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UNITED STATES NUCLEAR REGULATORY COMMISSION'S
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

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UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

(ACRS)

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FUTURE PLANT DESIGNS SUBCOMMITTEE

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TUESDAY

FEBRUARY 2, 2021

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The Subcommittee met via Teleconference, at 2:00 p.m. EST, David Petti, Chairman, presiding.

COMMITTEE MEMBERS:

DAVID A. PETTI, Chairman

RONALD G. BALLINGER, Member

CHARLES H. BROWN, JR. Member

VESNA B. DIMITRIJEVIC, Member

WALTER L. KIRCHNER, Member

JOSE MARCH-LEUBA, Member

JOY L. REMPE, Member

MATTHEW W. SUNSERI, Member

ACRS CONSULTANTS:

MICHAEL CORRADINI

STEPHEN SCHULTZ

DESIGNATED FEDERAL OFFICIAL:

DEREK WIDMAYER

C-O-N-T-E-N-T-S

P R O C E E D I N G S

(2:00 p.m.)

CHAIRMAN PETTI: Good afternoon. The meeting will now come to order. This is a meeting of the Advisory Committee on Reactor Safeguards Subcommittee on Future Plant Designs.

I am David Petti, a Member of the Subcommittee and I'm chairing this meeting at the request of the Subcommittee Chairman, Dennis Bley. ACRS Members in attendance are Charles Brown; Jose March-Leuba; Walt Kirchner; Mike Corradini, consultant; Joy Rempe; Ron Ballinger; Matt Sunseri and Vesna Dimitrijevic.

Derek Widmayer of the ACRS staff is the designated federal official for this meeting and Kent Howard of the ACRS staff is the backup. The purpose of today's meeting is to discuss the draft staff White Paper entitled Fuel Qualification for Advanced Reactors.

The Subcommittee will gather information, analyze relevant issues and facts and formulate proposed positions and actions as appropriate. The staff's current plan is to evolve this report into a NUREG document and publish it for public comment.

The draft final NUREG with public comments addressed will be presented to the ACRS full committee, which is currently scheduled for the September meeting.

The ACRS was established by statute and is governed by the Federal Advisory Committee Act, FACA. Therefore, the Committee can only speak through its published letter reports.

We hold meetings to gather information and perform preparatory work that will support our deliberations at a full committee meeting. The rules for participation in all ACRS meetings, including today's, were announced in the Federal Register on June 13, 2019.

The ACRS section of the U.S. NRC public website provides our charter, bylaws, agendas, letter reports and full transcripts of all full and Subcommittee meetings, including slide presentations.

The meeting notice and agenda for this meeting were posted on that website. As stated in the Federal Register notice and in the public meeting notice posted to the website, members of the public who desire to provide written or oral input to the Subcommittee may do so and should contact the designated federal official five days prior to the meeting as practicable.

Today's meeting is open to public attendance and we have received no written statements or requests to make an oral statement. We have also set aside ten minutes in the agenda for spontaneous comments from members of the public attending or listening to our meetings.

Due to the COVID pandemic, today's meeting is held -- being held over Microsoft Teams for ACRS and NRC staff attendees. There is also a telephone bridge line allowing participation of the public over the phone.

A transcript of today's meeting is being kept. Therefore, we request that meeting participants on the bridge line identify themselves when they are asked to speak and to speak with sufficient clarity and volume so that they can be readily heard.

At this time I ask that attendees on Teams and on the bridge line keep their devices on mute to minimize disruptions and only unmute when speaking. We'll now proceed with the meeting and I call on Michelle Hayes, Chief of the Advanced Reactor Technical Branch, NRR to make introductory remarks.

MS. HAYES: Thank you. So, I'm Michelle Hayes. I'm excited about today's meeting on the Fuel Qualification for Advanced Reactors because I'm a big fan of this White Paper.

It's the first step to closing one of the gaps in our advanced reactor guidance and the document itself embodies our vision for what advanced reactor guidance should be.

It includes innovative top down methodology with a well-defined nexus to safety, it's technology neutral, it clearly identifies NRC expectations, and incorporates feedback from internal, external and international stakeholders.

We're looking forward to getting ACRS' feedback today. Dr. Tim Drzewiecki has been a driving force behind this paper and he'll be giving today's presentation. So, Tim, take it away.

MR. DRZEWIECKI: Thanks, Michelle. Okay, so, yes. So again, yes, this presentation is based on the current draft of the White Paper and will be converted into a NUREG as was stated.

So, if I could have the next slide, please. Okay, so as far as -- well, I'll talk about -- first I'll go into, you know, what has happened in the past to kind of bring us up to this point, how we started this work and what kind of drove some of the timeline to get it done, when it was done as well as I'll highlight -- there is a lot of activity also going on in the area of fuel qualification besides this.

And I'm going to highlight some of the stuff that we're doing there. Then I'll go into -- try and give a high level view of what this paper is in terms of its scope, how we came up with the definition of what fuel qualification is, talk about what I mean by an assessment framework, which is a top down approach. Then I'll walk through the framework itself and then just kind of highlight what our next steps are.

Can I have the next slide, please? This is trying to give, you know, some of the landscape. And I'm going to work from left to the right. Starting off with advanced reactor stakeholders.

Going back a couple years, you know, we knew that there was going to be some work coming in the door that was going to be, you know, having staff look at things, you know, new fuel types or concepts or things that were not like light-water reactor fuel that we had guidance for.

And so, we weren't sure how we would do some of these reviews. And so, we tried to give a, you know, a leg up on that and began thinking about that.

Also, we are involved in NEA, Nuclear Energy Agency. There is a working group there that's a working group on the safety of advanced reactors where we have lots of foreign regulators.

They saw similar issues and we thought that this was a topic that we could work on and we began working on a paper through that working group.

So, this draft White Paper that you see here, it's got a sister paper and it's actually gone up and it's been approved by CNRA and that should be published pretty soon.

Something else that we've seen on the horizon is this concept of accelerated fuel qualification. I'll be referring to it as AFQ several times in this presentation.

I highlighted on the slide use of advanced mod-sim. I should also state that it also includes things like, you know, modern or more recent test techniques, things like Fission Accelerated Steady-state Testing meaning fuel and things like that, things to speed up some of the test process.

So, it's not just simulation. But it does rely a lot on simulation. And I'll have a slide on this actually later.

But this is a theme which we wanted to

have incorporated into this paper so that we, you know, knew how to think about it. And then on the right this is the act, Nuclear Energy Innovation and Modernization Act.

And this gave us a schedule and was really a foreseen function for the schedule really when we did what we did. Next slide, please.

Okay, so I just kind of want to lay some of the framework here in terms of what are the rules like, you know, where does staff have to make a finding when we do a fuel review?

And the one point that I want to make is there is not one specific rule or there is not really a rule which is specific to fuel qualification. The rules are for the facility itself.

So, if you go through this paper it says, you know, it can meet, you know, this regulation in part and we would use a lab. But the ones that I want to hit on here are design limits for normal operation, anticipated operational occurrences. That's driven by GDC 10 or Advanced Reactor Design Criteria 10. It's in both of them.

We have established criteria relief for, you know, for accident consequences. So, I have the list of radiological consequences there that's 10 CFR

5034(a)(1) and then the other one is Part 52. But there is also things to make sure that you can maintain a coolable geometry. And that's coming from, you know, GDC 27. It's also highlighted in ARDC 26 and then as well at ARDC 35.

Plants of course need to be designed to protect against natural phenomena. The one that affects fuel is really seismic. And so, we call it GDC, ARDC 2 there.

I do want to highlight all these rules. They're also consistent with what you would find in Safety Standard Review Plan, like in 4.2.

And then the one on the bottom that I want to highlight there that's on data. And it's the requirements to have sufficient evidence to show that, you know, a new or novel approach, you know, because you have evidence for that, that you have data to support things, you know, like urinalysis tools and that's 10 CFR 5043(e).

Next slide, please. Okay. So, there is some guidance out there. First, I want to highlight Standard Review Plan, NUREG 0800, Section 4.2. That's the one that really goes into the fuel design.

There's, obviously Chapter 4 is the whole core. But 4.2 is the one that's most relevant to this topic. And what's in that section, it really goes through and has a reviewer look at all the known fuel failure and degradation phenomena.

You make findings on those and ensure that you have limits there. Now of course, if you're looking at a design that we don't, you know, know what those are so we have to write it from a more generic perspective.

I also want to highlight the standard review plan. It assumes something about the safety case that the fuel plays in the overall safety of the plant. It's kind of, it's not stated explicitly but it's kind of baked in there.

This next item, ATF interim staff guidance, this was some guidance that was issued to staff to kind of, it would augment SRP 4.2 to help a reviewer who was looking at a chromium coated fuel design.

And that was developed by having a PIRT panel together to come along and try to go through and identify failure mechanisms that a reviewer can check for.

This one on the bottom looking at, this is looking at the Licensing Modernization Project and our focus on risk. And when you use that you need to know something, you know, about your source term.

And so, this is just to focus on there, try to incorporate some of this into what we're doing here. Next slide.

MEMBER REMPE: Tim?

MR. DRZEWIECKI: Yes.

MEMBER REMPE: This is Joy. And this comment isn't really directed at any one of your slides. I just couldn't figure out a good place to bring it up.

But when I was reviewing the White Paper, it talks about the three key safety functions. We always have seen in the prior and existing regulatory guidance documents and regulations control heat generation, control heat removal and control radionuclide release.

And a few weeks ago when we listened to Bill Reckley about their ongoing efforts to do Part 53, he had kind of reorganized the safety functions and said the big one is controlled radionuclide release.

And then when advanced reactor designers come in they're going to have to decide what the subsidiary safety functions or critical functions are and chemical reactions, controlled chemical reactions was one they often mentioned in their discussion.

And I'm kind of wondering about that philosophy and maybe that it should be considered in this White Paper because I didn't see chemical reactions in the White Paper anywhere.

And it is something that may become more important with the advanced reactors. And so, what are your thoughts about something like that and how you could accommodate it in this White Paper?

MR. DRZEWIECKI: Well, okay, my first reaction would be that you would have to understand that that is, you know, something which is important to the safety case of a fuel design.

And I do think that would be, you know, something that could be identified as a failure mechanism for fuel and that maybe you would capture that in your evaluation model.

So, it's not quite clear to me -- so, okay I will say that that aspect was not necessarily on my mind when this was written. But I don't think that that phenomena would be excluded, you know, a priori.

We tried to write it from a standpoint of like any kind of failure mechanism. Now, in terms of seeing it as a safety function, yes. I mean, we started off from our rules.

And our rules, I can't really find it in there. But, yes, I could see the head, yes. I have to think about it.

MS. CUBBAGE: Maybe just to help out Tim, I think, Joy, you raise a great point that -- this is Amy Cubbage, NRC staff -- that as things evolve with Part 53, we'll need to be mindful of that and you raise an excellent question.

Tim was developing this based on our current regulations to support near term applicants and then ultimately we do have that need as well to have regulatory guidance to support Part 53. So, we'll take that back.

You know, with regards to chemical attack on the fuel, as Tim was saying, that would be considered as one of the potential degradation mechanisms that would need to be contemplated in a fuel qualification program.

As far as a fundamental safety function (audio interference) to take that back.

MEMBER REMPE: Okay. Yes, just that's one of the things that happens with ACRS. We see a lot of different people come through so we try and connect the dots and I think it would be good to make sure those dots are connected.

MS. CUBBAGE: Yes, great point. Thank you.

MR. DRZEWIECKI: Thank you, yes, that's good. Thank you. Okay, can I have the next slide, please, unless there is more comments?

All right. So, there is a lot of stuff going on in the area right now of fuel qualification. So, some stuff that is already done and approved, there are two topical reports.

Last year you guys saw the EPRI topical report. That's been reviewed and approved.

As well as there was a topical report that was reviewed and approved that was really looking at quality assurance or things that you would have to do when you're looking at some of the Legacy data or metal fuel specifically. So, this is a report that was done by Argonne and, yes, it was approved.

The NRC is also sponsoring activity in other areas. One I want to highlight here as far as molten salt reactor fuel qualification, we tried to write this framework to be as generic as possible.

But it was written based on our past experience, which was with solid fuel. And so, if you look at, you know, a molten salt fuel, some things may not apply. Some things may be missing.

And so, we're getting help in that area. We're being supported by Oak Ridge on this activity. I believe that we'll be issuing a NUREG later on this.

Source term obviously has an impact here. So, we've got a couple draft papers out or actually, sorry, these are not draft. These are published and they're out there. Next slide, please.

MEMBER REMPE: Tim, this is Joy again.

MR. DRZEWIECKI: Yes.

MEMBER REMPE: And this question may not be fair to ask you because I don't know who from the staff approved the Argonne quality assurance program plan. I am familiar with it and I saw it.

But I guess, is it fair to ask, I was puzzled why the staff in their safety evaluation of it agreed to -- that they have like three ways you can qualify fuel and one of them is a peer review. One of them is corroborative data.

And typically NQA-1 has new test data and Argonne omitted that from the document. And is it just because they will never, ever have any sort of additional data or is it fair to even ask you?

Maybe you weren't the person who reviewed it. But it never came to us and I just was puzzled why that was highlighted in the safety evaluation.

And maybe someone else can answer it if you weren't the person involved.

MR. DRZEWIECKI: It was not. And I don't know if the person is here because that was done by our Quality Assurance Branch.

MS. CUBBAGE: Yes, I can chime in just from a very high level. Tim, this is Amy. That document was aimed at a process to demonstrate quality for legacy data.

MEMBER REMPE: So, it just wasn't applicable because you wouldn't have new data with it. Okay, because I just -- you know, when I was looking at the safety evaluation and I wasn't part of the discussions, it seemed strange.

And that was the only reason I could think of. But thank you. That's good enough. I just was curious. Trying to get a good background here.

MR. DRZEWIECKI: Okay. Next slide, please. Okay, there are some white papers that are being issued by -- this is by, being submitted by TerraPower to look at how they want to qualify fuel.

And so, staff is doing like a preliminary review and giving feedback and comment on these. So, there are going to be a series of these papers.

The first one that, I believe was looking at the fuel rod has been done. And we are expecting some more papers to be submitted this month actually.

There is another effort going on. This is the AFQ effort that's being led by General Atomics. They've had, you know, a lot of comments so far on this paper.

They've been, you know, volunteering comments and have been active at the stakeholder meetings, things like that. And we've been engaged in those meetings too.

We don't have a role in writing anything. But we do attend and observe the meetings and give presentations and things like that.

Then again, WGSAR we did, there is a sister paper to this draft that is being published through WGSAR and that has authors from several regulatory bodies. Next slide, please. Okay, so --

CHAIRMAN PETTI: So, Tim?

MR. DRZEWIECKI: Yes.

CHAIRMAN PETTI: A question. On the international NEA report how broad is the participation internationally? Who is at the table?

MR. DRZEWIECKI: Let me, so I've got a slide on that. But yes, it's Canada, France, Germany, IAEA, Italy, Russia and the UK.

Now, I've got to say, you know, a lot of the writing was done by me. But there was also significant contributors from the UK and from France as well that wrote a lot. But as far as ideas it was reviewed by that whole body.

MS. CUBBAGE: And then, yes, more broadly the group is several countries plus the IAEA and the European Commission. This is Amy Cubbage, Chair of the WGSAR.

CHAIRMAN PETTI: Thanks.

MR. DRZEWIECKI: Yeah and the one thing that paper has that this does not have is we got input from GIF or the Gen IV International Forum. It had gone through and did a, kind of a high level of overview of all the fuel types that are used in Gen IV reactors and what could be some of the challenges at a fuel qualification.

So, it does have that which is a bit longer. Some language is different to reflect, you know, some changes in terminology. For example, what I'll say in this paper as a safe shut down, they refer to it as a safe state there.

Also, there is a little more elaboration on the AFQ stuff in this paper which is really not in the NEA paper. Okay, next slide, please.

Okay. So, this is just there to show, you know, people, you know, what was one of the forcing functions in terms of the schedule to get this done and that, you know, staff was guided in order to come up with some guidance in the area of a fuel qualification.

And so, this draft paper serves to do that. We're going to convert it into something that's more formal. Next please.

Okay. So, these are a couple papers. Obviously, the one on top is going to be familiar to some people in the, on this call. You know, Dr. Petti is one of the authors here.

But this, you know, a 2007 paper that kind of lays out a framework, you know, in qualified fuel. And it lays out what I would say is a test-based approach.

And, you know, it spans a time frame of about 20 years, that are highlighted there, in order to go from the concept all the way to having a qualified fuel for use in a reactor.

