Official Transcript of Proceedings

NUCLEAR REGULATORY COMMISSION

Title: Advisory Committee on Reactor Safeguards
Metallurgy and Reactor Fuels Subcommittee

Docket Number: (n/a)

Location: Rockville, Maryland

Date: Monday, June 8, 2015

Work Order No.: NRC-1638 Pages 1-265

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

UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

+ + + + +

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

(ACRS)

+ + + + +

METALLURGY AND REACTOR FUELS SUBCOMMITTEE

+ + + + +

MONDAY

JUNE 8, 2015

+ + + + +

ROCKVILLE, MARYLAND

+ + + + +

The Subcommittee met at the Nuclear Regulatory Commission, Two White Flint North, Room T2B1, 11545 Rockville Pike, at 8:31 a.m., Ronald G. Ballinger, Chairman, presiding.

COMMITTEE MEMBERS:

RONALD G. BALLINGER, Chairman

DANA A. POWERS, Member

JOY REMPE, Member

PETER RICCARDELLA, Member *

GORDON R. SKILLMAN, Member

DESIGNATED FEDERAL OFFICIAL:

CHRISTOPHER BROWN

ALSO PRESENT:

TAE AHN, NMSS/DSFM

HUDA AKHAVANNIK, NMSS/DSFM

MICHELLE BALES, RES/DSA

KRISTINA BANOVAC, NMSS/DSFM

GORDON BJORKMAN, NMSS/DSFM

KRISTOPHER CUMMINGS, NEI

ROBERT ER, NWTRB

DONNA GILMORE *

PATRICIA GORTON *

JOHN GREEVES, TIG

ACE HOFFMAN *

CHRISTIAN JACOBS, NMSS/LTSFMB

CHRISTINE LEGGETT, NMSS

MARVIN LEWIS *

MARK LOMBARD, NMSS

TERRY PICKENS, Xcel Energy

MERAJ RAHIMI, NMSS/DSFM

JOHN SCAGLIONE, ORNL

HAROLD SCOTT, RES

DAVID TANG, NMSS

JOHN VERA, NMSS/DSFM

BERNARD WHITE, NMSS/DSFM

JOHN WISE, NMSS/DSFM

EMMA WONG, NMSS/DSFM

*Present via telephone

AGENDA

P R O C E E D I N G S

8:31 a.m.

CHAIR BALLINGER: Good morning, the meeting will now come to order. This is a meeting of the Metallurgy and Reactor Fuels Subcommittee. I'm Ron Ballinger, Chairman of the Subcommittee. ACRS members are present.

For those of you here, we have a new regime where you have to - it's push to talk on these microphones, sorry, and that includes the folks up front.

Members present are Dick Skillman, Dana Powers, myself, Joy Rempe, John Stetkar may be joining us and there may be others at some point during the meeting. Pete, oh, Pete Riccardella is on the phone, the bridge line.

The purpose of this meeting is to receive a briefing on the status of research and licensing approaches for high burnup fuel in storage and transportation, and particularly we'll hear about a draft Regulatory Issue Summary, RIS, considerations in licensing high burnup spent fuel in dry storage and transportation under development by NMSS. We will also hear from RES, ORNL, and NEI on this subject matter.

The rules of participation in today's meeting were announced as part of the notice of the meeting previously published in the Federal Register on May 22, 2015. We have received no written comments or requests for time to make oral statements from members of the public regarding today's meeting.

A transcript of the meeting is being kept and will be made available as stated in the Federal Register notice. Therefore, we request that all participants in this meeting use the microphones located throughout the meeting room. Push to talk, if you will, when addressing the Subcommittee.

Participants should first identify themselves and speak with sufficient clarity and volume so they can be readily heard. Please silence all phones and anything else that goes beep, please.

Since today's meeting is open to the public, we have an additional bridge line set up for folks who have requested to call in. I don't think there's anybody on the line, right?

MR. BROWN: I'm not sure, but -

CHAIR BALLINGER: Is it open?

MR. BROWN: - we can open it at the end.

CHAIR BALLINGER: Okay, we'll open it at the end. Dr. Rempe has identified as having a conflict of interest and will limit her participation during certain presentations.

We have tentatively scheduled this topic for the July full committee. The subcommittee will determine if we will go forward with this topic to the full committee at the end of this meeting.

We'll now proceed with the meeting and I'll call upon Mark Lombard, who is over there, Director of Division of Spent Fuel Management, to give a brief introduction and introduce the presenters. Mark?

MR. LOMBARD: Thank you, Dr. Ballinger. I appreciate it. As you may know, our position on high burnup fuel is that it's safe. Long-term storage of high burnup fuel and eventual transportation is safe.

And we appreciate the subcommittee taking up the review of this document, and we look forward to your comments and feedback on it. It's a very important document for us going forward.

You know, in many respects, we're finding as more and more research and more and more analysis is done, and we review more and more applications, storage and transportation applications for high burnup fuel, that in many respects it's actually better than low burnup fuel. The performance of high burnup fuel is actually better than low burnup fuel.

We have approved several transportation and storage applications that involve high burnup fuel, and again, that position that we have really staked in those applications as our - if we improve those, is that long-term storage and transportation of high burnup fuel is safe.

We developed the risks based on the risk Regulatory Issue Summary based upon lessons learned from those reviews, and we wanted to have all of that thinking, all of that information in one location so that applicants could use that information for future applications that they would present to us.

