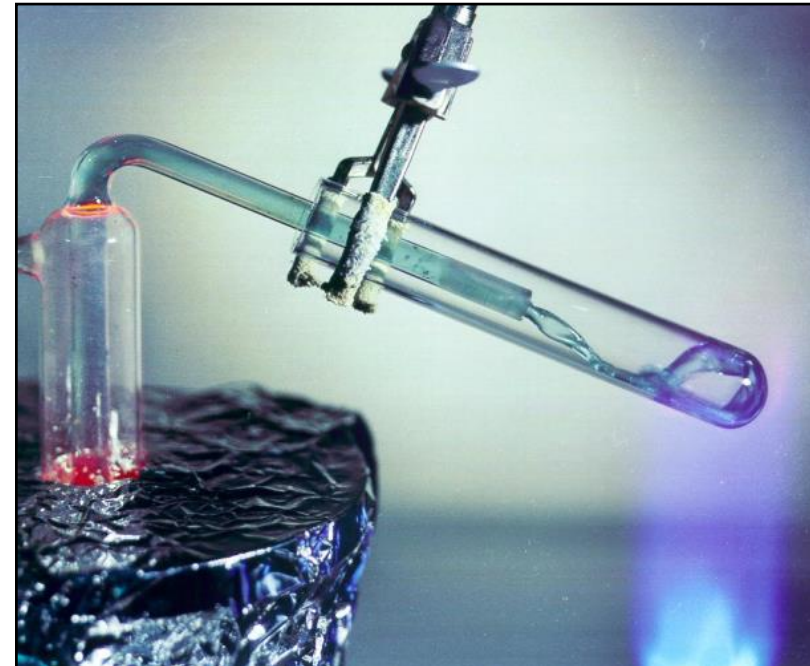
# Fluoride Salt-Cooled High-Temperature Reactor (FHR) Technology Basis

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Coated Particle Fuel  
**TRISO**



Liquid Fluoride Salt Coolant  
**Flibe (2LiF-BeF<sub>2</sub>)**





# Overview of Kairos Power

---

- Privately funded nuclear energy engineering and design company focused on the **commercialization** of the fluoride salt-cooled high temperature reactor (FHR)
  - Founded in 2016
  - Based in San Francisco Bay Area
  - Builds on UC Berkeley Concept Development and R&D
  - ~120 full-time employees (**and growing**) selected from diverse industries
- Development schedule driven by US demonstration by 2030 (**or earlier**) and rapid deployment ramp in 2030s
- Leverages technology from past advanced reactor designs, coupled together to provide a competitive design



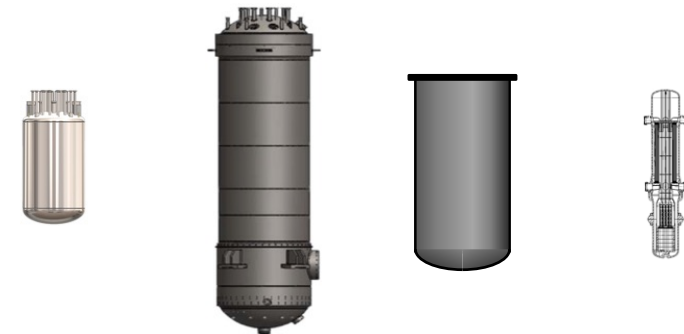
Kairos Power Headquarters  
Alameda, CA

# Design and Development Overview

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# KP-FHR Features: Safe, Compact, Economical

- **KP-FHR Inherent Safety and Economic Potential are Uniquely Aligned to Replace U.S. Natural Gas Capacity**
- **Robust Inherent Safety**
  - Large fuel temperature margins
  - Fission products retained by fuel and primary coolant
  - Low-pressure system
  - Passive decay heat removal
- **Lower Capital Costs**
  - Reduced reliance on high-cost, nuclear-grade components and structures through KP-FHR intrinsic safety and plant architecture
  - Leverage conventional materials, existing industrial equipment, and conventional fabrication and construction methods
- **Improved Operating Economics**
  - High efficiency
  - Flexible deployment of low-cost nuclear heat