Now, some more recent work has been focused on trying to speed that up by using things like advanced modeling and simulation. And that's this 2020 paper here.

The one thing I do want to highlight in both of these is that they both end up in this spot where you're doing integral, say engineering scale tests. The AFQ process to date, and I have slides on this. We're going to back up.

They're not trying to get away from that final step of the design qualification. Next slide, please, unless there are any comments.

Okay. So, yes, going back to the kind of stakeholder input that we had, you know, through WGSAR, you know, members from, you know, Canada, France, Germany, IAEA, Italy, Russia and the UK.

So, there was a lot of writing sessions there. So, that involvement was more formal, had a lot of review there.

Domestic stakeholder input that we got from our stakeholder meetings that we've had. We've gotten comments from the Union of Concerned Scientists, Nuclear Industry Council, Southern Nuclear Company, Kairos, General Atomics, Idaho National Laboratory as well as some members of the public.

And so, we've -- now those have not been formal comments. But they have been stated at those meetings and we try to capture them and incorporate them into the paper.

We do have a group inside of the NRC, what we call a Technical Advisory Group on Fuel, TAG-F. We meet periodically to go over, you know, any kind of fuels issues that are going on across the agency.

Major participants there are from, you know, this office, NRR. Used to be NRO and NRR but now we're all together, so that's why I'm saying -- new, and the op (phonetic) fleet are there. People from RES and NMSS. And they help kind of lay out the framework and, you know, give some input there.

As well as we've gotten, you know, vendor input through the AFQ group. So, I've highlighted that group is being led by General Atomics. But they have a lot of stakeholders that are there as well, people from Westinghouse, Framatome, Lightbridge and the laboratories there as well.

Next slide, please. Okay, so there I was trying to highlight, you know, how we kind of got here. What are the rules, you know? What are the forcing functions as well as who has been involved?

And so, now I'm going to go into the framework a little bit itself, kind of highlight what that is, you know, what's our definition of fuel qualification and things like that. Next slide, please.

Okay. So, we began working on this paper especially with our work at NEA and WGSAR. Some of the early feedback that we got was -- or some of the early input was it was a very broad topic.

We had, you know, people considering things in terms of the area of reactor physics, critical heat flux, you know, how you store frameworks and stuff. And so, we wanted to kind of bring in the scope.

And so, we figured we would need to have a scoping statement and this is what we have in the paper. But really this paper is trying to focus on fuel, life limiting and degradation mechanisms that occur as a result of irradiation.

So, somebody who does fuels all the time or who, you know, this may sound familiar to you but we did want to bring that in. So, it looks more like what you would find in SRP 4.2 type thing.

Next slide, please. Okay, so now I want to hit on this concept of, you know, what I mean by an assessment framework. And so, this is something that we've done before.

It shouldn't be too foreign. But really it's a top down approach. We're starting with the high level goal that can be somewhat, you know, abstract like fuel is qualified.

Break that down into supporting goals that may still be abstract and keep going down until you have goals that you think are pretty objective, that are less subjective.

Now, you know, we didn't get to a point where we got to things that were fully objective. Some level is going to, you know, still require some type of judgment there.

But for the most part, we think we broke it down pretty well. This isn't the first time that we've done this.

Certainly there is guidance out there like Reg Guide 1.203 which is that MDEP process for looking, you know, at transient methods in which, you know, you break it up into all these boxes and all these findings that you make.

But something that's more recent that I was personally involved in was this thing to develop a critical heat flux assessment framework, a critical boiling assessment framework. And so, that was actually led by Josh Kaiser.

But this framework has been used probably six or seven times now. And we saw significant reduction in the review time as well as we thought we had a review that was more comprehensive and transparent and seemed like it was kind of easier to follow all the way.

Even people during our review and concurrent process it just kind of made all that a lot smoother. We saw speeds up on the order of like five I think on that.

Next slide, please. Okay, so now I'm going to bring in the definition of fuel qualification. And what we saw in that, you know, 2007 Journal of Nuclear Materials paper we thought laid it out pretty well.

And that is, you know, a fuel that is qualified is, okay -- I'm sorry, the objective of the fuel qualification is demonstration that a fuel product fabricated in accordance with the specification behaves as assumed or described in fuel safety case. That's the focus of this paper.

It obviously goes on further to talk about, you know, the reliability of the fuel which of course is important. But this paper is based on the safety case.

And with that, you know, you have to clarify what you mean by safety case. And so, if you -- one thing that is I think a good example is if you compare say a TRISO fuel versus, you know, a traditional light-water reactor fuel in which you, you know, have barriers in the fuel itself in TRISO fuel and you could use it to support something like a functional containment approach as opposed to a light-water reactor fuel where you are expected to have a robust containment, you may have a different safety case.

Okay, next slide, please. Okay. So, now these next slides are just going to walk through the framework itself. And so, we'll just start off with the high level goal and then we'll break that down and try to go through most of the branches. We're not going to go through all of them.

We're going to go through most of it. So, again our top level goal is that if you have fuel that is fabricated in accordance with the specification it will perform as described in the applicable licensee safety case.

One note that I do want to highlight here is, you know, I want to bring your attention to a couple of word choices that I think are going to change because they have been flagged as being somewhat problematic. And that's the word high confidence.

And that's used over and over again. So, that's something that, you know, that's going to change in the paper. But I just wanted to highlight that here, bring your attention.

I also want to state as I walk through these things there is a color coding to it. So, if a box is white that means it's going to be broken down more. If it's gray it means that's the terminal goal that you would make a finding on that goal.

MEMBER REMPE: So, Tim, how are you going to change high confidence? Because that as well as the use of conservative were things that did catch my eye.

MR. DRZEWIECKI: Yes. In terms of the term that we'll use it may be something like, you know, reasonable assurance or something like that. We'll probably have to brainstorm more about that to figure out, you know, what's the right term to use.

We may just, you know, leave that just to a statement. So, I'm not quite sure right now. I can't answer that on the spot.

We have to think about what's the proper word choice there. If you have any thoughts that would be --

MEMBER KIRCHNER: Tim, this is Walt Kirchner. Your statement here, the goal is slightly different than your definition in the preceding view graph.

I actually think that this is a better definition and goal than the preceding one because the preceding one says behaves as assumed or describes. Behaves is an interesting word.

But perform is more accurate, I think. I don't want to be splitting hairs on this. But definitions are important. And I think this is a better statement here than the preceding view graph.

So, I'm saying I like it. But it's not exactly the same as the definition in the previous.

MR. DRZEWIECKI: Okay, yes. Thank you for that. Yes, that's a good point. I should make that more clear because, yes, you're right. You know, what's on the previous slide is, you know, a quote and I just kind of copied that.

But the reality is, yes, you're right. It's not a definition. And yes, thank you for that. I'll make that correction.

MEMBER KIRCHNER: Not to dwell on it. But this is a much more definitive statement. It doesn't say anything about assume.

It will. It's like shall. It shall perform as described, you know. So, probably enough said. Thank you.

MR. DRZEWIECKI: Thank you.

CHAIRMAN PETTI: So, Tim, just a comment on these words of high confidence. To me it's a function of the role the fuel plays in the safety case.

You know, we require 95/95 confidence intervals on CHF for instance and LWRs. TRISO fuel has always used 95/95 since some NUREG in the past that GA brought in years ago.

But if you had a system where the fuel didn't have that central a role, I think there might be wiggle room to argue for something more like reasonable assurance, particularly if there is large margins.

So, sometimes the concept of margin needs to somehow be worked in, I think as well. Again, depending on the reactor and the technology associated with it.

MEMBER REMPE: So, I think that would be fine. I just think it used to have a paragraph whether you use reasonable confidence or reasonable assurance or high confidence related to the required, it will be within the, you know, help them meet the required safety margins or something so that a design developer knows they've got -- what is expected from them by the staff.

MR. DRZEWIECKI: Yes. Just so, yes, so where I'm trying to get to is that if you met Goal 1 and you met Goal 2, like if you, you know, if you were able to make a finding that, you know, that there is a fuel manufacturing specification that controls the key verification parameters and were able to make a finding, you know, that the safety criteria can be satisfied or, you know, whatever word we choose there, you know, that that means the top level goal is met.

And so, then hopefully that will be clear as I roll through this thing. Okay, but you're right. Yes, I'll make it a point.

Okay. Can I have the next slide, please? Okay. So, actually this is one that I would like to get some, you know, some more feedback on.

So, this is in terms of like, you know, basically having a fuel manufacturing specification that can control the key verification parameters. And so, in looking at ones that we've seen so far this is the elements really called out.

And so, you know, key dimensions I think is pretty straight forward. You know, key constituents with allowances for impurities. There is a box on the right that talks about microstructure attributes.

The language in the paper itself, I mean we haven't seen people, you know, describe what that structure is. But normally what's done is they will describe a heat treatment or will have acceptance criteria based on the heat treatment to kind of get to that.

Some comments we have received so far at least, you know, the past couple weeks is this may be too specific and maybe we should use a different term there like end state that would encompass microstructure.

So, that was one thing that I wanted to bring up. The other thing is the fact that we also recognize that the life cycle of a fuel design can be so long such that certain manufacturing, you know, processes can change.

So, it was not our intention to pin people down to a specific manufacturing specification, but to have a sufficient regulatory footprint in order to pin down certain key attributes that we think would affect the performance of the fuel.

CHAIRMAN PETTI: So, Tim, my take on this is that, yes, if you're going to make minor changes to the fabrication process that's one thing. But if you decide to make the fuel in a very different way, let's look at metallic fuel that's cast versus extruded, the database is largely based on irradiations from cast fuel.

Extruded fuel can have a texture. And so, there are some attributes, microstructure to me is okay, that I would think they themselves would want to know that they're getting the same product from the two processes.

There has to be some equivalence. And maybe that is, it's a microstructure or a process, you know, that there is a subsequent heat treatment so that, you know, they look the same.

But microstructure is a holy grail of materials development. I think it needs to be in there when you're talking about the different idea of how to heat this fuel compared to what's been done.

MEMBER KIRCHNER: Dave, could we alert whoever's cell phone or phone number 410-678-1803, would you mute your phone?

MR. WIDMAYER: Hey, Walt.

MEMBER KIRCHNER: Yes.

MR. WIDMAYER: That's the public line.

MEMBER KIRCHNER: What?

MR. WIDMAYER: That's the public line.

MEMBER KIRCHNER: It's getting a lot of interference.

MR. DRZEWIECKI: Okay. I just muted it. I mean, can we mute that line until we get to a portion where we can open it up?

MEMBER KIRCHNER: Yes, Tim, that's fine because it was interfering with your presentation.

MR. DRZEWIECKI: Thank you.

MEMBER KIRCHNER: And I have a comment too on this one, Tim. This is Walt Kirchner.

On microstructure I'm not sure that's the right word, but I know what you're getting at because the actual grain structure like in oxide fuels and other fuel types can have an enormous impact on fission gas release, as an example.

So, it's not enough to just get the first two boxes right. It is important for solid fuel forms to actually control the microstructure because that will have a very important impact on things like fission gas release, swelling, gap closure if it's a clad fuel.

I could go on and on. So, I think it's an important aspect that can't be ignored.

MR. DRZEWIECKI: Thank you. Really good

examples, thank you.

MEMBER BALLINGER: Yes, this is Ron Ballinger. I agree and understand what Walt is talking about.

But we need to be, I think a little bit careful that we don't -- that the specification doesn't get into micromanagement. And that's a fine line.

I understand that for the manufacturing specifications that's tied ultimately to the performance. And you've assessed the performance and decided what manufacturing specification is required to achieve that performance.

But micro -- but making specifications so tight that you don't allow a vendor leeway, maybe that's the wrong word. But I just think we should be a little bit careful not to imply micromanagement.

MEMBER KIRCHNER: Yes. But, Ron, this is Walt. But the thing is here as you well know, no matter the fuel form you've got to, whether it's the composition, the amount of uranium say versus oxide or the heavy metal loading or whatever parameters, it's not micromanagement.

Let them define it. But then they have to be able to stick to it and demonstrate that that microstructure performs under, you know, irradiation and thermal conditions to meet their requirements in terms of the safety case.

MEMBER BALLINGER: I agree. But there is a big difference between an oxide fuel and a metallic fuel with respect to the importance of microstructure.

MR. DRZEWIECKI: Yes. There is language in the paper -- I just want to highlight that there was language in the paper.

For example, you know, I haven't actually seen the evidence myself but I've heard of the fact that, you know, if you have, you know, say like a metal fuel and it's, you know, and it's injection cast that it may not be sensitive to other, you know, yes --

MEMBER BALLINGER: Yes, the Lightbridge fuel, for example that's extruded. But anyway --

MR. DRZEWIECKI: Okay. And so, yes, and so there was language in there that you could justify that, you know. That's not sensitive to that.

And so, we just think that, you know, as a reviewer, you know, just trying to get you to kind of look there to make sure that you could either justify or make a finding there.

So, yes. But, yes, thank you. You know,

great comments. You know, a great conversation. This is similar to the kind of feedback that we get, you know, at our AFQ meetings by the way. I mean it's hard to get it right, I think. And so, you know, feedback here is, you know, very welcome. Next slide, please.

Okay. So, this is going into that goal that was on the right. You know, which of the safety criteria can be satisfied.

And this is really coming from our rules themselves. So, we have a Goal 2.1 which is, you know, which is looking at like the margin to design limits under normal operation including AOOs.

The box in the middle is looking at, you know, an accident source term there making sure that you can demonstrate that you, you know, have a release, you know, which is within limits.

And then the box on the right is looking at the safe shutdown. And just to get the safe shutdown, I don't really break it down necessarily in the main body of the slides.

It is in the back up. But I did want to highlight what we're talking about here is maintaining the coolable geometry and maintaining the ability to insert a reactivity control element.

Next slide, please. Okay, so now starting from that structure I tried to kind of, you know, have that here on the top right and then highlight the fact that I'm in this branch on the left now which is the margin to design limits under normal operations and AOOs.

And again, I have this, you know, color coding here. And so, the box on the left is, you know, define the fuel performance envelope.

And the box on the right is have an evaluation model to, you know, to assess it over that envelope. So, that's -- you know, that's a pretty, that's pretty simple which is really know where you are going to be and have a tool to do an evaluation when you are there.

And so, in terms of defining a fuel performance envelope we do think it's pretty straightforward. But we have some notes there, you know, to say that, you know, it should cover things, you know, like your normal ops.

It should also cover, you know, what kind of DBAs you're going to have and things like that too because it's not only used to support this goal, it's used to support other goals too.

But now I'm going to go into the evaluation model aspects. Next slide, please. Okay, so this is looking at you have acceptable evaluation model.

Two goals here again, they're pretty straightforward, is one that you have appropriate modeling capabilities which is important. But I do want to highlight that, you know, Goal 2 we think is more important. And that is that that tool has been assessed against data.

I also want to make a statement here in terms of what we mean by evaluation model. We're using this as a generic term.

And what I mean by that is, you know, traditionally evaluation model especially for fuel could be a sophisticated code something like a BISON or, you know, a LIFE-METAL or FAST, something like that.

It doesn't have to be. We think that there could be some scenarios where you can have just, you know, see a spreadsheet or just some hand calculations. If you have the margin, maybe that will work. But anyway, next slide, please.

Okay. So, as far as capabilities of the model itself, I do want to highlight that these goals here were largely influenced by some of the work that came out of Sandia, this capability maturity measurement models which kind of breaks down the things that you have to do. You've got to have confidence in the tool. And so we think, as far as these goals, be able to model the geometry. Be able to model the materials in that fuel as well as in its surrounding environment and have the appropriate physics.

Now, physics of course was going to be things like heat transfer and things like that. But I also wanted to highlight that this is kind of where you should be able to have the appropriate models to capture the fuel failure mechanisms.

And to get that to kind of support those findings one thing that would be called out is, it would obviously be -- one thing that we've seen used a lot and which is kind of called out in that MDEP Model or Reg Guide 1.203 is the use of a PIRT panel or an expert panel to help you go through.

I do have a caveat here though that like whatever you do, we expect that the model is going to be assessed by data. And so if there's errors in there, we should be able to quantify what those are.

So, next slide, please. So, model assessment. Assuring that, that you've assessed a model of, I guess appropriate data.

Again, I have this blue box here because we have a separate framework that only looks at data, because that's really one of the big drivers in this whole thing is data that's going to underpin the whole evaluation of this.

But this goal on the right, Goal 2.2, that the evaluation model has demonstrated the ability to predict fuel failure and degradation mechanisms over a test envelope. And so, what does that mean?