We did have a meeting with NEI. NEI presented their comments to us about a month or so ago. We met three weeks ago with them to go over their comments. That was a public meeting.

We not only received feedback from the industry, from NEI and the industry, but also from several members of the public. And again, we look forward to more of that feedback as we go forward in this important endeavor.

I think from that standpoint, that takes care of my opening remarks. Presenting today we have Huda Akhavannik, who actually was our lead for this project. She's been working on this for about two-and-a-half years, not full-time, but working on it really very diligently for about two-and-a-half years and done a great job. She'll be kind of leading us off today.

And then Meraj Rahimi is the branch chief of Criticality, Safety, and Risk Assessment Branch, who also has been a key player in this. He's been leading the effort from his standpoint.

John Scaglione from Oak Ridge has been a very important player in this as well, and he'll be presenting today.

And someone who used to be known by a different name as Dr. Rempe went through this morning, Michelle Bales is here, formerly known as Michelle Flanagan. She's been a key member of leading this effort from the research standpoint, Office of Research standpoint, and she'll be presenting later on this morning as well.

So, I will turn it over to Huda to take it away.

MS. AKHAVANNIK: Actually you're turning it over to Meraj.

MR. LOMBARD: Oh, I'm sorry, turning it over to Meraj. Sorry, Meraj.

MR. RAHIMI: Sure. Thank you very much. Thank you, Mark. I guess before I start I do need to acknowledge the contribution of many folks, the High Burnup Task Force, the Division of Spent Fuel Management, there are a number of members or the members, you know, David Tang, and Jimmy, Bernie White.

So if I don't list all of the names, I want to thank the High Burnup Task Force and really the efforts of the Office of Research and Oak Ridge National Laboratory, and so I want to acknowledge, you know, their contribution.

We would like today to present the big picture of the high burnup. As you all know, this high burnup issue has been existing for, I guess, quite a few number of years, and especially in licensing and transportation casks, transportation and packaging and storage casks.

We have to at the same time to resolve the technical issue but through the licensing action, so it was going in parallel. So with that, let's start.

As Mark mentioned, my name is Meraj Rahimi. I'm the Chief of Criticality, Shielding and Risk Assessment Branch in the Division of Spent Fuel Management at NMSS.

Okay, what is high burnup fuel? Well,

historically how have we been licensing storage casks and transportation packages? Historically, safety analysis for design of storage casks and transportation packages has relied mainly on the fuel, spent fuel cladding to confine the fuel pellets, and as loading, and fuel assembly being intact.

In a way that the applicants normally do the safety analysis report for the criticality, shielding, and confinement and containment to some extent, and thermal, assuming the fuel assembly's geometry does not change. That has been the assumption especially in the low burnup, when the fuel has been low burnup.

And low burnup, what I mean, when the spent fuel assembly average burnup is less than 45 gigawatt-days per metric ton of uranium. That's a demarcation line and we call that low burnup.

So historically that's what the applicant has been assuming, that the geometry does not change under design basis load of the storage casks and transportation packages. And next slide, please.

So what are the - as loaded condition - and - research has been done. Some research has been done. I cite the Bilone research. But they indicated there is a possibility of when the fuel is burned more than

25 gigawatt-days per metric ton, and when the fuel is placed in a cask or transportation package and it goes through the draining and drawing process, the temperature of the cladding increases.

And because of this high increase - because this is the first time spent fuel assembly has been out of its sort of normal environment, being in a water coolant, and you're putting for the first time in the storage casks and you're draining and drawing.

And during that time, when it's going through a transition and you don't have your heat transfer system taking place, so the cladding temperature increases, and as a result of this, increasing temperatures - next slide, please.

What is called - a phenomena is called the hydride reorientation could happen. And what is hydride reorientation? Normally in a cladding, spent fuel cladding, you've got hydrides, some of them hydrides from the - when it was manufactured, and most of it was during hydrogen uptake when it was in the reactor during normally three cycles of operation.

These hydrides, they are in circumferential direction. And when the temperature increases in the cladding, these hydrides, they go into solution form in the cladding. And as a result of the temperature going up, you've got the pressure inside the fuel increases as well.

So you've got the hydrides in the solution form and you've got high pressure in there, you know. It could go 90, 100, 110 megapascal. And what it does, it pushes the hydrides in the cladding to go from circumferential to radial direction.

CHAIR BALLINGER: 90 to 100 MPa?

MR. RAHIMI: MPa.

CHAIR BALLINGER: Oh, stress on the cladding.

MR. RAHIMI: Yes, and so it's in the solution form. That's during drawing. This is what's happening when the temperature increases and the pressure inside increases.

MEMBER SKILLMAN: When you introduced the topic you said, "might occur."

MR. RAHIMI: Right.

MEMBER SKILLMAN: Explain might. Five percent of the time, 95 percent of the time? What do you mean when you say might, please?

MR. RAHIMI: This has been sort of reproduced under a laboratory environment, this cladding. We, you know, we haven't confirmed because right now there are tests going on at Oak Ridge with real spent fuel to see if indeed that is the case. And it depends on the hydride contents, the amount of hydrogen.

It happens at various, you know, temperature. I mean, it could happen - back in 2003 when we wrote ISG-11, we thought that the - if the temperature is below 400 degrees Celsius, the cladding temperature, this stuff doesn't happen.

But when they did more tests, they said, "Well, it's a possibility it might happen even at the lower temperature," and the amount of hydride reorientation changes. It depends on the cladding. You know, is it ZIRLO? It is M5? So each material is different.