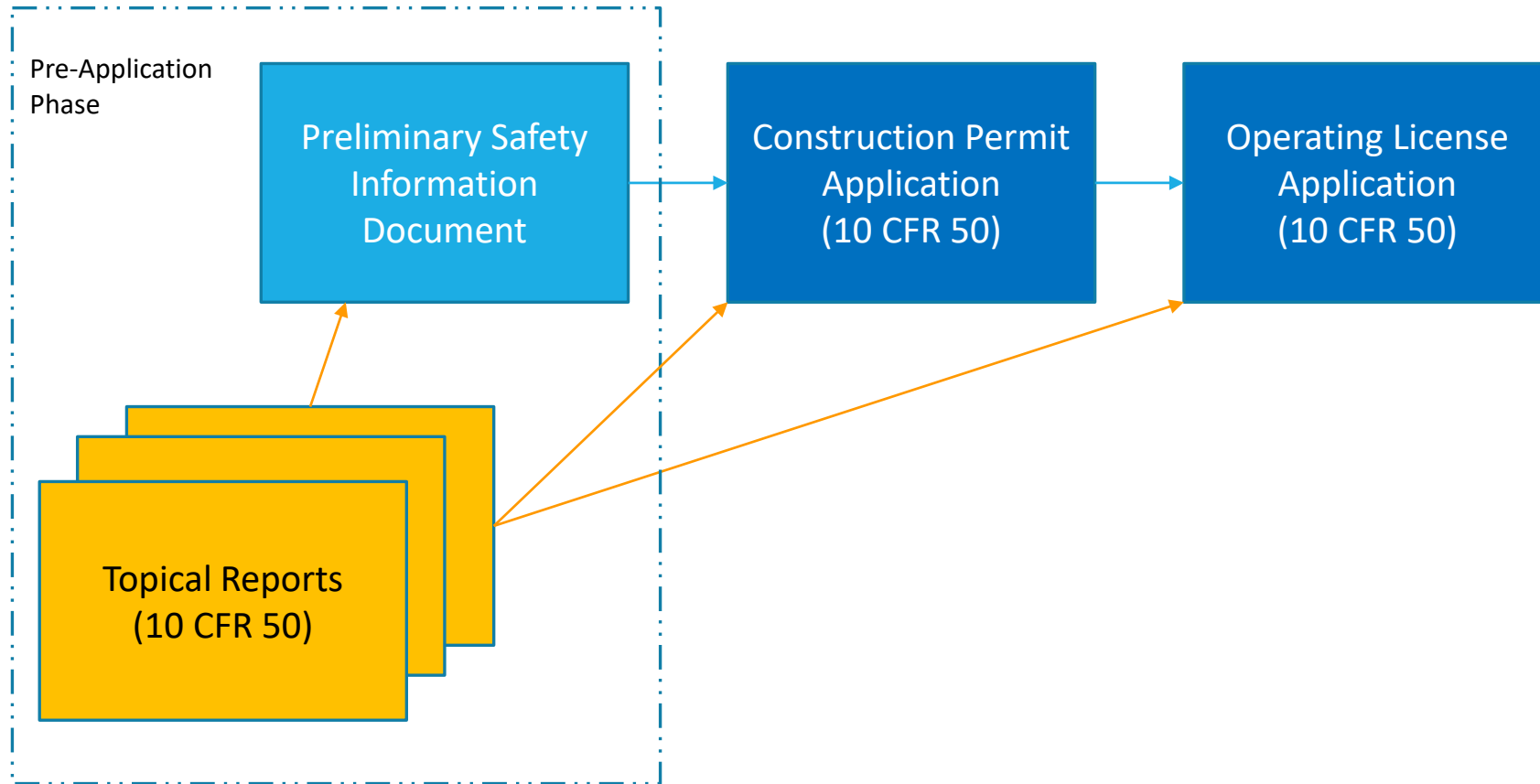


KP-1	HTR-PM	ARC-100	NuScale
Flibe	Helium	Sodium	Water
320 MW <sub>th</sub>	250 MW <sub>th</sub>	260 MW <sub>th</sub>	200 MW <sub>th</sub>
140 Mw <sub>e</sub>	100 MW <sub>e</sub>	100 MW <sub>e</sub>	60 MW <sub>e</sub>