Next slide. So, some of these are straightforward. So, to make that finding, have you gone through and tried to quantify error in your model versus how it performs against data? So, that should be a pretty objective check. Is that model, does it actually ban your performance envelope? Is there sparse data regions, and if there are, can you justify them?

And that we have some means to restrict the use of that model within its test envelope or an area where it's not validated. Now, there was language in this paper that tries to argue that there may be scenarios in which you can justify extrapolation outside of your test base.

And this is an area in which we've gotten some input from the AFQ community trying to argue in a way that having a physics based model may make that an easier thing to do versus a purely empirical model.

And so, some of that language is in this paper, trying to highlight some of those things. Okay, next slide.

Okay. So, now I'm just looking at the data itself. What do we expect in terms of the data that's going to be used to assess your model?

One, it should be independent. Now, there was language in this paper as well which highlights the fact that in some areas you may have very limited data. For example, design basis accident testing. You may not have a lot of points where you can go through, train a model and then separate data in order to do the validation.

So, got to have some kind of flexibility there. But in areas -- you should try to make some kind of argument as best you can that data is independent. That you've collected the data over a test envelope that's going to cover your performance envelope. And we do want to highlight some testing that we think they should do there.

This list was actually largely informed by the Journal of -- of a 2007 paper from the Journal of Nuclear Materials, which highlighted steady state medical testing, high power and cooling tests, power ramp testing to cover things like especially if you're going to do something say like load follow with the reactor design, and design basis accident tests.

Then we have these other two goals that we think are, that are broken down further. One is that you measure your data accurately and that the test specimens used in that testing actually represents your actual fuel design. Next slide, please.

MEMBER KIRCHNER: Hold on. The last one bears some, perhaps some conversation, Tim. This is Walt Kirchner.

MR. DRZEWIECKI: Yes.

MEMBER KIRCHNER: Representative, do you mean literally prototypical of the configuration, both dimensions and material composition and microstructure?

MR. DRZEWIECKI: Well, in part. Some of those, okay, so I have a slide. It's two slides away, because this gets broken down more in terms of what that means.

MEMBER KIRCHNER: Okay, I can wait.

MR. DRZEWIECKI: Okay, okay. Yeah, okay. All right, so next slide. This will just be over, okay, yes. So, this is just a small detour.

But it's, okay so in terms of, is your data measured accurately, and if the first goal here is that you have a quality assurance program for that facility or somehow can make that argument. And I do have a note there that we do expect that, if you had issues with, say a malfunctioning or broken instrumentation, that your QA program would take care of that.

I understand that this has happened in the past. And so, but normally, staff appear, you know, at White Flint wouldn't always be aware of that. So this could be a challenging thing.

But anyways, yeah, I just had that note there. You know, the data -- it was collected using established, well understood measurement techniques.

And then the goal on the right that you have some kind of error analysis on your data so that you know if there are sources of uncertainty and things like that, that's been accounted for.

Okay. So, next on test specimens. And, yeah, this I think is a good topic. And so, in terms of the microstructure, I do want to highlight that test specimens are fabricated consistent with the manufacturing specification.

Now, I also understand that you may not

have a finalized specification at the time of the testing. But we think that you can justify that.

And, just going back to the points in terms of, what's some of the impact that you could have in terms of the microstructure on how it behaves in certain things. So I do think that it would be important that those are there. But there is also this other goal that if you had any kind of distortions --- and the term distortion really comes from, anyone who has done, like, thermal hydraulic scaling work. It kind of came from there. But I thought it fit here.

And this has to do with any kind of differences, and if you had a different fabrication technique, can you justify that? Is it a different size?

One thing that's obvious, like, if you do transient testing in a test reactor, a full size specimen is not going to fit in there, right. So it's kind of expected.

But we just want people to be looking there. Any more discussion? Walt, did that get to your comment?

MEMBER KIRCHNER: No, I have some -- I think probably this is an area where it will be case-specific, based on the advanced reactor concept. And if they're relying, I'm trying to say this in a very generic way. If they're relying on a past database for their particular fuel type, one of the considerations that may become important is how relevant is, if the structure, say they're using the same fuel material, but different structure or different manufacturing technique and so on, then it raises the question, how relevant the past irradiated experimental database may be for application for this new design.

I said that, I have a few specific examples that are not appropriate to bring up here. But, yeah, it would -- this would be perhaps the area where the staff may have to put added effort to review what the applicant, if the applicant is relying on a past database, but they've changed the geometry substantially, then, and there is no current irradiation of that new geometry, for example, then that raises a number of questions about things. You know, simple things like, does the structure crack or whatever under operating conditions versus the previous designs?

MR. DRZEWIECKI: Yeah, yeah. And, I mean I think we're going to be there in several breaker designs because I mean, especially designs that are going to rely on the EBR-II database. And so, yeah, I hear you. Thank you. Okay. Can I have the next slide, please?

So, yes, so it's an overview of the framework. Two goals we did not break down, but they're in the backup slides, are the ones associated with radiological release and then the one that's associated with maintaining a coolable geometry. So, those were two of the other safety criteria.

But they were very similar in approach to what we have for AOOs and things like that. However, there is some language inside of the paper which highlights the fact that we may not have as much data for things like, for some of those testing, because some of the DBA testing can be destructive. And that's got certain risks associated with it that you may not want to collect a bunch of data.

But I want to highlight. So, in terms of the overall framework, you have your main framework and that's supported by two other ones. One on evaluation models, another one on experimental data. A total of 60 findings or specifications.

And so, somebody who is doing a review would go through, you know, try to find, you know, try to make smaller findings in all these areas and that would support the overall finding that the fuel is qualified for use.

Next slide, please. Okay. So, all that's left is to talk about what our next steps are. What we're going to do with this and, yeah, next slide, please.

So, one thing that we have to do is to go through and exercise this framework. So, before I had mentioned that we could have done something similar in the area of critical heat flux and we certainly knew where some of the gaps were or some of the challenges were just by using it, and trying to exercise it. And that helped out a lot.

And so, we're trying to do that here. We are in the process of placing a contract to work with Argonne and Idaho National Laboratory to evaluate a generic metal fuel design using this in order to see if there's any gaps, any information and also to see if there's gaps in our model and to see if there's any gaps or anything that could be done to help support licensing of this fuel.

And I do want to say that what we have here this is consistent with the approach that we're trying to apply for the Aurora COL which is reliant on

EBR-II fuel data which, you know, back to Dr. Kirchner's point, may look a little bit different than, you know, our EBR-II fuel.

Next slide, please. Okay. So, in terms of what we have to do. Convert this into a NUREG. That actually has been done.

But we have gotten comments just a few weeks ago, you know, that were volunteered by the AFQ Working Group and, you know, we will get some more. But we're going to try to work on those comments, update the paper accordingly. Go through legal review and to make sure that we're not saying anything wrong there, and then go through a formal notice and comment and come back and talk to you guys in September at a full committee meeting. So, that's what I've got.

MEMBER KIRCHNER: Tim, this is Walt again. To Joy's earlier point, have you -- I was thinking about this. I didn't have a chance myself to go through the exercise.

Have you walked through your framework for liquid fuel reactors? And are there any changes or additions?

Certainly, you know, there since you're intimately mixed with the coolant, then chemistry becomes extraordinarily important. Also, well, you could have it with solid fuel, too. But eutectics and liquid fuels is a major consideration as well.

Have you had a chance to just kind of mentally or just kind of desktop exercise go through any of this for liquid fuel, and does it kind of touch all those same bases that you think you would need for those concepts?

MR. DRZEWIECKI: So, you know, we have not beyond the work that we have contracted to have done for molten salt reactor fuel qualification. And so, you know, so I think some of that activity has been done.

Of course, that work was started before this draft was out there. And I think that they've recently been looking at how to incorporate some of these ideas.

We do recognize that for this framework it really was developed for, based on what we've done in the past, which was all solid fuel.

DR. CORRADINI: Tim, this is Corradini. I had a question.

When you were talking to Walt about his questions relative to the specifications, does the staff have a preference whether it's a product specification for the fuel or a process specification?

MR. DRZEWIECKI: I mean, no, I don't. Just as long as you have -- you know, we just want to get to a point where we have some confidence that you can lock down certain things that we think are going to be key.

Now, going the process, maybe that will be easier. And frankly, that's what we've always seen. We've always seen people describe a heat treatment. And frankly, we have acceptance criteria that are based on the heat treatment for a clad or something like that.

So, that's what we've seen. But I wouldn't say that I'm partial either way.

DR. CORRADINI: Well, the reason I'm asking the question the way I did is, it seems to me it will allow for a diversity of solutions as long as it's a product specification, so you're not locking down the recipe.

You could have multiple recipes, to the extent that the product specification is complete enough that you prove that you've met the specification. Then you could do it a number of different ways. That seems to me to be more preferable.

MR. DRZEWIECKI: Yes.

MEMBER BALLINGER: This is Ron. That's what I was trying to at least allude to in the previous comment I made, that not getting to, you don't micromanage too much.

DR. CORRADINI: That's what comes to mind.

MEMBER KIRCHNER: Yeah, Mike and Ron, I think a product specification would be preferred, because in the final analysis, that's what you're concerned about.

You know, the process part has a lot to do with reproducibility, not generating a lot of waste product and so on and so forth. But in the final analysis, it's the product spec that you really have to meet so that you can demonstrate it's going to meet the safety licensing case.

CHAIRMAN PETTI: And the completeness of that specification. You know, does it have everything that imparts the good behavior to the fuel, yeah.

DR. SCHULTZ: Tim?

MR. DRZEWIECKI: Yes.

DR. SCHULTZ: This is Steve Schultz. I want to talk a little further on the qualification testing portion of it, to follow on what Walter was talking about, at least partially.

And that is the way the structure is set up it seems like it's a very nice program and process. But it assumes a lot about having available, if you will, a fairly final design and experimental program that leads from that design to testing and qualification.

Most of the development and then evaluation of fuel products are not, have not in the past been performed that way. In other words, the design is established based upon a wide range of experimental databases that have been accessed in order to move through the development.

And it's usually not possible to have what you might consider or want to consider to be a final design or a prototype design that looks just like you're going to have in reactor with the envelope established and so forth to do that full program testing.

In other words, the justification of the qualification is usually based upon a wide variety of testing programs.

CHAIRMAN PETTI: But ultimately, Steve, there is like sometimes a lead test assembly. Some fuel folks call them proof tests.

DR. SCHULTZ: Yes.

CHAIRMAN PETTI: You know, at the end, so that you try to, you know, there's all these changes that have occurred over the development. But in the end --

DR. SCHULTZ: Right.

CHAIRMAN PETTI: -- you test the final one to make sure that there's nothing, it's more than empirical proof. But --

DR. SCHULTZ: Yeah, I do see that at the end and I see it in the qualification testing and the prototype assembly that might go into the operational testing portion of it.

But when you're talking about the qualification of the fuel design for the whole envelope of testing that's described earlier on, that's got to draw upon a much broader experimental database in order to set up the qualification of the analysis tools and then justify how the fuel is going to perform in those environments.

To have something that looks like a final design which we set up in the first part here and expect that's going to be justifiable through testing in all of these experimental areas is really expecting too much.

MR. DRZEWIECKI: Jordan, can you go to Slide 40, please? So, I just wanted to highlight this. And this next one, too.

So, this may look familiar to Dr. Petti. This is coming off from that paper.

CHAIRMAN PETTI: 2007?

MR. DRZEWIECKI: Yes, 2007 Journal of Nuclear Material papers, that kind of highlights some of the steps. And that's what I thought that you were kind of getting at is some of the earlier stuff that you have to really draw on to inform some of your decisions.

But I do want to state we were writing from a perspective of this kind of last thing, that people are going to do integral -- maybe like engineering scale tests.

MS. CUBBAGE: This is Amy Cubbage. I mean, I think your comment may be just reflective of the iterative nature of the reactor design business, in that you're going to start off on a fuel development project with a design in mind and you're going to start your design with a fuel in mind.

You're not going to come to the table cold on either of those. And then you're going to sort of set the specifications of what you need your fuel to accomplish to meet your design objectives, and you're going to have to iterate somewhat.

But at the end of the day, when it comes to regulatory review, we come in at the end where you have a proposed design and a proposed fuel and you need to be demonstrating that your fuel is qualified for the range of conditions in your design that's proposed. Is that what you're getting at?

DR. SCHULTZ: Yes, it is. You've described it very well. But in that process, you're going to need to rely upon a wide variety of all of that experimental and evaluation program that's gone before.

MS. CUBBAGE: Yes, yes. Both on the fuel side and with the design, the broader design. And it all has to come together in an integrated manner to justify the safety. And it's a very complex problem, no doubt.

MR. DRZEWIECKI: Yes. I do want to highlight because like, some of those early steps, some of those things are not things that the NRC has always been, we haven't really been seeing some of that data which is informing some of those design optimization decisions.

DR. SCHULTZ: And perhaps setting up a structure like this, and as you said at the very outset, Tim, this hasn't been part of the NRC's overall review process.

So, setting this up as an expectation going forward with the advanced designs is really important to do.

MS. CUBBAGE: Yeah, for sure.

DR. SCHULTZ: And should help.

MS. CUBBAGE: This is Amy Cubbage again. I think we need to set those expectations and provide predictability for applicants going forward such that if they go through a multi-year fuel qualification program, they know what the objectives need to be.

And also, our history more recently has been in the LWR fuel. And you're talking about tweaks and adjustments and they can start their design based on a reference fuel and then they can later justify upgrading to the latest new fuel bundle so it's more of an evolution.

But this is a totally different ball game we're in with these new designs.

(Simultaneous speaking.)

MEMBER KIRCHNER: This is Walt. Since you actually put this up, is the expectation, is it reasonable to convey to the applicants that the expectations as highlighted here in yellow, especially the second line, will it be part of what would be expected in an application?

MS. CUBBAGE: Do you mean more broadly than the fuel, or are you speaking --

MEMBER KIRCHNER: No, I'm just talking about fuel. I'm reading the second row here in yellow.

Fabrication of referenced fuel derived from production supply sources irradiated to design conditions and utilization of radiation in a representative environment.

MS. CUBBAGE: That pretty much sums up what we're trying to convey.

MEMBER KIRCHNER: That's the expectation.

CHAIRMAN PETTI: That's a proof test by definition, I think.

MR. DRZEWIECKI: Yes. Now, we do want to say that there is room to where perhaps you can justify doing something different or you could use something like a lead test program, something like that in order to try to bootstrap stuff. But, yes.

CHAIRMAN PETTI: I mean, on the opposite perspective, let's say you had a new clad that you had. But the fuel meet in a pin clad system have been through a lot of testing with the different cladding, you know.

I don't think just irradiating the clad alone would be enough to come in and say okay, we have this old fuel with this old clad and then we just irradiated the new clad over here. Look, it didn't do anything.

I still think that integrated test at the end is required. And I honestly think most people in the fuel development business would agree with that. It's the process that it takes to get you here that there may be more than one path.

The path laid out in 2007 is a typical experimental path. AFQ is more let's bring in more modeling to see if we can accelerate getting to this end state. But this end state is still, I think really important from the regulatory perspective.

MR. DRZEWIECKI: Hey, Jordan, could you go to the next slide, Slide 41? I just want to back up Dr. Petti's statement. You know, this is the AFQ process.

This is a figure from the AFQ paper. And it's exactly right. They are not proposing to get rid of that final step.

CHAIRMAN PETTI: Yes. I think this is a very interesting discussion, because if you talk to some of these AFQ modelers long before AFQ was a term, and some of them have come from other industries.

And apparently, in other industries there is a lot more separate affects testing and model development in this integration and much fewer integral tests. Whereas nuclear tends to have a history of the other way around, where we jump to the integral testing largely because of the complexity and what we could do back in the 70s.

So, it's an interesting question as to whether or not the paradigm that's used in other technologies can work here and can accelerate the process in the end.

DR. SCHULTZ: Tim, this is a very important slide -- this is Steve again -- that really does demonstrate how this could work, because I think the structure that you've laid out in setting things up fits very well with the overall process shown here.

MR. DRZEWIECKI: Thanks.

CHAIRMAN PETTI: And my recommendation when you get into this NUREG is some of these figures could be very useful in the document itself to help people go from sort of an abstract requirements based, which is how I read the document, to helping them think about how the piece parts fit together.

DR. SCHULTZ: Yeah, what I was missing

before and trying to describe was that feedback loop that you have in the Phase 2 diagram here between the integral fuel testing and the separate effects testing.