So that's what they produced under the laboratory, you know, conditions. That's why - I mean, I don't want to use the word definite because, you know, it depends on the cladding type. It doesn't happen for all cladding types.

MEMBER REMPE: Meraj? I guess I'd like to pull that string a little further.

MR. RAHIMI: Yes?

MEMBER REMPE: Back years ago when they did the low burnup fuel tests out there at Idaho, they spent some time doing temperature profiling, right?

And again, it's kind of fortunate that I saw that Dr. Einziger is in the audience. But apparently they did some characterizations where they had the - during the vacuum and drying process, they had the temperature go to 415 degrees C for 72 hours?

MR. RAHIMI: Mm-hmm.

MEMBER REMPE: And that was low burnup fuel. So wouldn't one think that high burnup fuel would go to higher temperatures?

MR. RAHIMI: Yes, you know, when we wrote even ISG-11, we even allow for a period of time to go up to 570, you know, degrees Celsius, you know. In 2003, we did nothing -

MEMBER REMPE: Okay, and then the other question I had when I read this article, apparently they used thermocouple lances just like the ones they're going to put in the high burnup test, and those thermocouple lances are, I mean, thermocouples in the guide tubes.

They're not on the cladding. So how do you know what the temperature is on the cladding when all you have is a thermocouple quite a distance away with a lot of gaps and stuff like that going on?

MR. RAHIMI: I believe the demo you're referring to, the future demo, correct?

MEMBER REMPE: Well, in the past one they have data for low burnup fuel, and again, it was only thermocouples placed in the guide tube a distance away from the cladding.

And so how do you know what the temperature is on the cladding for the high burnup demo that you're going to use as a basis for this concern about the hydride formation and things like that? I just am puzzled.

Did somebody in these tests that are laboratory tests, do they actually have thermocouples on the cladding? And how do they account for the heat transfer from what you're measuring, and how would you account for it in the high burnup demo versus what's on the cladding? Is there a good basis for that - what that peak temperature is?

MR. RAHIMI: I mean, normally, you know, as you said, they measure the temperature inside the cavity, inside the cask cavity, and normally there is sort of a calculation, you know, predicting what is the cladding temperature.

But in this upcoming demo which is done by industry, the plan is for EPRI, DOE, and industry to perform a similar demo that was done in the 80s and 90s at Idaho. I believe they are planning to measure the temperature right at the cladding.

MEMBER REMPE: No, I don't think that's true.

MR. RAHIMI: And they have -

MEMBER REMPE: It's the same type of plan.

MR. RAHIMI: Still there -

MR. CUMMINGS: Kris Cummings, NEI. So it's just not practical to be able to directly measure the cladding on the fuel. It's just not a practical -

MEMBER REMPE: I understand that.

MR. CUMMINGS: - consideration in a big cask that's sitting on a SCC pad at a utility site. Now, because -

MEMBER REMPE: I understand that it's not practical, but this whole process is really counting on, "Oh, we're going to keep the temperature below a certain value -

MR. CUMMINGS: Sure.

MEMBER REMPE: - for a certain amount of time on the cladding," and you've got to make some assumptions about heat transfer between what you're measuring and the cladding, and I just am trying to understand the basis for those assumptions.

MR. CUMMINGS: Right, so the demo with the thermocouple lances and measuring the temperature in the guide tubes will allow the thermal model verification.

So there will have to be a calculation that will have to take the temperature measured by the thermocouple lances and correlate it or take it back to a temperature on the cladding. That's about the best that we can do at this time without making a direct measurement because that's not possible.

CHAIR BALLINGER: But that's not really a correlation then. You have no benchmark.

MR. CUMMINGS: Maybe correlation is not the right word, right.

CHAIR BALLINGER: Yes.

MR. CUMMINGS: Right, but it will rely on a thermal analysis.

MEMBER REMPE: Yes, but I'm just kind of wondering what's the basis for that thermal analysis? For example, if one were doing another demonstration looking at drying, such as an IRP demonstration at Penn State, one might be able to try and simulate that and get a basis for that heat transfer loss is what I'm king of wondering about.

MR. CUMMINGS: Well, there is some other work being done in terms of drying. There is a drying at South Carolina State.

MEMBER REMPE: It is South Carolina, not Penn State, you're right.

MR. CUMMINGS: Yes, so they are. I don't know whether they're looking at the temperatures on the cladding in that because that's specifically looking at how much water you actually get out and this issue about residual water. So I don't think the purpose of that test is to get -

MEMBER REMPE: Right.

MR. CUMMINGS: - cladding temperatures. And that's being done with, I believe, dummy fuels.

MEMBER REMPE: But they simulate different heat.

MR. CUMMINGS: They do simulate different heat.

MEMBER REMPE: Yes, and so it could be done. But right now I don't understand, back to the main question, how one has confidence in the temperature of the cladding when all you're measuring is the temperature inside some guide tube.

MR. CUMMINGS: Going into this, we talked about whether - having EPRI come to talk about the demo, and we could certainly have them come and do that, and we talked a little bit with Ron Ballinger about that at a future ACRS meeting providing some of the additional details.

But if you want to get into, you know, how is that correlation or that calculation going to be done, and how you actually do that from thermocouple lance to the cladding temperature, then we can have EPRI come and talk about that.

MEMBER REMPE: Yes, and how you have confidence in the values. Thank you. Sorry to pull the string so far, but I am curious about it.