*\* Reactor vessels drawn to approximate scale.*



# Baseline Licensing Strategy for KP-1



# Licensing Overview

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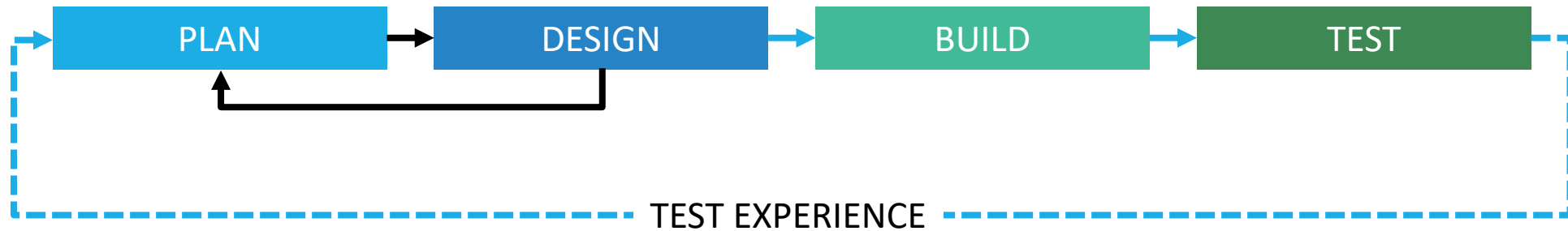
- Kairos Power intends to leverage the intrinsic safety characteristics of the KP-FHR fuel and coolant that provides uniquely large safety margins under accident conditions to achieve three high level goals:
  - Goal 1: Achieve Early Acceptance from NRC of Fundamental KP-FHR Safety Case
  - Goal 2: Minimize Unique Safety-Related Design Requirements for the KP-FHR
  - Goal 3: Retain Flexibility for Design Modifications for Future KP-FHR Iterations

# Testing and Development Overview

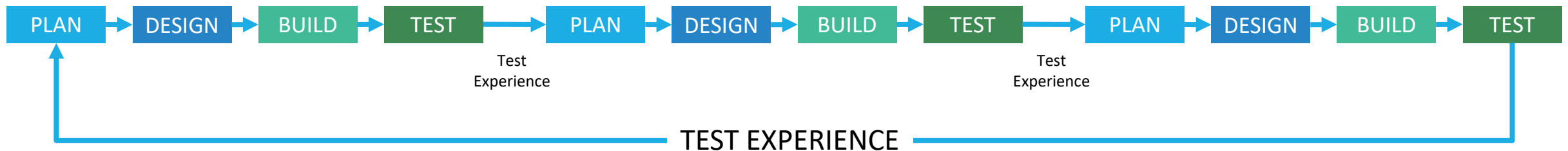
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# Kairos Power Nuclear Development Paradigm Shift

## Conventional Nuclear Development Cycle

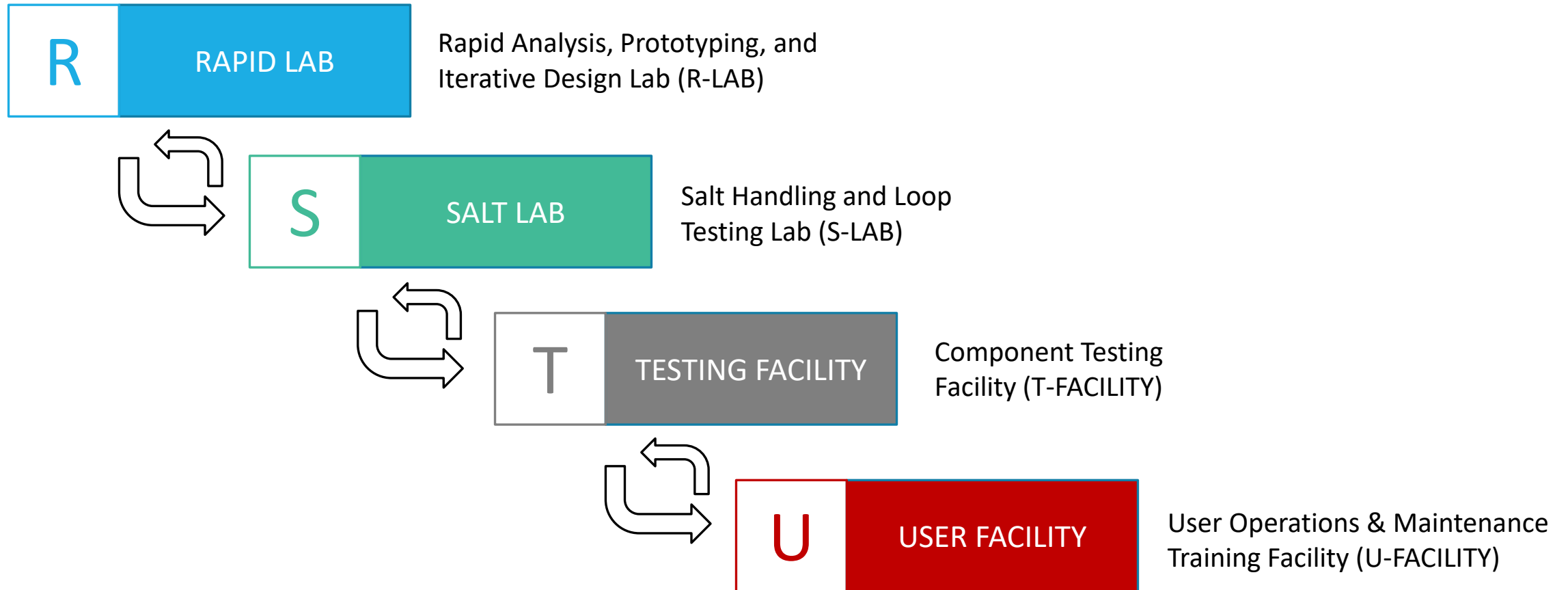


## Kairos Power Accelerated Test Cycles for Innovation and Optimization



# Kairos Power Testing Program - Facilities

Rapid Technology Demonstration Requires **Non-Nuclear** Development and Qualification Facilities