MR. DRZEWIECKI: I do want to highlight that this is, okay, this figure here is from a paper that was authored by Kurt Terrani and others as well out of Oak Ridge National Laboratory.

I just wanted to highlight that, really that they're not proposing it to move away from that final step. But, yes.

DR. SCHULTZ: Understood.

CHAIRMAN PETTI: And, you know, the key thing to me is, if you look at the history of fuels work it's always something that wasn't thought about that got the fuel design.

Looking in the rear view mirror you look at it now and it's always easy. But the real question is, how good are these models going to be to predict something that you've not seen before?

And that's really, I think where it all hinges.

MEMBER REMPE: So then, the actual time of the test, the duration of the test and operational performance comes into play big time. And the unknown unknowns are the one thing I was wondering about when I was looking at this White Paper too, Dave.

CHAIRMAN PETTI: Yeah, Phase 2 here could be much longer if you end up, if stuff comes up that you just didn't see. The real problem in fuel qualification is not, this is the optimistic success oriented schedule.

The problem usually is something happens when you go to the first integral test or even a partial integral test that was not foreseen, requires you to go back and fix something and then start again.

And that's what kills the fuels. The question is, today's tools, can they help make sure you don't have to go backwards and iterate as much?

MEMBER REMPE: They have to be validated.

DR. SCHULTZ: Well, just sticking with this for a moment more. Tim, you mentioned earlier that if I look at the third box, Phase 3, where you have the integral fuel fabrication and so forth, that box looks a lot like what is the foundation of what you've described today in terms of the regulatory process.

And then the previous two boxes, Phase 1 and Phase 2, represent that area of development that, as you indicated earlier with LWR fuels and so forth, the NRC hasn't really been involved with.

And so, a program that looks like this that incorporates involvement by the regulator as well as industry could be very helpful so that by the time industry gets to Phase 3, there is a lot better understanding as to what has gone into the fuel development and justification.

MS. CUBBAGE: Yeah, this is Amy Cubbage again. I would just like to highlight that is one of the areas that we strongly encourage pre-application engagement well before an applicant is ready to come to the NRC, so that we can have that involvement, both in the plans for fuel qualification and in the execution.

DR. SCHULTZ: That would be great. That makes a lot of sense.

CHAIRMAN PETTI: Yeah. Also, I think, you know, the yellow box, two to five years is extremely optimistic. The hardest thing to do here is not the actual test.

The testing takes a certain amount of time, right? So, many neutrons on the target and to hit the transient testing. But to stand up at industrial scale a fuel vendor is not an insignificant activity.

And probably it's starting in the blue box. There's a little bit of overlap. That could be two to three years longer than what they think there, just because of specifics and specific technologies.

MS. CUBBAGE: And, Tim, this is Amy Cubbage again. This is representative of AFQ goals, right?

MR. DRZEWIECKI: That's right.

MS. CUBBAGE: This isn't necessarily indicative of the, what we currently expect.

MR. DRZEWIECKI: It is not, it is not. I mean, what okay, so this framework that's in the White Paper, it was written from a perspective, again, we typically engage at this final step. Will you have integral fuel test data?

Now, in terms of this process in the middle we are engaged with the AFQ group right now. But again, we have engaged from a perspective that we do expect to see this kind of integral data at the end.

CHAIRMAN PETTI: Any other Members of the Committee have comments before we ask for the public?

MEMBER BROWN: Yes, Dave. This is Charlie.

CHAIRMAN PETTI: Go ahead.

MEMBER BROWN: I couldn't find my mic. This is more of a technical question and I guess since I'm not a statistician, that's why I'm asking it.

There are a number of places in this White Paper, throughout this decomposition and composition approach, where they make the statement that we may not be able to get data due to the environmental safety or economic needs associated with determining, with obtaining the sufficient amount of data.

And then they go on to say, we will figure out a way to use less data. I'm trying to integrate that with some of the past experience before I left Naval Reactors and figure out what do we mean by not having enough data --

MR. DRZEWIECKI: Yes, so --

MEMBER BROWN: -- to be able to balance stuff. I am not a statistician, and this sounded like if it costs too much, we'll figure out a way to determine some boundaries without having sufficient data.

And that was a little bit disturbing. Not a critical comment. It just seemed to be contrary.

MR. DRZEWIECKI: Yeah, I see what you mean. And so, I would point to it's what we do now for, you know, like rod ejection events or reactivity induced accidents.

We have our fuel failure criteria, the cladding failure criteria, what are due to over temperature or PCMI. And we have some data there.

We may have, like, 20 some data points maybe in the 30s. But that's not really enough to get you to like a 95/95 type of a limit.

And so, what's typically done there is, curves are drawn that we think are suitably conservative but also reasonable. And so, but there is not like a thorough statistical analysis done there.

So, that's kind of the surrogate that we're trying to get to there, because we recognize that to get 59 or 100 points from tests that can be destructive. Not only is it expensive, it also creates waste and maybe there's things that just aren't appropriate.

So, we've done it in the past and we think we can do it in the future.

MEMBER BROWN: What do you do, just put lines so you bound all of it?

I guess I am still struggling a little bit with that understanding, if we're going to base the transient performance or the accident performance based on data points which are sparse. I mean it's --

MR. DRZEWIECKI: Yes, I mean I will say it's done on a case by case basis. Certainly a drawing a line which is bounding is one approach.

But based on what I've seen, like what we've done per reactivity induced accidents, not necessarily the case. Those curves are pretty reasonable, slightly conservative, but not bounding.

However, we think, one safety case for those is the fact that there is margin in the methods themselves, the way that you analyze a reactivity induced accident like a rod ejection. There are conservative in those methods such that, you know, we didn't want to pile on additional conservatism in the number of counted failed fuel rods.

But that's what's done there. And so, I guess my answer would be that it's really done on a case by case basis.

We want to ensure that there is reasonable, that it's conservative. But at that same point, there's going to be some kind of judgment in there. It's not purely objective.

MEMBER BROWN: Okay, thank you.

CHAIRMAN PETTI: Other comments? Okay. Well, let's open the public line and see if there is any members of the public that wanted to weigh in. Okay, I don't hear anything.

MR. DRZEWIECKI: It was not unmuted. I could -- that's the -- let me, it's still muted.

CHAIRMAN PETTI: Yeah, I see it's still muted, yeah.

MR. DRZEWIECKI: I don't know who is running the meeting, if they could unmute them or not.

CHAIRMAN PETTI: Derek, can you unmute them?

MR. MOORE: Thomas, this is Scott. Can you unmute the public line, please?

MS. CUBBAGE: And it's muted within Teams. So, someone needs to I think hit star 6 on that line.

CHAIRMAN PETTI: Okay. It's unmuted. Any comments from the public? I don't hear any.

So, Tim, could you just lay out again your going forward schedule, how you see, you know, when are you going to go out for comments and then when are they going to come back?

MR. DRZEWIECKI: So, Jordan, perhaps --

DR. FELTUS: Hi. This is Madeline Feltus from the Department of Energy. I have one question for the group, if you can hear me.

Prototypical testing may not be available, for instance, if we don't have a FAST reactor design or if, you know, if we use the ATR, we don't get exact conditions.

So, the question would be, besides interval testing in a test reactor, would we still be required to have demonstration reactors or some way to test the reactor conditions before a commercial power reactor could be built?

I want to make sure that we address some of the questions that came in from the AFQ Working Group about having testing in actual reactors as mandatory.

MR. DRZEWIECKI: Well, I could say that the way that the structure is written now, you know, there would need to be some kind of data in order to support the evaluation model and the safety case of that fuel.

If there is some kind of, some kind of a test, a distortion, like you mentioned, perhaps it wasn't in the FAST spectrum, can you make an argument that's okay? I believe that people have tried to make that.

I'm not familiar with it myself. I believe people have tried to make some of those arguments, trying to use or do things to simulate a

FAST spectrum inside of something like ATR.

There is other options too. This was written from a perspective that you were going to try to satisfy 5043(e)(1) and have that data. There are other options.

There is a prototype option which is out there. You can also do other things as well. You can do things like test assembly if you don't have high burn up data.

In the absence of any data at all, we would have to think about that. I think that would be challenging.

CHAIRMAN PETTI: Okay. Tim, can you go back to the schedule?

MR. DRZEWIECKI: Yes, yes, sorry. So, yes, there was a schedule.

So, we -- I'm going to try to get the, as far as the NUREG, to address comments to get that through, I think, by I'll say this month and then through OGC a couple weeks after that.

And for notice and comment, Jordan, do you have the dates for the notice and comment period?

MR. HOELLMAN: Hey, Tim. This is Jordan Hoellman. I don't have the exact dates, I guess. I think we were shooting for May to release it for public comment.

I wasn't sure how long it would take us to address the comments volunteered from the AFQ Working Group, or how long it would take for us to get those incorporated. And then the NUREG process has its own, you know, special process where you've got to go through the office of the administration and things like that.

So, we were targeting May for release of the direct NUREG for public comment expecting the 60 day public comment period, and then we'll, you know, address the public comments and come back to the full committee here.

CHAIRMAN PETTI: Okay. Well, with that, unless there's any final comments, I guess we're done. So, I want to thank Tim and Amy and everybody else who was involved.

And I think we enjoyed the discussion, lots of interesting comments and questions and look forward to the September meeting.

MS. CUBBAGE: Thank you. We appreciate all the feedback.

(Whereupon, the above-entitled matter went off the record at 3:34 p.m.)

Fuel Qualification (FQ) for Advanced Reactors (Draft White Paper)

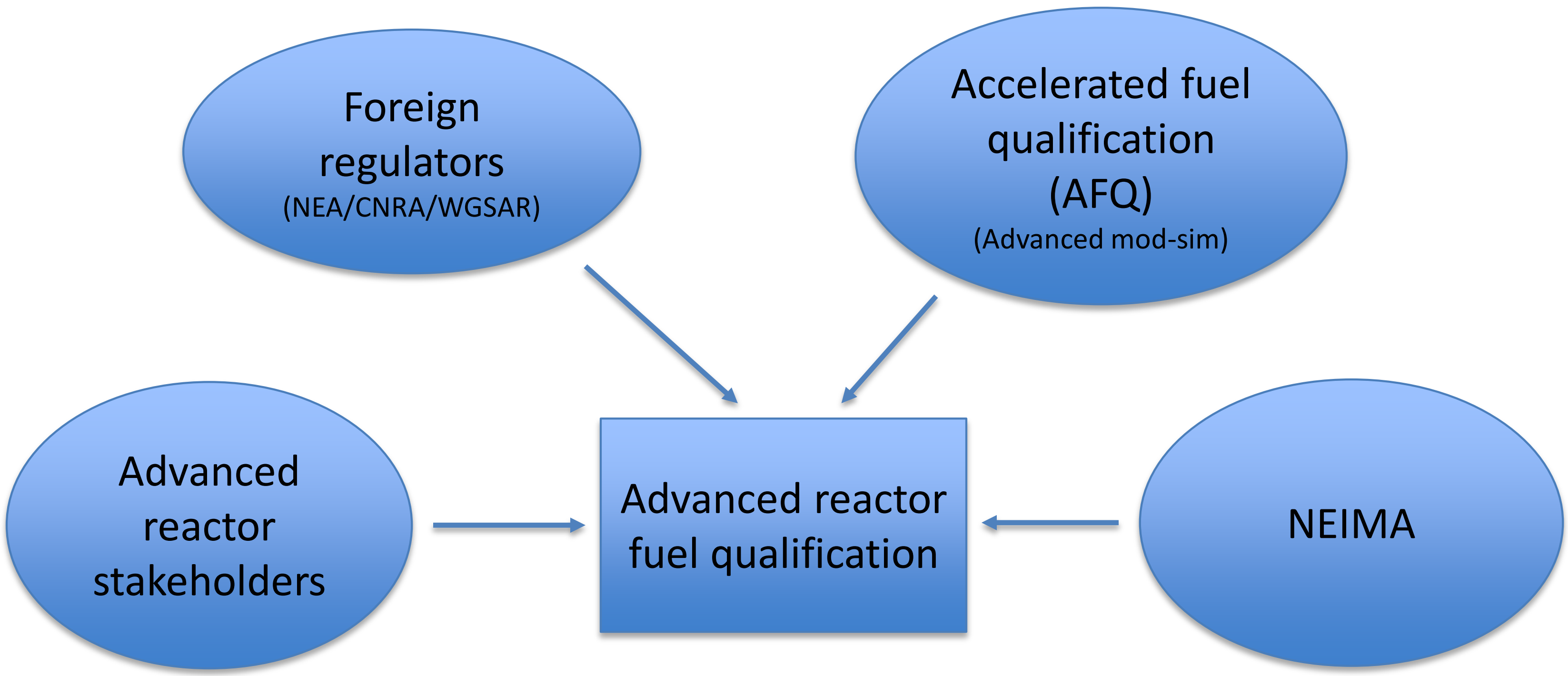
ACRS Subcommittee Meeting

February 2, 2021

Outline

- Introduction and Background
  - Associated Regulations
  - Activity affecting FQ guidance
  - Nuclear Energy Innovation and Modernization Act (NEIMA)
  - Input to FQ assessment framework
- General Approach
  - Scope of FQ
  - Description of assessment frameworks
- Overview of FQ assessment framework
- Near term activity/next steps

Introduction



Regulatory Aspects of Nuclear Fuel Qualification

- No requirements specific to nuclear fuel qualification
- Requirements on fuel qualification are provided by top level requirements attributed to the facility
  - **Design limits for normal operation and AOOs:**
    - GDC/ARDC 10, *Reactor design*
  - **Accident acceptance criteria (Coolable geometry/Dose)**:
    - GDC 27/ARDC 26 – *Reactivity control systems*
    - GDC/ARDC 35 – *Emergency core cooling system*
    - 10 CFR 50.34(a)(1)(ii)(D), 10 CFR 52.47(a)(2)(iv), and 10 CFR 52.79(a)(1)(vi)
  - **Natural phenomena (Seismic)**
    - GDC/ARDC 2, *Design bases for protection against natural phenomena*
  - **Data** - 10 CFR 50.43(e) – Demonstrate safety features

Regulatory Aspects of Nuclear Fuel Qualification

- Guidance
  - NUREG-0800, Standard Review Plan
    - Section 4.2, Fuel System Design
      - Identifies acceptance criteria derived from know fuel failure/degradation mechanisms for light water reactor fuel
  - ATF-ISG-2020-01
    - Significant changes to fuel design must be assessed for potentially new failure/degradation mechanisms
  - Reg Guide 1.233, Licensing Modernization
    - Emphasis on risk – requires understanding of accident sequence consequences (i.e., source term)

FQ Activity

- NRC reviewed and approved:
  - EPRI-AR-1, "Uranium Oxycarbide (UCO) Tristructural Isotropic (TRISO) Coated Particle Fuel Performance," May 2019
  - ANL/NE-16/17, Rev. 1, "Quality Assurance Program Plan for SFR Metallic Fuel Data Qualification," May 2019
- NRC supported activity:
  - MSR fuel qualification:
    - ORNL/LTR-2018/1045, "Molten Salt Reactor Fuel Qualification Considerations and Challenges," 2018 (ML18347A303)
    - ORNL/TM-2020/1576, "MSR Fuel Salt Qualification Methodology," 2020 (ML20197A257)
  - Source term:
    - SAND2020-0402, "Simplified Approach for Scoping Assessment of Non-LWR Source Terms," 2020 (ML20052D133)
    - INL/EXT-20-58717, "Technology-inclusive determination of mechanistic source terms for offsite dose-related assessments for advanced nuclear reactor facilities," 2020 (ML20192A250)

FQ Activity

- White paper assessment:
  - TerraPower, *Advanced Fuel Qualification Methodology* (ML20209A155, ML20310A278)
    - Additional papers expected in February
- White paper development:
  - General Atomics – Accelerated Fuel Qualification (AFQ)
- NEA – Working Group on the Safety of Advanced Reactors (WGSAR)
  - Fuel Qualification Report

NEIMA

- SEC. 103. ADVANCED NUCLEAR REACTOR PROGRAM
  - (c) REPORT TO INCREASE THE USE OF RISK-INFORMED AND PERFORMANCE-BASED EVALUATION TECHNIQUES AND REGULATORY GUIDACNE

(4) REQUIRED EVALUATIONS.—Consistent with the role of the Commission in protecting public health and safety and common defense and security, the report shall evaluate—

(A) the ability of the Commission to develop and implement, where appropriate, risk-informed and performance-based licensing evaluation techniques and guidance for commercial advanced nuclear reactors within existing regulatory frameworks not later than 2 years after the date of enactment of this Act, including policies and guidance for the resolution of—