MR. RAHIMI: So that's the hydride reorientation phenomenon. Next slide, please. So now after the drying, now what happens? The cask is put in dry storage, and as the cask and the fuel are cooled down, the fuel is cooled down, and what happens to the cladding, it could go through a transition going from being ductile to brittle, and that is based on some of the tests that are done at Argonne.

Those are some of the data for some of the - a few data points for some of the claddings for ZIRLO. And that transition at that temperature when the cladding temperature goes down around you can see from - it goes below 200, around 200 degrees Celsius. It goes - it could go through a transition becoming more ductile, and what the call that transition point is ductile to brittle transition. Next slide, please.

So now, having gone - the cladding being ductile, when you're on a design-basis load that I had mentioned earlier where the storage casks, what are the design-basis load, seismic event. You know, casks tip over.

And the transportation, under the transportation, what are the design-basis load under transportation? You've got normal vibration under normal condition of transport and you've got impact.

And normally these casks, they need to withstand under hypothetical accident conditions which includes a 30-foot drop, which would bound all the real accident in there.

So historically, low burnup fuel, based on analysis, it has been assumed the fuel cladding can survive those design-basis loads. But with the burnup fuel, we are confirming indeed that is still the case. Next slide, please.

MEMBER SKILLMAN: Let me ask you a question, please. You introduced the topic of the transportation loads and you were quick to point out the casks dropped to nine meters, the 30 feet onto an unyielding solid surface. Where in the Reg Guide - and I'm going to ask the question. Now maybe it's the wrong time and you can later.

MR. RAHIMI: Sure.

MEMBER SKILLMAN: Where in the Reg Guide is there, if you will, a reconciliation of the 71.73 hypothetical accident conditions to the testing that is being done recognizing perhaps the fragility, that is the transition from ductility to brittle, fuel?

What I'm particularly interested in is the impact load. I understand the point drop and I understand the drop onto the unyielding surface. I understand the lance.

But what has my attention is the 70 or 100 mile an hour cask on a truck or on a railroad car, and how the package, even with its overpack, protects the contained fuel within the parameters of the R&D that you're going to talk about?

That is the mechanical strength, the residual mechanical strength of the fuel. Can you speak to that or tell me that you will speak to that sometime later in the morning?

MR. RAHIMI: We can speak to it now. David Tang of the High Burnup Task Force, he's a structural engineer.

MEMBER SKILLMAN: I'm really - I'm drawing out of 71.73.

DR. TANG: Okay, thank you. David Tang, Senior Structural Engineer, spent fuel management. I believe that what you refer to is 71.73 C1, free drop nine meters drop condition.

MEMBER SKILLMAN: Right.

DR. TANG: Now, we have been looking to see the load bear on fuel. For that matter, we considered the fuel to be ductile, the fuel cladding to be ductile. So we have licensed and issued a certificate of compliance for that matter.

For high burnup fuel, there has been some consideration whether the fuel cladding will be, let's say, brittle. For that matter, whether it can, again, sustain this kind of challenge was a question. That's why we are focusing our investigation and research on that.

Now, having said that, in general for this 30-foot drop scenario, the cask, for instance, for the side drop, for the most, say, damage condition, was subjected to about 50 to 60 G, that kind of challenge. I'm talking about the casks being protected by impact limiters.

For the drop, there could be close boxing conditions that the fuel geometry could change. That condition, again, would be about 50, 60 G. So we know what kind of general accident conditions the fuel will be subjected to, and we have been doing this for low burnup fuel without any problem in general.

Now having said that, the current consideration is for the normal conditions of transport, that's one, vibration. For the shock, there could be some kind of bounce in some railroad track you have to cross by. So that kind of vibration or shock is very minimal, perhaps it is about 10, 15 G to the most. I'm talking about normal conditions of transport.

Again, for the hypothetical accident condition, the nine meter drop we talked about, 60 G or 50 G, and for that scenario. Does that answer your question?

CHAIR BALLINGER: I'm not sure you did.

MEMBER SKILLMAN: Well, yes and no. I hear you say that the 10-meter drop gives a 50 to 60 G loading whether it's an end drop or a side drop. I got that.

DR. TANG: Correct.

MEMBER SKILLMAN: What I'm wondering is as you provide the ISG, the Interim Staff Guidance, if you're going to provide what is either a Tabular connection or some presentation that demonstrates that the research that you're conducting for the ductility, for the fragility for the high burnup fuel is being addressed by the accident requirements of 71.73 for that fuel?

Because the going in position here is once you load these casks, these casks do two things. They sit quietly at a site and sometime later they get transported to some place.

And so, it seems to me that there needs to be a discussion about how, when the package is developed and later shipped, that the data in the ISG and the testing confirms that the fuel will remain intact for the spectrum of accidents that that cask can experience.

DR. TANG: You are totally correct. What we will try to present today, this morning, is for the normal conditions of transport. That is one part. The second part deals with, say, hypothetical accident conditions, how the high burnup fuel will survive, or some other considerations such as, say, consequence analyses, our fuel will be retained or not retained.

It's an analyzed configuration for the high burnup fuel for these kinds of challenges, for one, whether the moderator will be allowed to get into the casks. So there are many other provisions or considerations that can be considered, can be factored into the design, the evaluation of the high burnup fuel transportation.

MR. RAHIMI: Thank you, David.

MEMBER SKILLMAN: Thank you.

MR. RAHIMI: We're going to address this now that I understand a little bit more of what you're asking. And actually, I was going to ask Dr. Bjorkman to speak.