# Scaling Methodology Topical Report

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# Purpose of the Scaling Methodology Topical Report

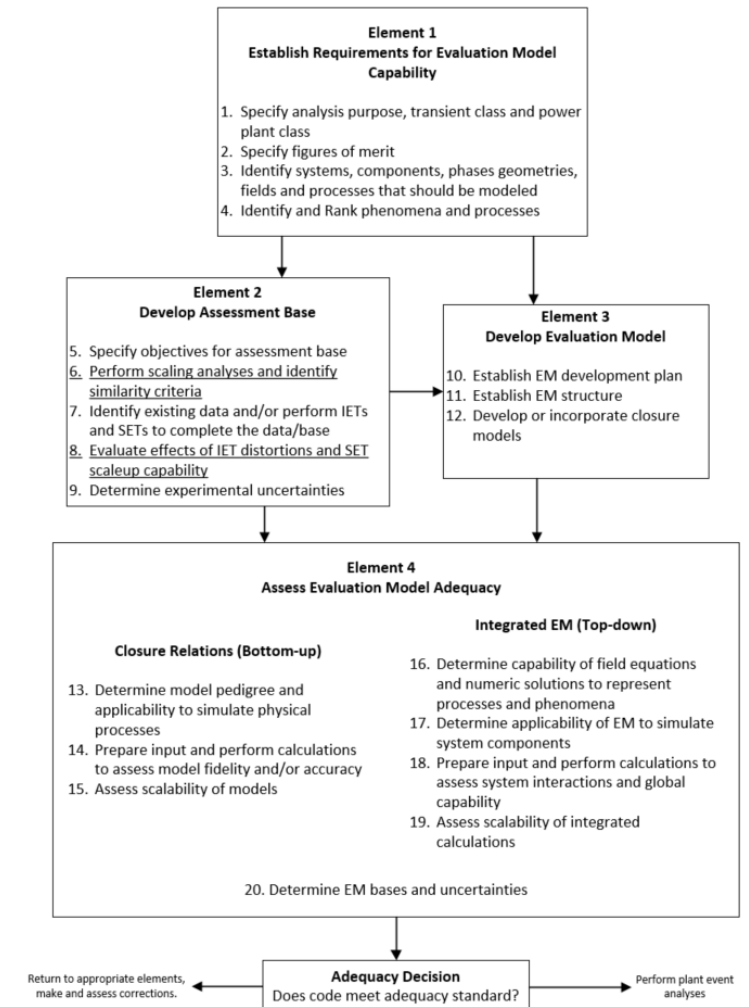
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- The methodology is used to scale integral effects tests (IETs) and separate effects tests (SETs) supporting the KP-FHR evaluation model assessment base
- Surrogate fluids enable direct and comprehensive, local measurements of the phenomena under 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

# Scope of the Scaling Methodology Topical Report

- Based on the Hierarchical Two-Tiered Scaling (H2TS) methodology
  - Generic scaling method previously developed for and approved by the NRC
  - Selected by Kairos Power for scaling of thermal fluids IETs and SETs
  - Includes quantification of distortions
- Addresses scaling of primary heat transport system thermal fluids IETs for the KP-FHR at normal operation conditions (forced flow) and transients involving natural circulation
  - Use of specific class of heat transfer oil as acceptable surrogate fluid for IETs
- Addressed scaling of specific phenomena- and component-level SETs
  - Use of specific class of heat transfer oil or water as acceptable surrogate fluids for SETs

Source: U.S. NRC (2005). *Transient and Accident Analysis Methods. Regulatory Guide 1.203.*