(i) issues relating to—

(I) licensing basis event selection and evaluation;

(II) use of mechanistic source terms;

(III) containment performance;

(IV) emergency preparedness; and

(V) the qualification of advanced nuclear reactor fuel; and

(ii) other policy issues previously identified; and

FQ Input - Literature

- Journal of Nuclear Materials (JNM 2007) Paper

ELSEVIER
Available online at www.sciencedirect.com
ScienceDirect
Journal of Nuclear Materials 371 (2007) 232–242
journal of nuclear materials
www.elsevier.com/locate/jnucmat

An approach to fuel development and qualification

Douglas C. Crawford *, Douglas L. Porter, Steven L. Hayes, Mitchell K. Meyer, David A. Petti, Kemal Pasamehmetoglu

Idaho National Laboratory, Idaho Falls, ID 83415-6140, USA

- JNM 2020 Paper

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Contents lists available at ScienceDirect
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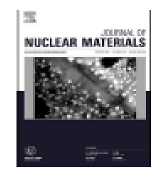
journal homepage: www.elsevier.com/locate/jnucmat



Accelerating nuclear fuel development and qualification: Modeling and simulation integrated with separate-effects testing☆

Check for updates

Kurt A. Terrani [a, *], Nathan A. Capps [a], Matthew J. Kerr [b], Christina A. Back [c], Andrew T. Nelson [a], Brian D. Wirth [a, d], Steven L. Hayes [b], Chris R. Stanek [e]

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Stakeholder Input

- Foreign regulatory authorities via WGSAR:
  - Canada, France, Germany, IAEA, Italy, Russia, and UK
- Domestic advanced reactor stakeholders through stakeholder meetings
  - UCS, USNIC, SNC, Kairos, GA, INL, public
- NRC internal stakeholders through the Technical Advisory Group on Fuel (TAG-F)
  - NRR (new and operating reactors), RES, NMSS
- Vendor input through AFQ working group

Outline

- Introduction and Background
  - Associated Regulations
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  - Input to FQ assessment framework
- General Approach
  - Scope of FQ
  - Description of assessment frameworks
- Overview of FQ assessment framework
- Near term activity/next steps

FQ Framework - Scope

- Broad interpretation of fuel qualification (many aspects of nuclear safety are impacted by the fuel)
  - Neutronic performance
  - Thermal-fluid performance (e.g., margin to critical heat flux limits)
  - Fuel transportation and storage
- Need to restrict the scope of the report

  *The scope of this report focuses on the identification and understanding of **fuel life limiting and degradation mechanisms** that occur as a result of **irradiation** during reactor operation.*

Assessment Framework

- Development of a generic assessment framework for fuel qualification:
  - Top-down approach used to decompose the top level goal of "fuel is qualified" into lower level supporting goals
  - Lower level supporting goals are further decomposed until clear objective goals are identified that can be satisfied with direct evidence
- NRC has used assessment framework approach to evaluate thermal-margin models (e.g., critical heat flux - see NUREG/KM-0013)
  - Significant reduction in review time
  - Comprehensive/transparent review

FQ Framework - Other Considerations

- Definition of fuel qualification (from JNM 2007)

  The objective of nuclear fuel qualification is ***the demonstration that a fuel product fabricated in accordance with a specification behaves as assumed or described in the applicable licensing safety case****, and with the reliability necessary for economic operation of the reactor plant*

- Clarify "safety case"
  - The role of nuclear fuel in the safety case can vary significantly between different reactor designs (e.g. TRISO fuel contains fission product barriers within the fuel itself)

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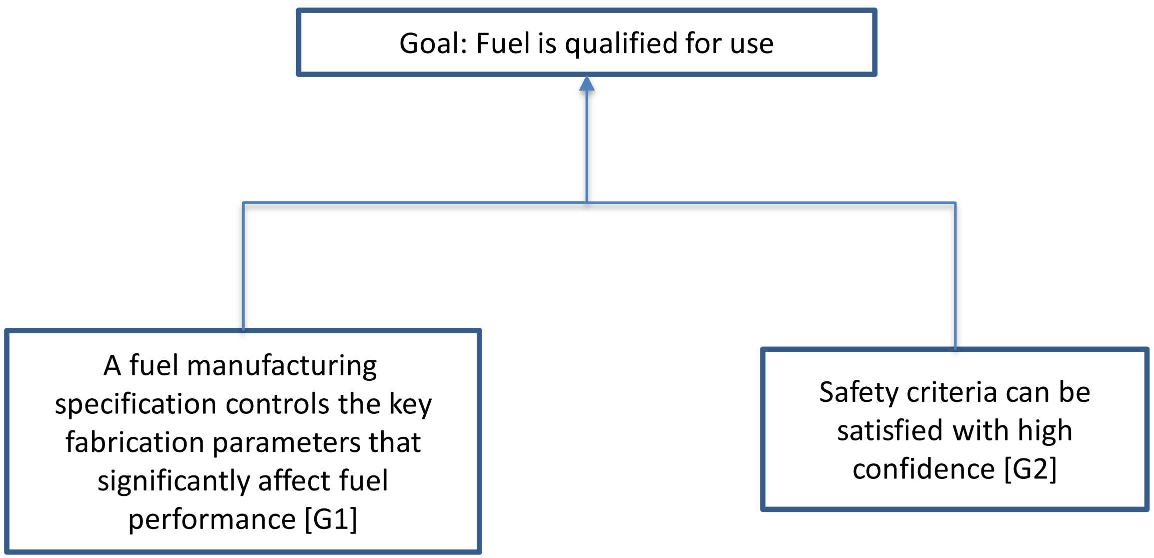
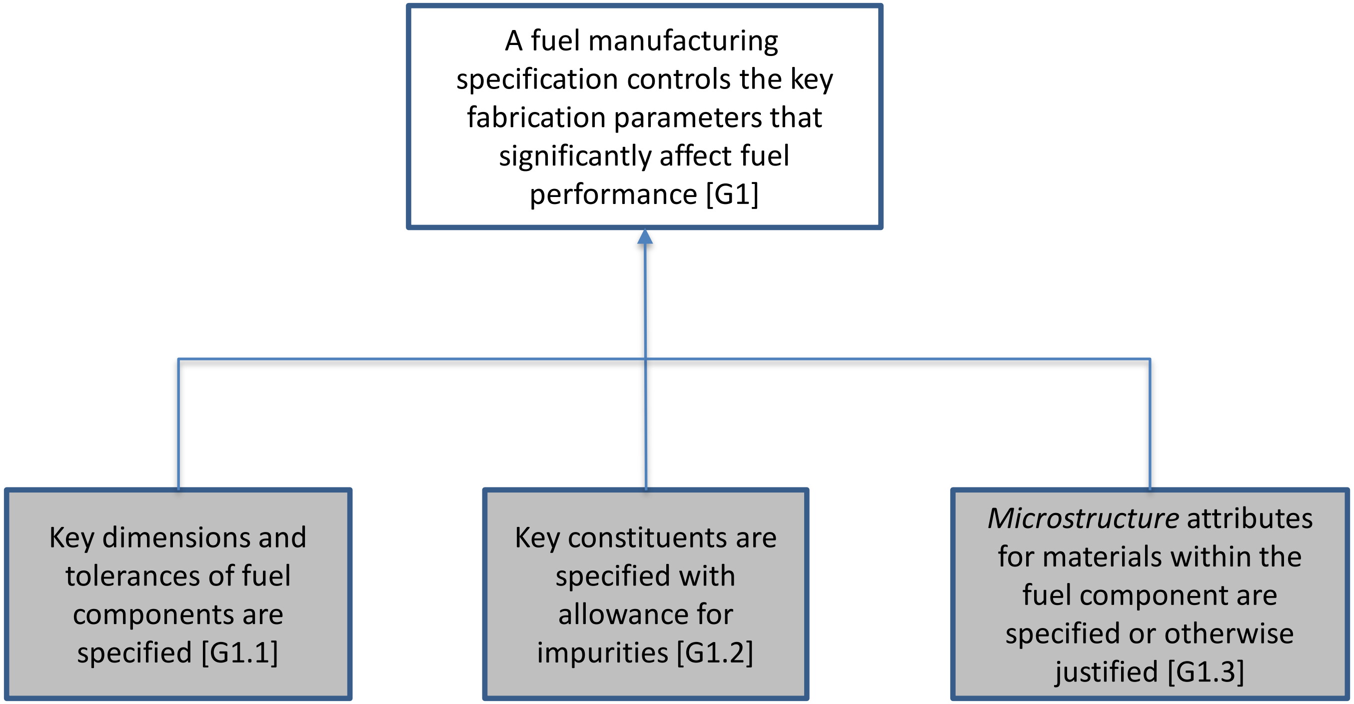
FQ Assessment Framework: Goal

- Goal: Fuel is qualified for use

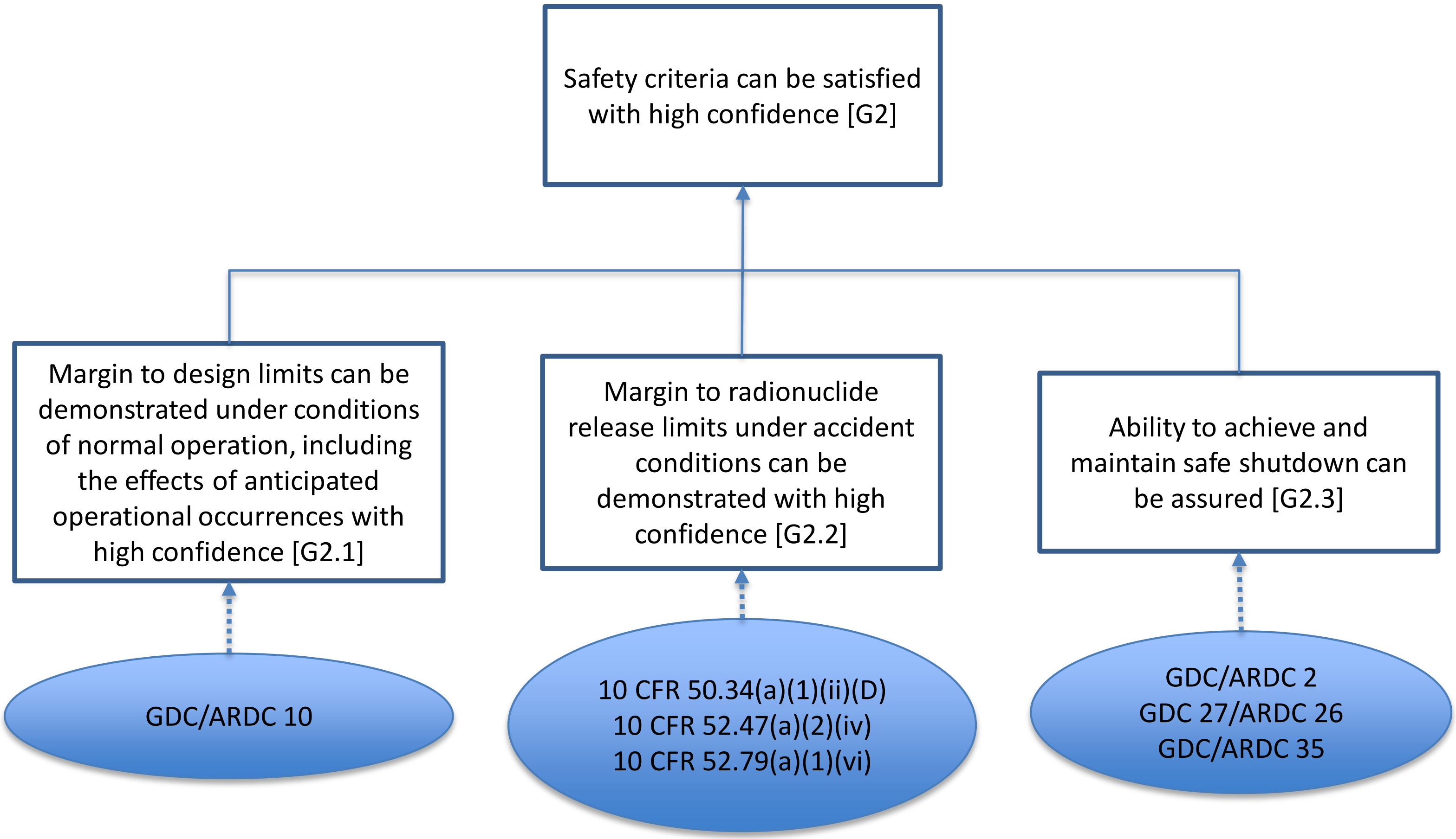
  = High confidence exists that the fuel **fabricated in accordance its specification** will **perform as described in the applicable licensing safety case**