Especially the last slide, we're going to show exactly how these test ductile to brittle transition, how we're going to fold it into sort of a form of a guidance and provide guidance to the applicant. Gordon will provide a little bit of explanation.

DR. BJORKMAN: Typically in the -

MR. RAHIMI: Introduce yourself.

DR. BJORKMAN: My name is Gordon Bjorkman. I am a Senior Advisor for Structural Mechanics in the Spent Fuel Management Division. Is this microphone working?

MR. RAHIMI: Is it on? Yes, it is on.

DR. BJORKMAN: Okay, typically in a side drop, as David mentioned, you're going to get something on the order of about 50 to 60 G. At that load level, the strain in the cladding is well below one percent strain. Likewise, in an end drop, the buckling of the fuel rods will produce strains that are well below one percent strain as well.

And as you'll see in the data that's going to be provided to you today, the fuel cladding, high burnup fuel cladding can sustain strains well above one percent strain without failure.

So the data that we're going to be presenting and the research that we're doing is, you know, we're very - it's very, very encouraging. Let's put it that way. So it's very, very important.

MEMBER SKILLMAN: You've answered my question. Thank you. I understand. Thank you, sir.

MEMBER POWERS: Well, you do raise a question. When you say well above one percent, well above is defined as two?

MEMBER SKILLMAN: Well above. Would you give us a definition of well above please, Gordon?

DR. BJORKMAN: Well above one percent strain. As you'll see from the stress strain curves which will be shown today, strains are - can easily go prior to failure, and we saw no failures in these static tests. The strains got well into the approximately two percent strain.

MEMBER SKILLMAN: Thank you.

MR. LOMBARD: If I might add too, in compliance with Part 71, the hypothetical accident condition requirements, it really depends on the package itself, the specific package. So some packages will assume cladding integrity is maintained.

Other packages assume some level of cladding failure and are still meeting requirements of Part 71 even with some cladding failure.

MEMBER SKILLMAN: Well, I was going to ask that as a followup question sometime later because the package and the overpacks really determine what the acceleration load is.

MR. LOMBARD: Exactly, that's true.

MEMBER SKILLMAN: So it can be that at some point in time for the high burnup fuel a standard package is fine if you have a different overpack to arrest the acceleration, so I understand that thoroughly. But this has been a good side discussion. Thank you.

MR. RAHIMI: Well, thank you for the question. All right, next slide, please. Okay, so the basis - there are really two main pillars for this Regulatory Issue Summary that they just issued for public comment and I will go into details.

Years ago when we started this, we said we want to go in parallel. We want to do tests and at the same time do consequence analysis in case the tests, you know, reveal that the high burnup fuel are not as robust as what we think. So that was a few years ago when we started on tests and the consequence analysis.

So the test, this is the sort of a new reg that we issued. It's the phase one of the test results, and the tests are going. We're about to embark on the second phase of the tests. These tests are done at hot cell at Oak Ridge National Laboratory, and Michelle Flanagan - Michelle Bales will speak to those tests.

And the consequence analysis that we're doing at the same time, John Scaglione from Oak Ridge, he'll go into details. So basically the high burnup risks, these are the two pillars.

It says that if applicant - these are some of the tests we've done on specific cladding, and they can go through the test routes and apply those tests to their application. If those tests are not applicable for their cladding type, they can go through a consequence analysis. So that's basically the approach of the Regulatory Issue Summary. Next slide, please.

Those are the two, the basic technical

study. The other two are the ISGs that feed into the Regulatory Issue Summary. This is ISG-11 Revision 3, which is the - goes into temperature limit, pressure limit, in order to avoid the hydride reorientation.

And the other ISG that was issued, the ISG-24, is the use of a demonstration program which applies basically to the storage side. So you've got those two ISGs and those two technical studies. They make really - they are the makeup of the Regulatory Issue Summary on high burnup fuel. Next slide, please.

So what is the Regulatory Issue Summary? It provides a road map on some approaches acceptable to the NRC. Remember that when we started a few years ago, we had an application in front of us at the same time to review for high burnup fuel.

We can't say, you know, don't submit any application until we finish our research. So our approach is informed by real design, real situation. And as Mark mentioned, we have approved a number of the application codes for storage and transportation.

So this is for providing sort of a general guidance, intermediate guidance, to the industry, making sure the licensing process is more efficient. Because we did spend quite a lot of time on the application, high burnup application, because of lack of the guidance in terms of providing guidance to the applicant through numerous interaction.

But of course, most of the applicants, even their high burnup approach, they made it proprietary that the other applicants couldn't have a - I mean, they don't have the benefit. That's why we saw that in the meantime we needed to issue a risk, provide the big picture, that way it would be helpful to the applicant.

So it contains - is based on those research and consequence analyses, and the ISGs, and is based on the guidance provided today. Next slide, please.

So today you're going to hear about those three documents, Regulatory Issue Summary, the NUREG/CR-7198, which is - these are the tests that have been done at Oak Ridge and are being done at Oak Ridge, and NUREG/CR-7203. That's the consequence analysis. And ISG-24 and ISG-11, those have been issued, you know, some time ago.

And what the plan is all this guidance will fold into the Standard Review Plan for 1536, those 1536, 1537, those are storage for the casks and site specific licenses, and the new reg 1617, that's the Standard Review Plan for transportation on spent fuel.

And that is our plan for providing, you know, interim guidance through RIS, and eventually fold in all of that information into a Standard Review Plan.