# 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



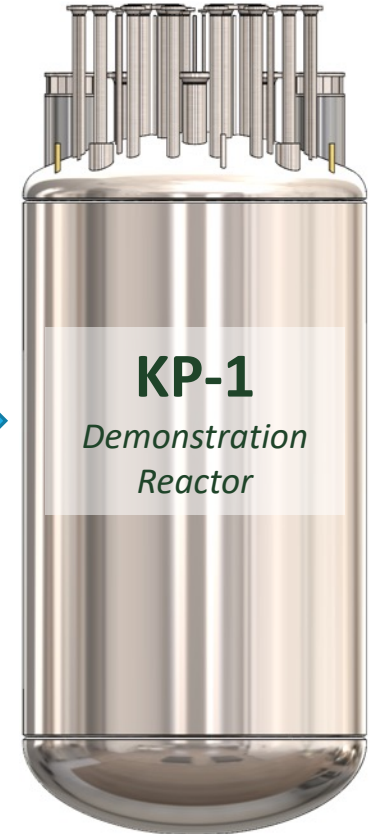
Heat transfer tests  
Heat transfer oil (72°C)  
Reduced geometric scale



## KP-IETs

*R-Lab  
2020  
½ Height*

Validation of KP-FHR  
Evaluation Models

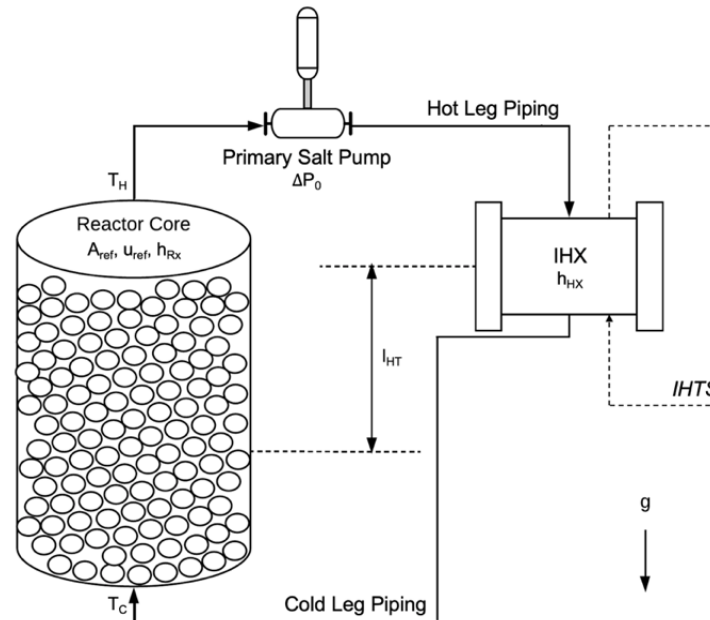


Full scale  
Flibe coolant (550-650°C)  
TRISO fuel pebbles

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

# IET Scaling Methodology

- 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:



# SET Scaling Methodology

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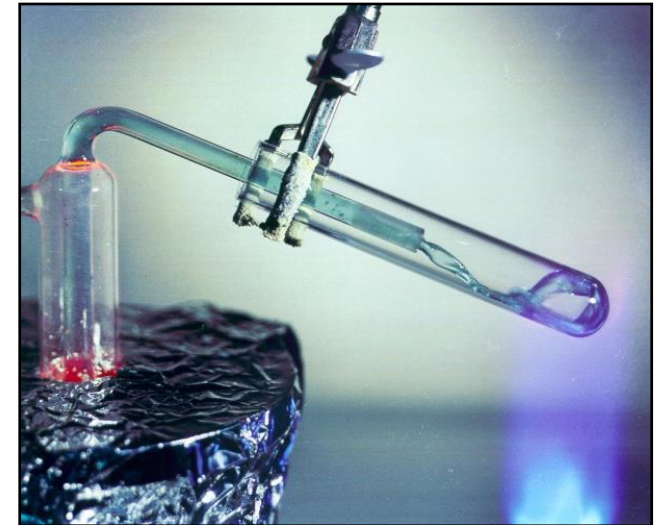
- SETs are used to develop closure models and correlations for module/component-level phenomena
- Topical report covers generic fluid dynamics and heat transfer phenomena, and KP-FHR design specific phenomena:
  - Forced circulation fluid dynamics
  - Convective heat transfer
  - Conjugate heat transfer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

# Reactor Coolant Topical Report

---

# KP-FHR uses Flibe ( $2\text{LiF}:\text{BeF}_2$ ) 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<sub>2</sub> mixture (Flibe)*

# Reactor Coolant Topical Report

---

## Purpose:

- Establish a common basis for safety related analysis between the NRC and Kairos Power
- Kairos Power requested NRC review and approval of Flibe specifications and thermophysical properties.

## Scope and Use:

- Thermophysical properties of Flibe
- Chemical Specification used in KP-FHR
  - Methods and assumptions for setting specification limits
- Specifications and properties for future safety analyses in license applications.





Questions