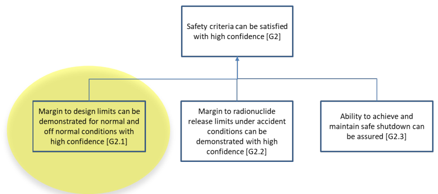
G1: Manufacturing Specification

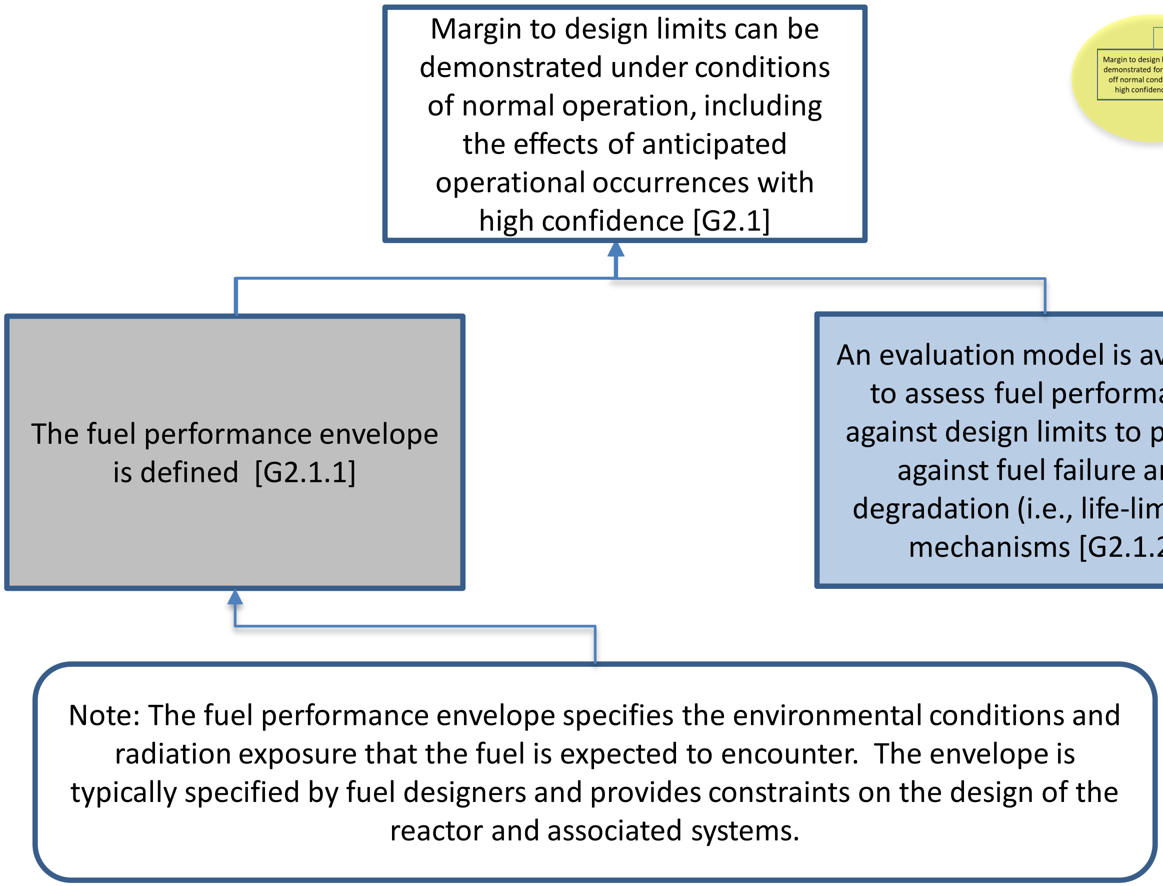


G2: Safety Criteria



G2.1: Design Limits for Normal and Anticipated Operational Occurrences





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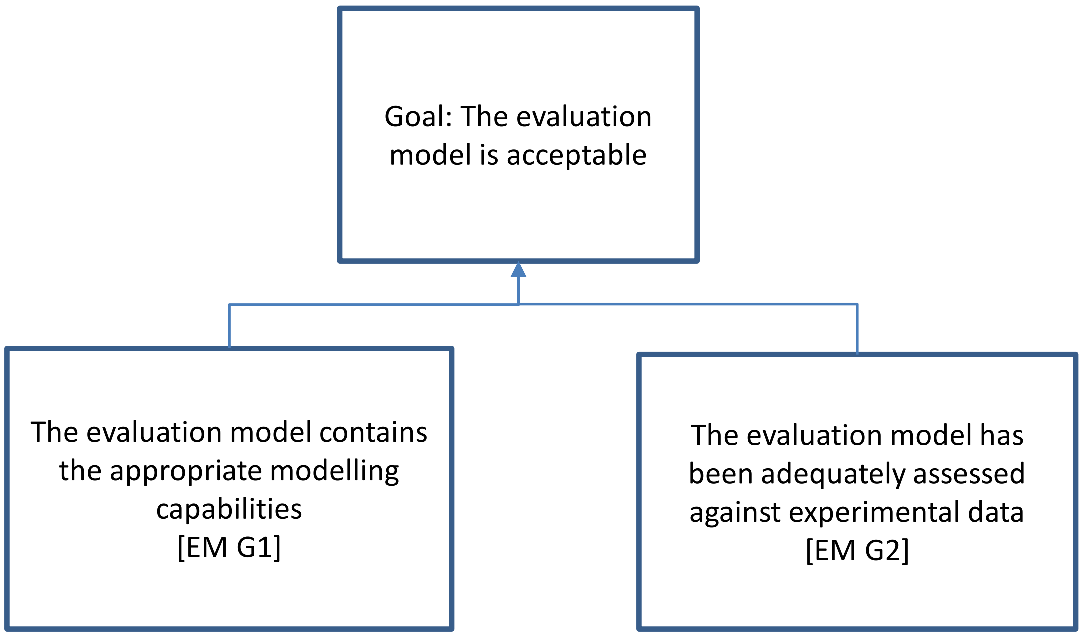
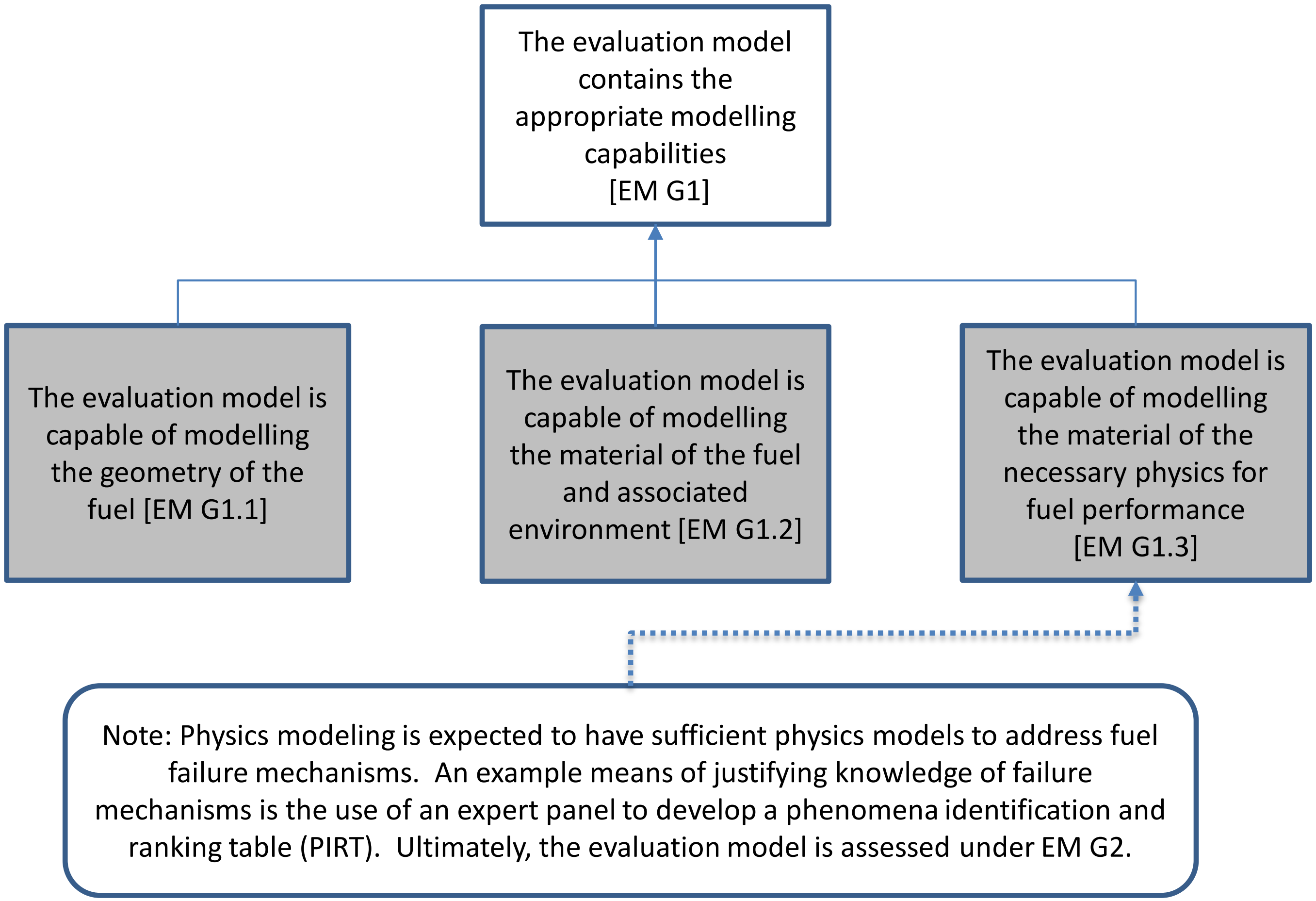
Evaluation Model (EM) Assessment Framework



EM G1: Modeling Capabilities



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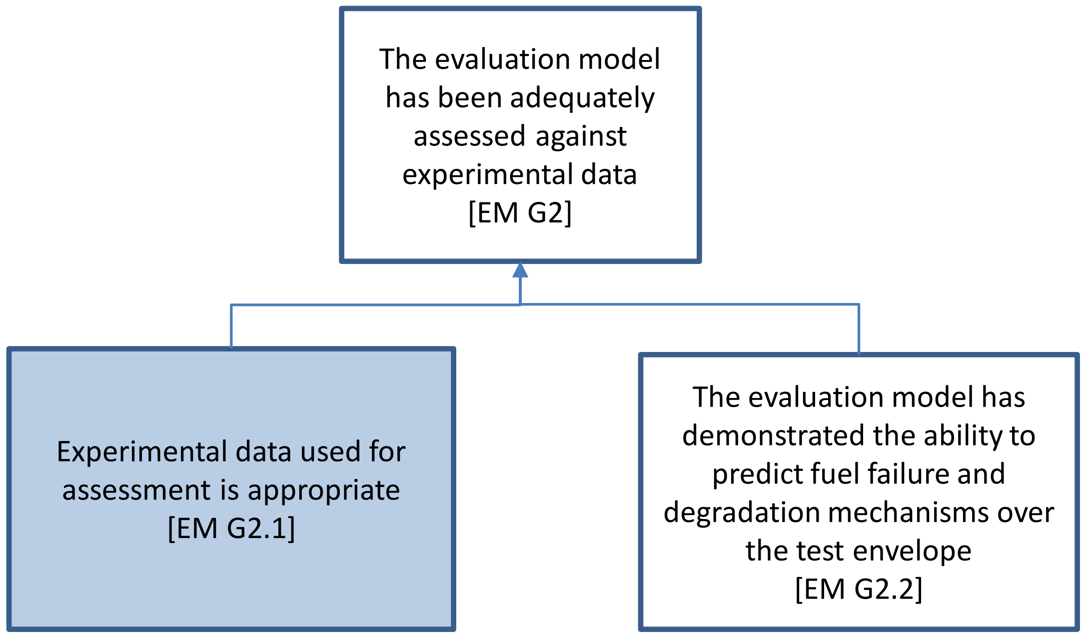
EM G2: Assessment



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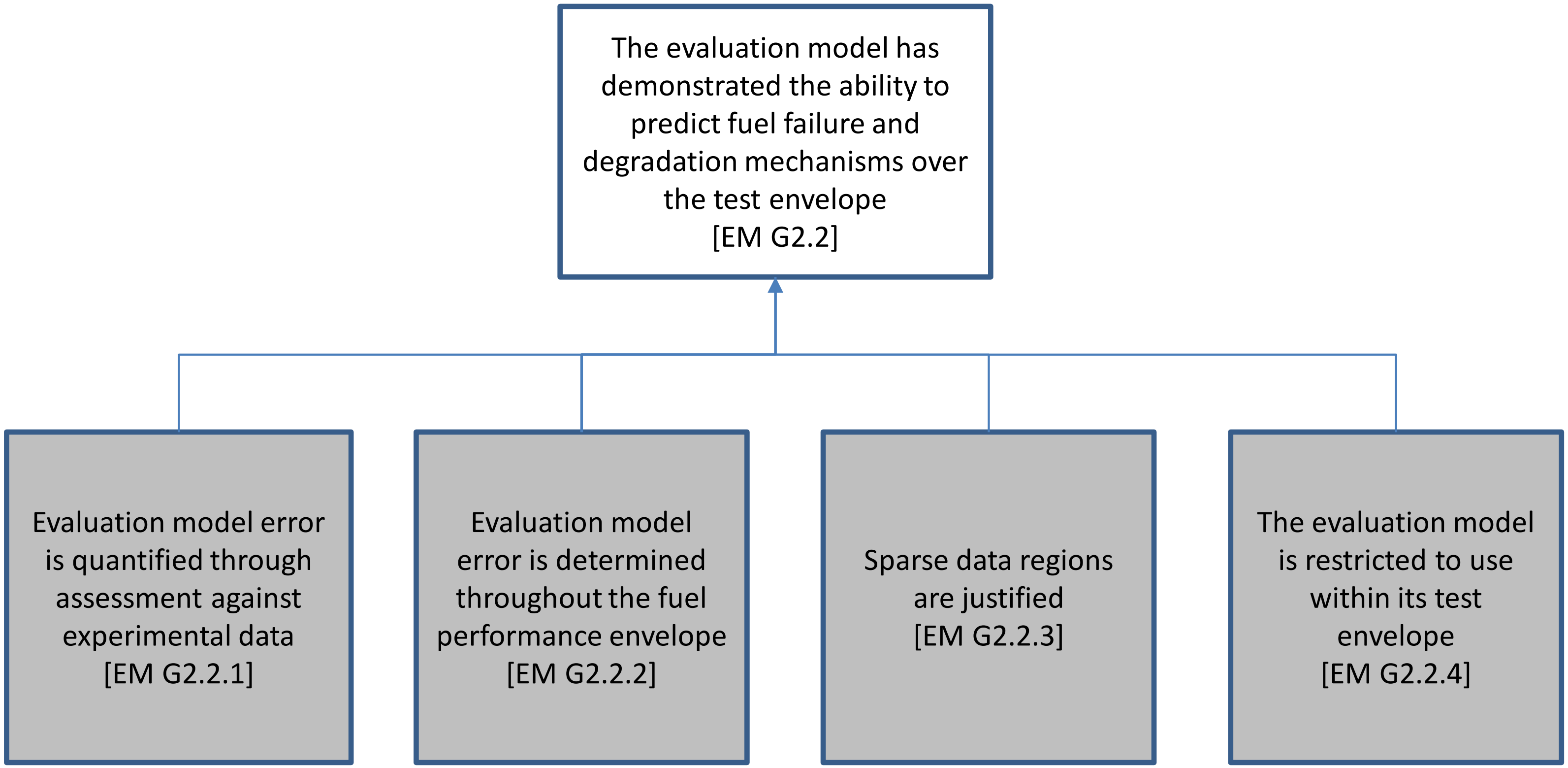
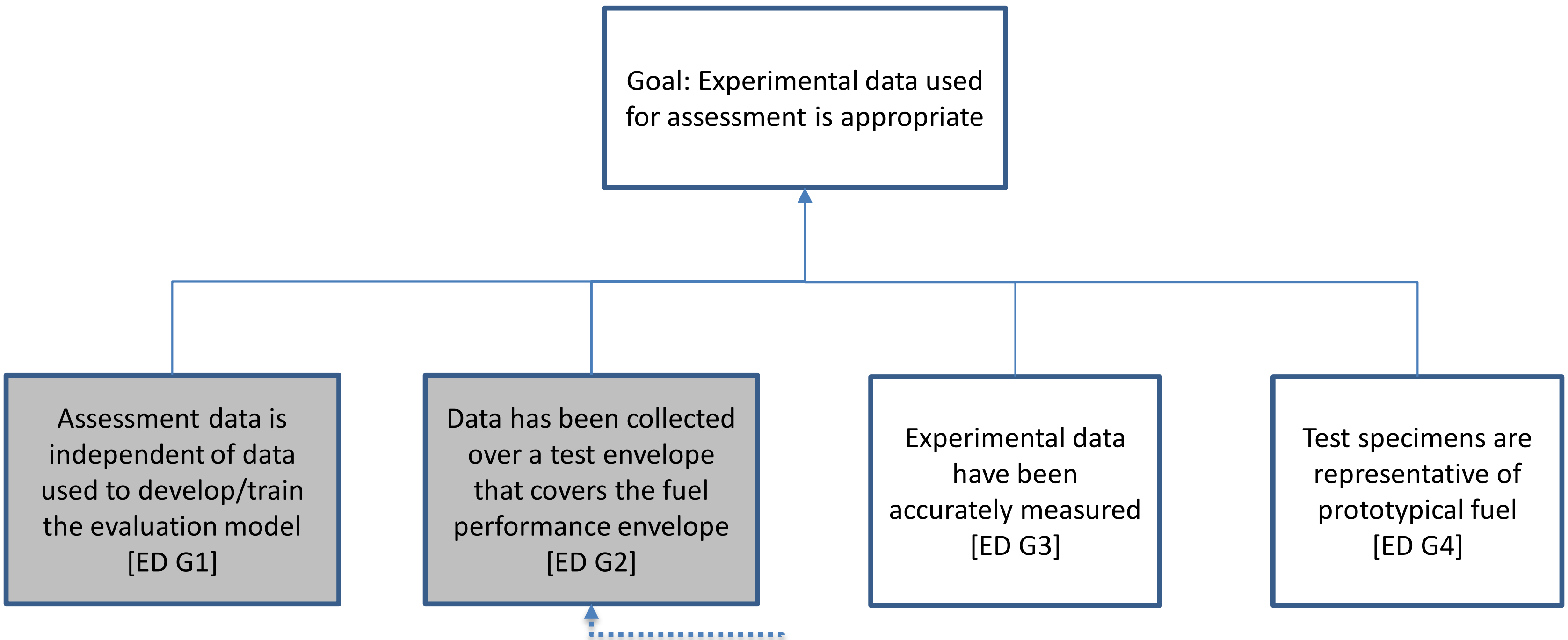
EM G2.2: Demonstrated Ability over Test Envelope