So with that, next you're going to hear from Huda talking about the Regulatory Issue Summary that we just, we issued the draft for public comment, and the public comment period has closed and we've received comments. Huda?

MS. AKHAVANNIK: Good morning, ladies and gentleman. So my name is Huda Akhavannik as mentioned, and I acted as the PM for our High Burnup Task Force. And today I'm going to be presenting our draft Regulatory Issue Summary on Considerations in Licensing High Burnup Spent Fuel in Dry Storage and Transportation.

So this is an overview of my presentation. I will first give a brief history of the RIS, then go into each section of the RIS just summarizing it, and then state our path forward and, you know, take any questions and comments.

So previously we have presented a pretty close variation of these approaches in January, end of January last year at an NEI public meeting, and then at the 2014 RIC in March, we had a poster presentation, and also in November of 2014 we presented at our Division Regulatory Conference this RIS.

And then as Meraj mentioned, we issued the

RIS for a 45-day public comment period which ended on April 20, and we also, as Mark mentioned, we had a public meeting with NEI on May 18 where we discussed their comments.

So with that, we can just kind of get into the sections of the RIS. The addresses are holders and applicants for a Part 71 CoC, Part 72 CoC, Part 72 General Licensee, and Specific Licensee.

And then the next section is the intent, which as Meraj mentioned earlier, the intent of the RIS is provide high level information on some of the approaches that are acceptable to the NRC for applications containing high burnup fuel.

And we highlight some because, you know, we're willing to accept more approaches that may be acceptable to staff upon our review. And although it's not stated in the RIS, we've had this discussion.

We've developed the RIS based on research and guidance that we've had up to date, and we've developed it based on some of the approaches that we've already approved and are currently in-house.

So with that, we can get into the background section of the RIS. And currently we've been licensing low burnup fuel using the basis in ISG-11, Rev. 3, and the confirmation obtained from the

Idaho Cask Demonstration. And we've been licensing high burnup fuel up to 20 years using also ISG-11, Rev. 3.

And a note about ISG-11, Rev. 3, is that it was originally developed to limit the formation of radial hydrides and to limit creep deformation to less than one percent.

But as you mentioned earlier, there is later research that's showing that the radial hydrides may still form even if the temperatures and stresses that are in the ISG are not exceeded.

So as Meraj mentioned, you know, there are radial hydrides we need to consider and also hydride reorientation that we need to consider.

And I don't want to get into detail about this as Meraj mentioned, but you know, the question that we have to ask is what is the impact that hydride reorientation and DBTT has on our regulations?

So the regulations that are impacted, in storage it's 122(h) which is protecting fuel against gross rupture, the 122(l) which is the retrievability of spent fuel.

And in transportation, we need to make sure that the fuel condition meets the CoC conditions during transport, and that is related to 71.55(d)(2) which is that during normal conditions of transport, the geometric form of the content is not substantially altered.

So this is - we talked a little bit about this earlier too, but -

MEMBER SKILLMAN: Can I ask you a question?

MS. AKHAVANNIK: Yes?

MEMBER SKILLMAN: Please speak to us, Huda, about what licensing high burnup fuel beyond 20 years practically needs, not theoretically. What does that mean to us? We've got these emphases throughout industry. Most of the industries not at high burnup will be in the future probably.

MS. AKHAVANNIK: Right.

MEMBER SKILLMAN: But when - you've provided a bullet that I use personally. The presentation bullet is HBF beyond 20 years. How should we think about that?

Should we think about 60-some sites 23 years from now contending with a new technical issue that we're scrambling to address today, or should we be thinking this is a handful of sites where this will be a very strictly focused concern? In other words, how broad does that statement -

MS. AKHAVANNIK: Well, I think we're expecting that most of the fuel in the future will be high burnup fuel because it's more economically, you know, for economic reasons they do that. So I would say - I guess I don't have a number to give you as to how many SBCs are expected.

But we are planning to get several, I think six or seven storage applications for renewal that are coming up, and in those there may be high burnup fuel, which is, I guess, one of the reasons we are kind of scrambling right now. I'm not sure if I answered your question.

MR. CUMMINGS: Kris Cummings.

MR. RAHIMI: Let me take a stab at it. So yes, most of the utilities that, you know, as you well know because of the, I guess, not having a strategy on spent fuel disposition, they're going into dry storage every day.

More reactors are going into dry storage. Right now we've got over 2,000 casks already loaded at different sites. And they're pretty much done with loading the old, cold fuel. They're loading high burnup gas.

And at the same time, we're approaching the end of the 20-year, their initial licenses that they got. We've already got an application, a number of applications for renewal. If they're renewal, it takes you beyond 20 years, and it may not be only one renewal.

Initial renewal is up to 40 years. They can come in. We just granted Calvert Cliffs a renewal. They can go up to 60 years now. And our projection is, I believe Mark has that graph for 2018, Mark?

We're expecting to get a peak number of renewal requests that is all beyond 20 years for these dry storage systems that we approved 20 years ago. And so, the number is growing. There will be more.

And even if there is a central storage facility somehow in the country, these are the same fuel that they're going to take, that they're going to go beyond, way beyond 20 years. So right now on the horizon, there is no disposal, you know. It's all storage.

And so, there are quite a few of these applications and these fuel are going to go beyond 20 years at the storage.

MR. LOMBARD: If I may, there is a piece to your question that I think I heard that - do we anticipate a new issue to be resolved some 23 years from now? And we don't see that as being an issue to be resolved now.