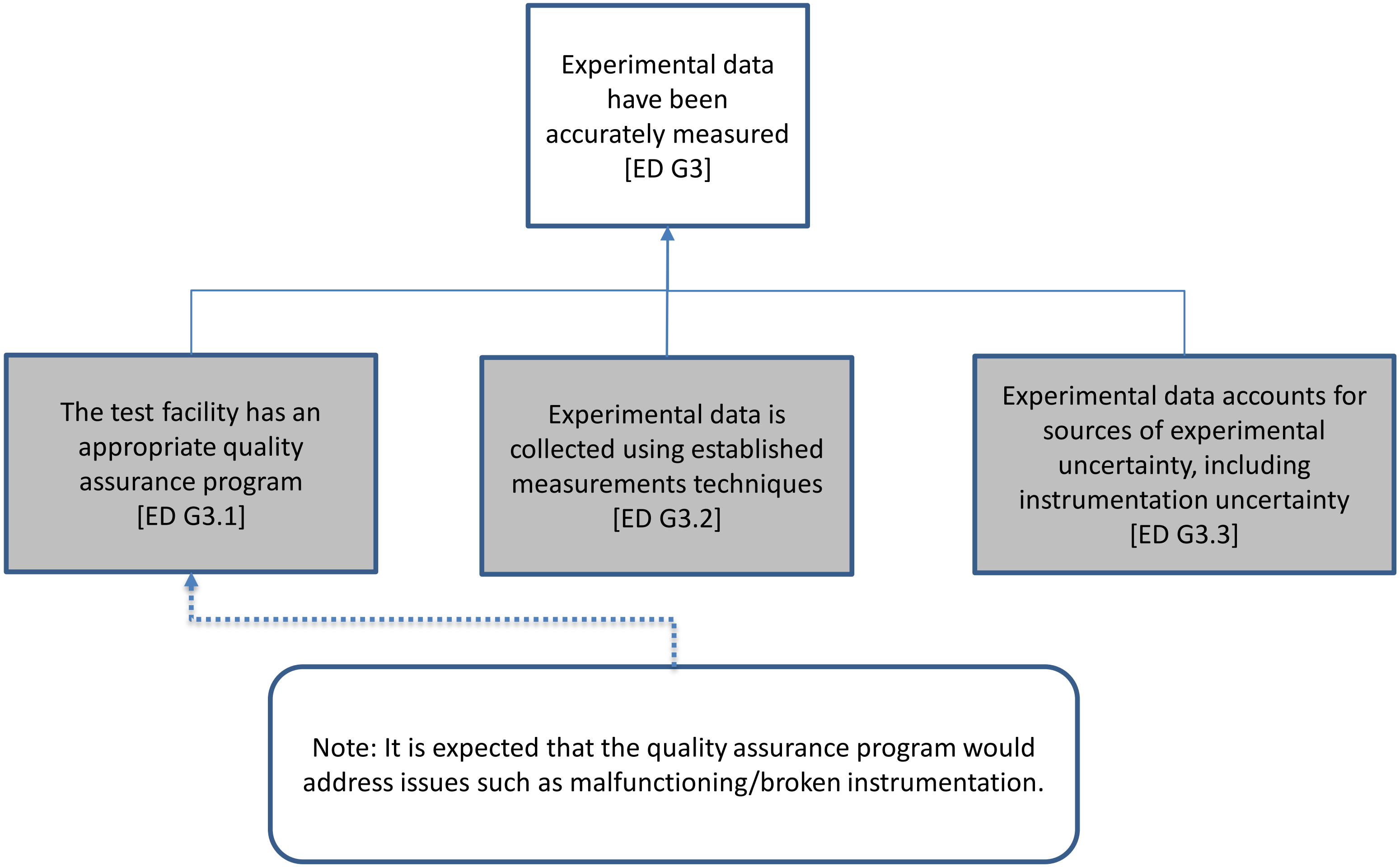


Experimental Data (ED) Assessment Framework

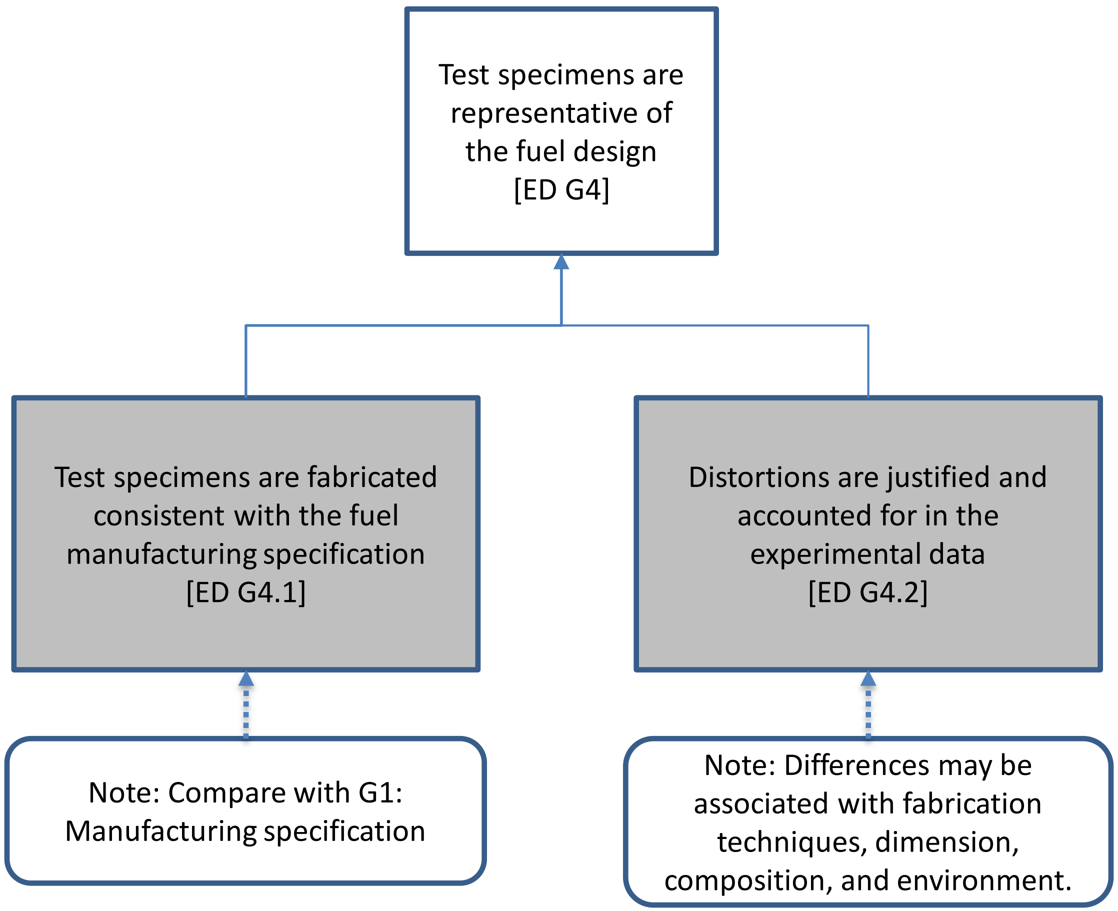


Note: The types of test that should be considered in the test envelope include (1) **steady-state integral testing** of the fuel system in a prototypical environment, (2) **high power and undercooling tests** to address AOO conditions and to assess design margin, (3) **power ramp testing** to assess fuel performance during anticipated power changes, and (4) **design basis accident tests** to establish margin to fuel breach and contribution to source term under accident conditions

ED G3: Data Measurement



ED G4: Test Specimens



Summary of FQ Assessment Framework

- Supported by two additional assessment frameworks
  - Evaluation Models
  - Experimental Data
- A total of 60 terminal goals
  - 11 in the main FQ Assessment Framework
  - 2 x (14 in the Evaluation Model Assessment Framework)
  - 3 x (7 in the Experimental Data Assessment Framework)

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Near Term Activity

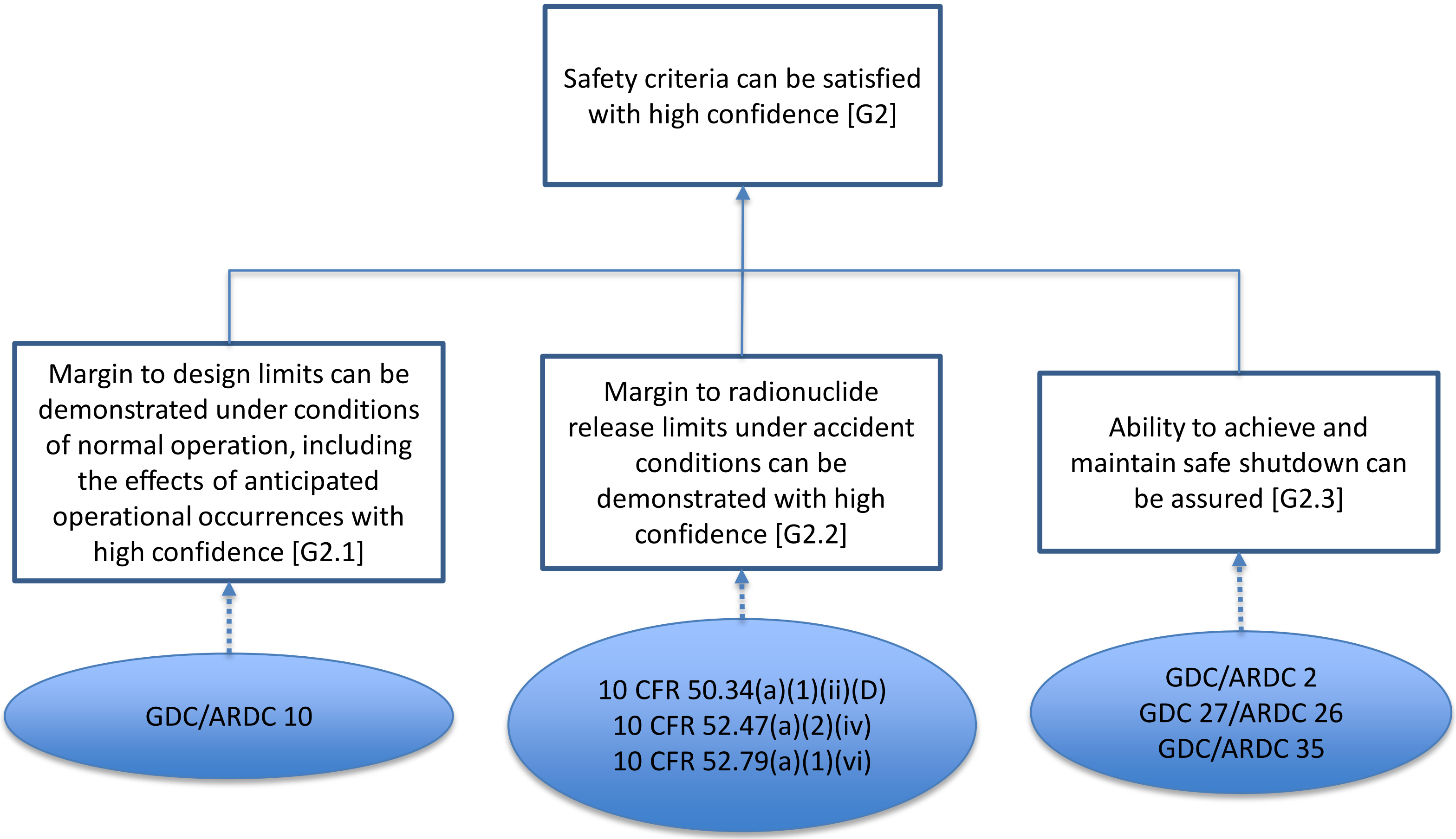
- Exercise framework
  - Contract with Argonne and Idaho National Laboratory to evaluate a generic metal fuel design (e.g., EBR-II Mark-V/VA)
  - Consistent with approach for Aurora COL
    - Reliance on EBR-II data

Next Steps

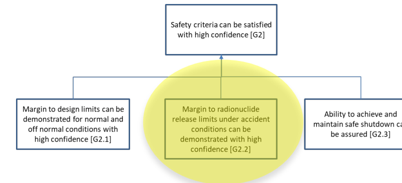
- Convert report into a regulatory document (e.g. NUREG)
  - Address/incorporate volunteered comments
  - OGC review
  - Notice and comment
  - ACRS Full Committee – September 2021

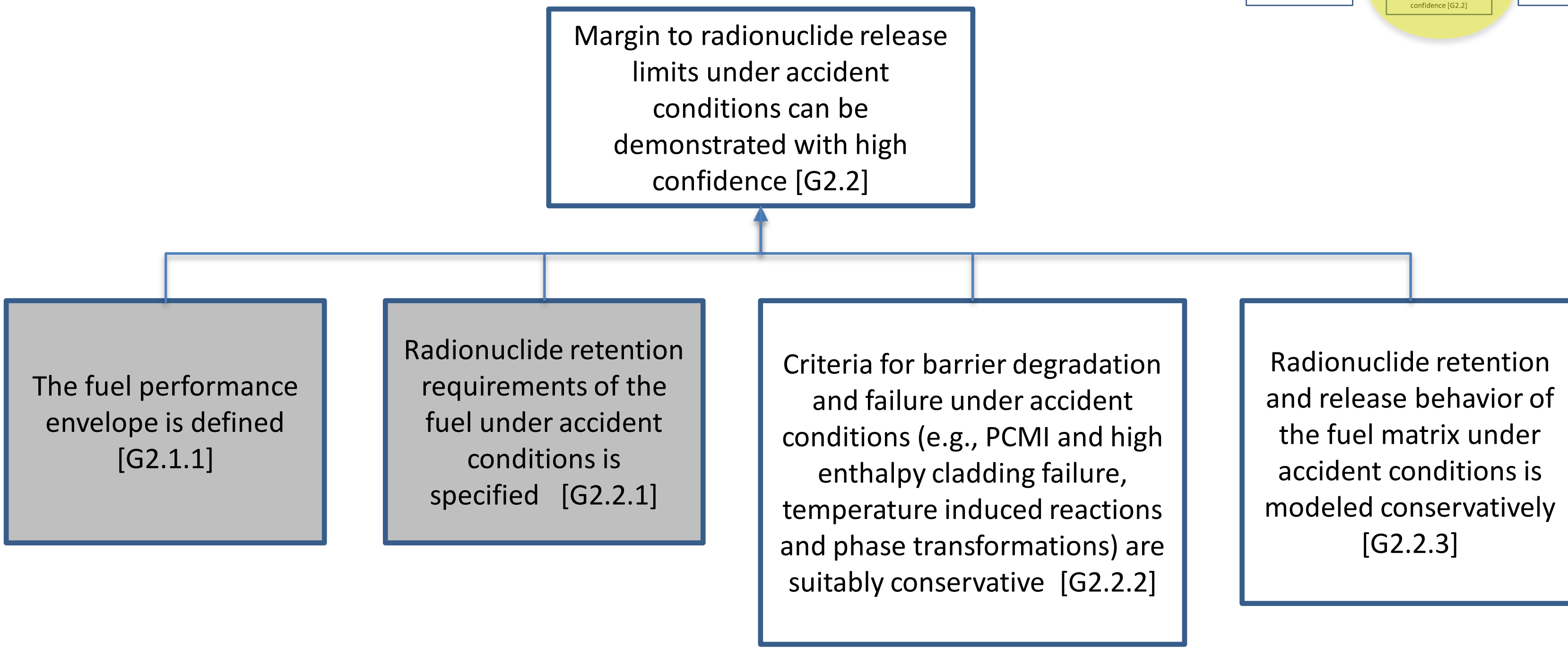
Backup Slides

G2: Safety Criteria

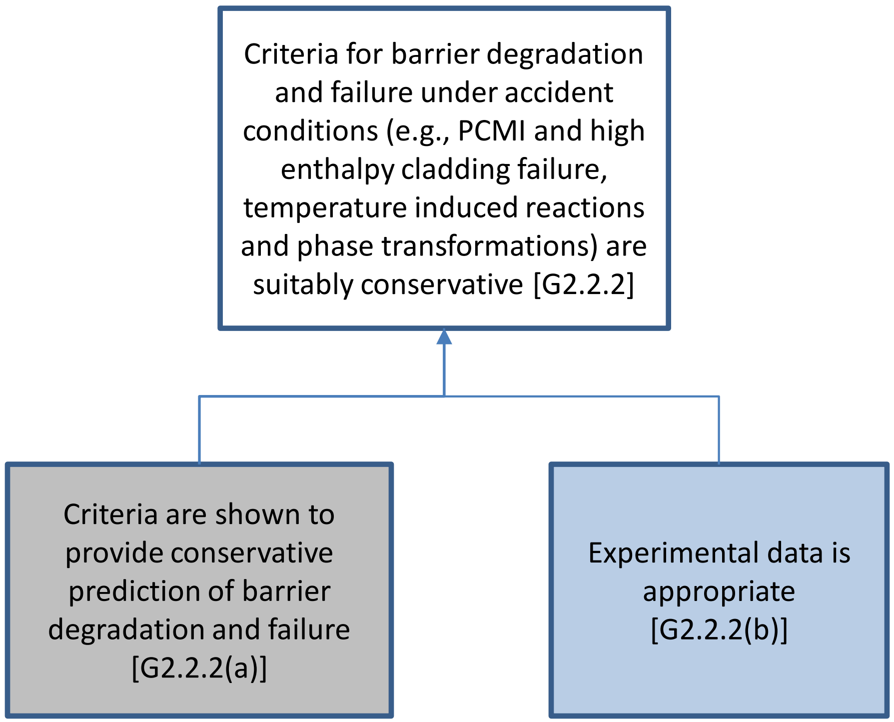


G2.2: Radionuclide Release Limits





G2.2.2: Criteria for Barrier Degradation



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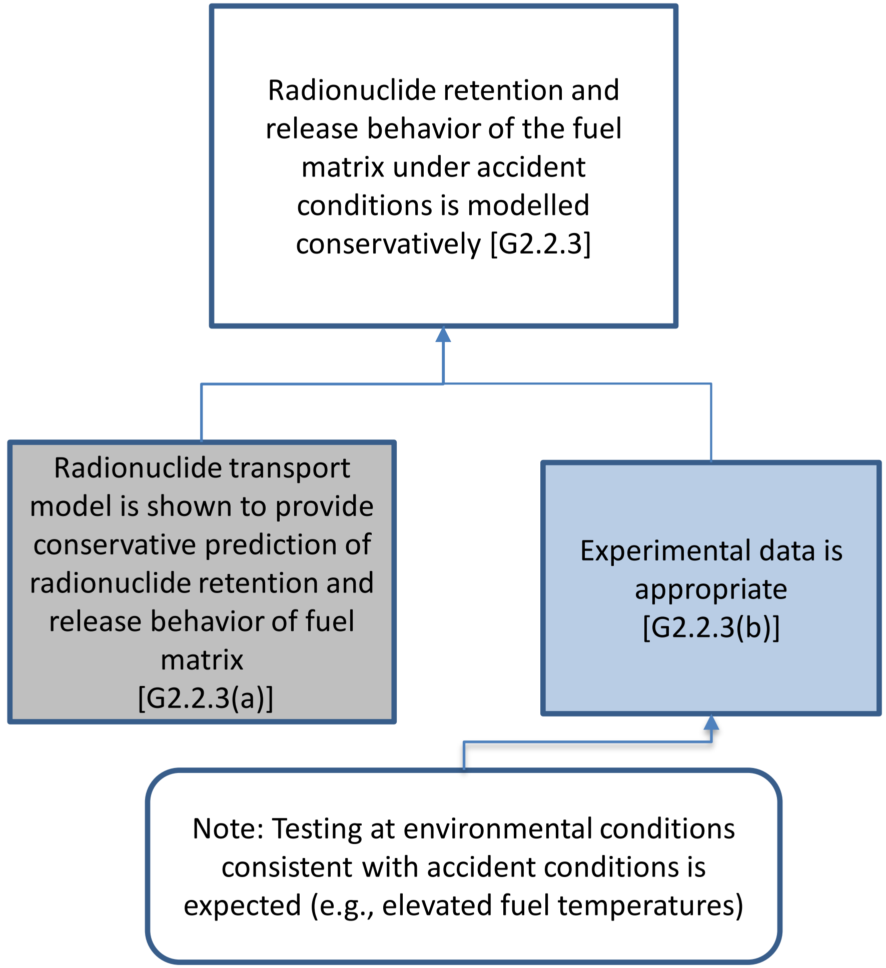
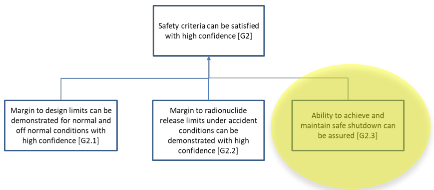
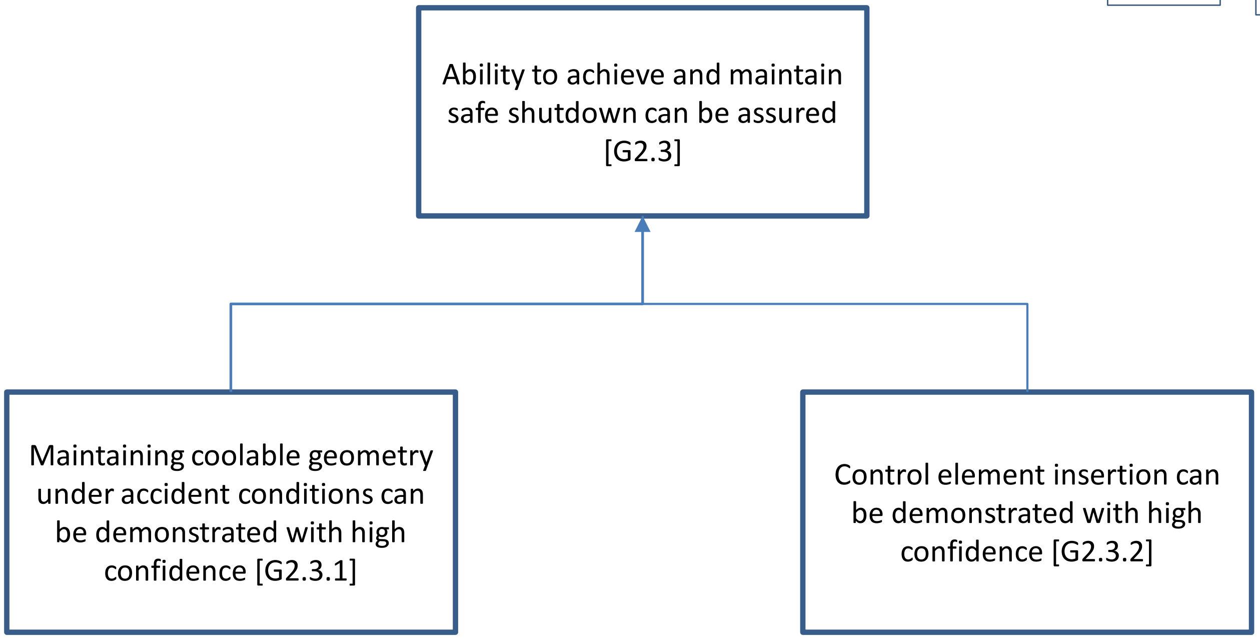
G2.2.3: Conservative Modeling

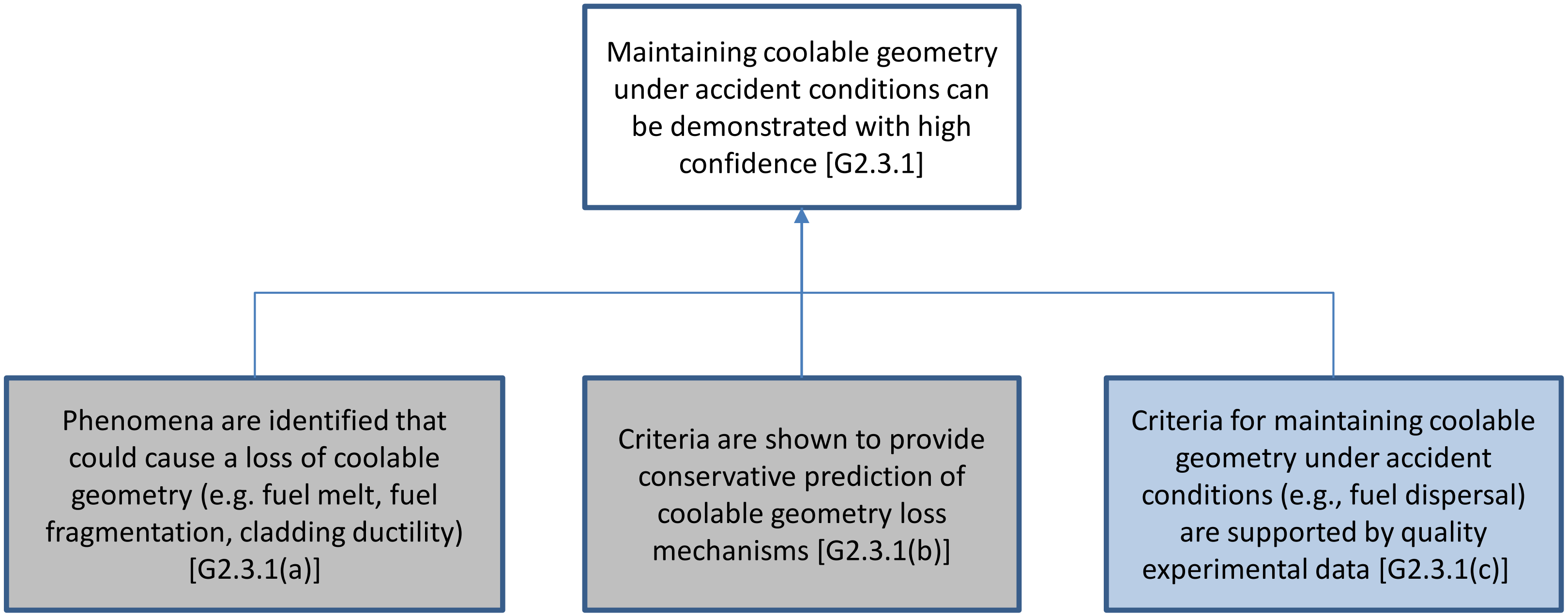


G2.3: Safe Shutdown





G2.3.1: Maintaining Coolable Geometry



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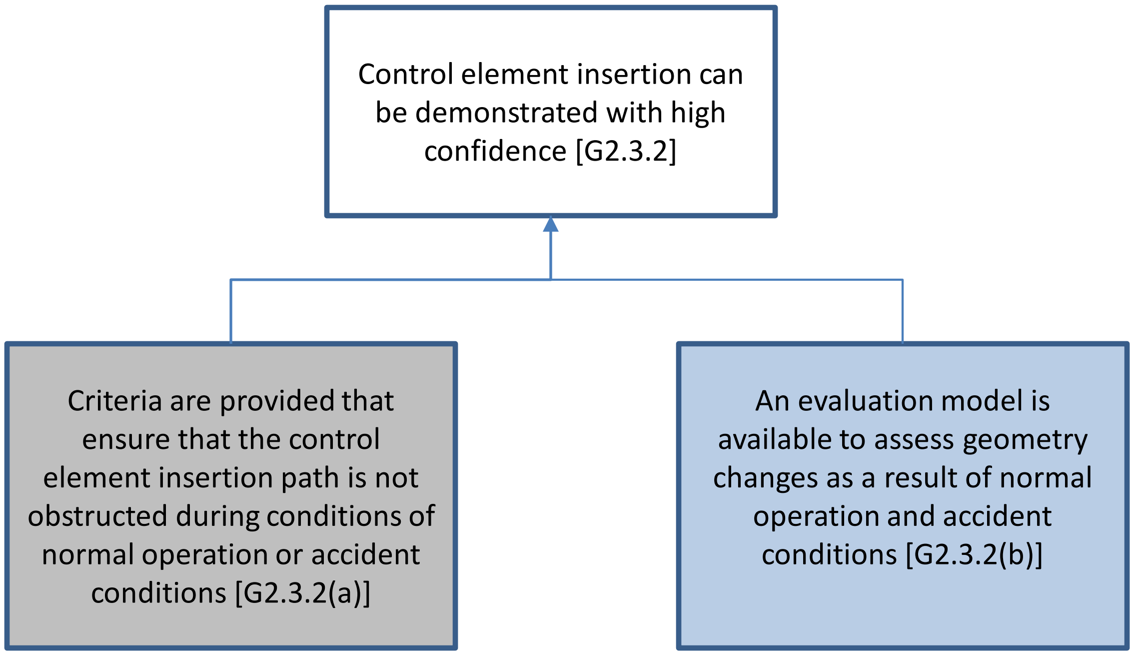
G2.3.2: Control Element Insertion



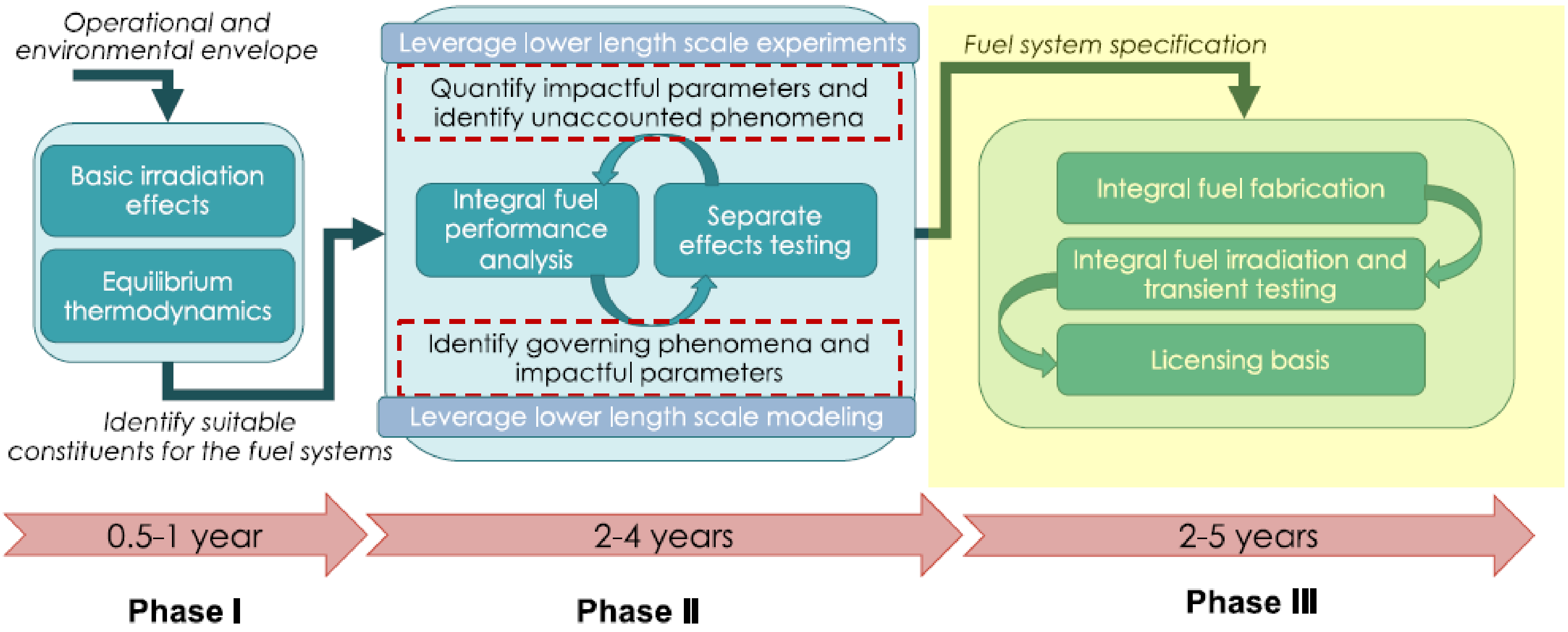
SRP vs White Paper

	NUREG-0800	White Paper
Safety Case	Implicitly assumed to be similar to a traditional LWR (i.e., limited consideration of fission product retention within fuel)	Flexible – data requirement is commensurate with assumed contribution to source term
Fuel failure mechanisms	Fuel is evaluated against known fuel failure mechanisms for LWR fuel	Relies on evaluation model assessment to identify important fuel failure mechanisms
Criteria for manufacturing	Not explicitly stated, but manufacturing dependent failure criteria are provided in associated guidance (RG 1.236)	Specification of key parameters (geometry, composition, and microstructure) identified as objective criteria

Test Based FQ (JNM 2007)

		concept	property measurement, and ex-pile tests	2
4	Final Process Selections and integration	Component and/or bench-scale validation in a laboratory environment	Establish proof of concept. Fabrication of irradiation testing samples in accordance with QA requirements. Design parameters and features established Performance phenomena identified with proof-of-concept irradiation testing	
5		Component and/or breadboard validation in a relevant environment	Irradiation testing of prototypic rods/compacts under nominal representative conditions (e.g., fission densities, fuel and cladding temperatures, cladding damage rates) is performed and assessed	3
6	Full-scale integrated testing	System/subsystem model or prototype demonstration in relevant environment	Prototypic rod/compact and assembly/element irradiation in representative environment, under full range of relevant normal and off-normal conditions. Representative compositions Design parameters investigated Information is sufficient to support a Fuel Specification and a Fuel Safety Case (which, in turn, support larger System Demonstration to achieve TRL7)	
7		System prototype demonstration in prototypic environment	Fabrication of reference fuel derived from production supply sources irradiated to design conditions and utilization Irradiation in representative environment Prototypic design. Prototypic fabrication processes. Representative compositions	4
8	Full-scale demonstration	Actual system completed and qualified through test and demonstration		
9		Actual system proven through successful mission operations		

AFQ (JNM 2020)



Operational and environmental envelope
Basic irradiation effects
Equilibrium thermodynamics
Identify suitable constituents for the fuel systems
Leverage lower length scale experiments
Quantify impactful parameters and identify unaccounted phenomena
Integral fuel performance analysis
Separate effects testing
Identify governing phenomena and impactful parameters
Leverage lower length scale modeling
Fuel system specification
Integral fuel fabrication
Integral fuel irradiation and transient testing
Licensing basis
0.5-1 year
2-4 years
2-5 years
Phase I
Phase II
Phase III