We're confident in the packages, the systems that we have approved to date for long-term storage. One renewal we have already approved. Another renewal is coming soon. The VSC 24 will be done soon, and Calvert Cliffs was approved actually last October.

We don't see any issues that will come back to bite us in that 20 to 60-year time frame for those renewals. And a lot of it is because the aging management programs are focused on providing the confinement of the material inside the canister systems, so those that are canistered and inside the metal systems.

For those, I don't think we've approved any recently on metal systems. But we're focusing on maintaining the aging management program for those systems to make sure that they are providing confinement of the material inside the system.

So we don't see any - even if there were an issue that might affect cladding integrity long-term, which we don't anticipate based on the plethora of data that we have, and we've done, and what DOE's done, and we've reviewed and that we've done ourselves, we don't anticipate a problem.

But even if there was a problem, we're

confident that the systems will still perform their intended safety functions long-term.

MEMBER SKILLMAN: Thank you.

MEMBER POWERS: You raise a question in my mind. Maybe you know the answer. Are we locked into finite licensing terms for these facilities or is there a potential to build a license for a period of sufferance, that is until a problem arises?

Because you are being asked to prognosticate for 40 years, which is not bad, but the truth of the matter is you want to prognosticate for 200 years which nobody feels real comfortable about. On the other hand, like you say, you have done a great job up until now and you're fairly confident in what you've got.

So one has to ask, or I ask, why in 40 years put people through another paperwork exercise if there's nothing new on the horizon to get a license renewal? Why not a license for sufferance?

That is if something shows up between now and the next 200 years, that because of human failings we simply failed to anticipate, then we'll go back and consider relicensing. Otherwise, keep doing a good job on these things. Do you know the answer to that? Are we just locked into a -

MR. LOMBARD: A two-part answer. I think back when 72 was revised the last time it allowed up to 40 year renewal periods and actually up to 40 year initial periods. And I think folks felt at that time that was a time frame they felt comfortable with, that 40 years.

But in reality, we look back at 1927, the reg in 1927, Rev. 1, and the draft that we have out now, and it really defines the learning aging management program. So what we - while we built that, we have built it on the premise that it is sustainable for a very long period of time.

I am not going to say infinity. I might not even state 200 years, but for a very long period of time, certainly beyond the renewal periods that we're looking at now.

Because it is learning and not just focused on the potential material degradation mechanisms that we know of today, but if new material degradation mechanisms come up, they're plugged into that aging management program.

New inspections are defined. New acceptance criteria are defined for those going forward. So it is somewhat of a self-sustaining program going forward. Does that answer your question?

MEMBER POWERS: Well, I mean, you tell me why we did what we did, and I think it was probably prudent at the time. But looking forward, I wonder if it's the useful extended true root of both regulatory and licensee resources to continuously go through relicensing exercises in the absence of any evidence that we've learned anything new, anything significantly new. We always learn something new.

I mean, it's just something that instructs me we ought to raise with the commission to think about. You've written a rule with a finite term of license here and prudently so when you didn't know very much about this.

As you accumulate the next 40 years worth of information, might you not think about a licensing under sufferance rather than term licenses?

MR. LOMBARD: Sure, absolutely.

MR. RAHIMI: I should add a point. Yes, that's true, but in the meantime, you know, we are in kind of a new territory, you know, a long extended storage. I mean, we've got one program, part of the division extend storage studies that we're looking at what are the issues?

We're looking at the, okay, drying, you

know. As these drying - these casks have been dried completely, will it cause new issues? Stress corrosion cracking, that was another thing that, you know, the issue came up, and it was discovered that the system, the canisters, you know, they might go under, you know, a marine environment or they're stored at, you know, sea coasts. They go through that type of degradation.

So we continued to look at these long-term storage study. Yes, someday you could say, "Yes, we've identified all of the issues," but I'm not sure at this point we can say we've identified all of the, you know, long-term storage issues that we could have, you know, indefinite, you know, period for licensing storage. But yes, that's something that can be looked at and finite licensing.

CHAIR BALLINGER: But that's like saying anything can happen. I mean, we have a pretty good handle about the - I wouldn't say that the stress corrosion cracking issue of the canisters was unknown. In fact, it's been known for 50 or 60 years. Why we chose that material for the canister, I'll never be able to figure out.

But in terms of the fuel itself, we pretty much know that we have a fixed system to start with.

We have a predictable, reasonably predictable temperature history that's going forward. That's the cause of the precipitation of hydrides and the transition.

So like Dr. Powers was saying, since we know a lot of that and we can project ahead of time the temperature distribution in the canisters, why not do this license for sufferance as he's termed it?

MR. RAHIMI: Well -

CHAIR BALLINGER: Or at least a probable ballistic system.

MR. RAHIMI: Yes, I'm not sure that if we have, you know, we've had a lot of experience in storing spent fuel in dry environments, spent fuel. I mean, all of our experience has been, you know, wet storage, you know.

This is the sort of the first time, you know. We were going, you know, spent fuel storage in a dry environment now beyond 20 years. I mean, that's why - actually we have an extended storage and transportation program.

And that's why even, as Mark mentioned, our aging management, which includes the fuel, it is a learning aging management. Yes, you are right, but I'm not sure we can get to a point ever saying we've identified, you know, all of the issues we know.

CHAIR BALLINGER: I didn't say that. You said that.

MR. RAHIMI: And that's why, you know, we do have learning aging management. And there might be, you know, issues, you know, later on that might be identified. But I'm not sure at this point we can say that we can give indefinite approval for any period of time up to 60 to 100 years.

MEMBER POWERS: Licensing under sufferance doesn't preclude learning something in the future. In fact, it gives you a great deal more flexibility in that if you learn something, you can immediately address it in a licensing review rather than waiting until the term of the license comes to an end.

It just - the only thing you're avoiding is an episodic wave of license renewals showing up episodically in time. Instead, you say, okay, look at your thing on a regular basis, and if something comes up, we'll address it.

For instance, you bring up marine environments, coastal environments having stress corrosion cracking. Then only those people are subjected to a review.

I mean, the licensing under sufferance gives relief to the licensee who doesn't have any problems, and flexibility to the regulator for those that do have problems.

MR. RAHIMI: Okay.

PARTICIPANT: I mean, this also goes to the point of risk informing the process.

MR. RAHIMI: David, did you have something?

DR. TANG: David Tang again. I just wanted to add what you are going to hear today is the phase one of this testing done at Oak Ridge. There is going to be a phase two, a supplemental phase, different ways the hydride reorientation effect on fuel cladding and fuel rods.

So see, the feeling that the differences between the reoriented hydride configuration and the circumferential orientation may not be that much of a difference there. So like, say, Mark pointed out, high burnup fuel may be not as bad as what you might think like a regular burnup.

So the point is, there has been thinking as to what - say you've heard of these DBTT readings mean, about the hydride reorientation, what hydride reorientation will have, fuel rod performance.

So they have been really under consideration seriously, and we are going to see at least part of that after, say, a few months from now, these reoriented hydride may have on the fuel cladding and fuel rods. So that is a starting point for a particular essay, Robinson (phonetic) fuel, but the other fuel materials can be considered later.

MR. RAHIMI: Thank you, David. Go ahead, Huda.

MS. AKHAVANNIK: Okay, so we were just talking about hydride reorientation, and this also goes back to an earlier discussion we were having. We were discussing the 30-foot side drop. So the 30-foot side drop could potentially result in a pinch mode.

And a pinch mode is when the inertia loads which have a large tensile stress are perpendicular to the radial hydrides, which was during the 30-foot side drop in the transportation regulations. So that was kind of the main load that we considered, I guess, to be bounding, as we were mentioning earlier.

So using that knowledge, we developed our licensing approaches to have the theme that we don't expect fuel to reconfigure due to hydride reorientation during storage or normal conditions of transport, and we've built in a confirmation. And we're expecting to get confirmation through our current and future research results.

So this is just our licensing approaches. And as we mentioned earlier, we used pieces from previous high burnup applications. We also used our - kind of how we've been licensing low burnup fuel. But as I mentioned in the last slide, we modified it to account for confirmation.

But we are expecting that as we get more data, we do get more confirmation through operating experience, we're not going to ask for it in the safety analysis report.

And then as Meraj was mentioning earlier about the consequence analysis, if you maybe don't have data on the specific cladding type, there's kind of this defense-in-depth analysis route which I discussed earlier.

And in general, the structure of our approaches consider whether or not the fuel has been in a damaged fuel can, and the length of time it's been in dry storage.

So with that, let's start with the storage licensing approach, and this is the overall structure of it. So as you can see, it's first split into whether you have uncanned fuel or canned fuel, and that can refers to the damaged fuel can, and then the length of time it's been in storage. So is it up to 20 years or beyond 20 years?

And we'll first just discuss canned fuel. So canned fuel does not depend on the time that it's been in dry storage, and the structural performance of the can must be demonstrated, and then a safety analysis would be performed which assumes that fuel is reconfigured to the boundary of the fuel can.

Then our next branch is the up to 20 years. So as previously mentioned, fuel that's going to be in storage for only up to 20 years would follow our current licensing approach which is what, you know, we've already been doing, and we get that basis from ISG-11, Rev. 3.

Then we're going to discuss dry storage beyond 20 years. So to meet normal and off-normal conditions, there are two routes. So first we'll discuss the test data route which relies on ISG-24 guidance to use a demonstration cask as a method of confirmation. And a demonstration cask that would meet ISG-24 is the DOE/EPRI high burnup research demonstration project.

And I would also like to highlight the importance of using a demonstration cask. As you can see there is this asterisk right here on the normal/off-normal conditions box, and the asterisk is just highlighting that the validity of the approach is that the results that come from a demonstration cask must confirm the original fuel licensing assumption.

The second route is the analysis route, and that's that kind of defense-in-depth approach that we mentioned earlier. And for this approach we need some sort of confirmation first.

It's not going to be as, I guess, intense as a cask demonstration project, but it could be something like performing a non-destructive demonstration such as gas sampling or, you know, possibly doing dose measurements to get some information, and in the RIS we call that a lead system examination.

And when we get this confirmation, then a safety analysis which would assume one percent fuel failure for normal conditions of storage and ten percent for off-normal conditions, and that fuel failure would be for all the technical disciplines, for thermal, confinement, shielding, and criticality. They would do an analysis assuming those values of fuel failure.

And just those values come from the

confinement analysis that's done for low burnup fuel. They're considered to be pretty bounding values. But we're also allowing for the applicant to come in with their own defensible fuel failure values if, you know, they can.

And we're going to be hearing about the analysis route more from John in his presentation. He'll kind of go through the consequence analysis that was done that also has those fuel failure percentages in it for all of those disciplines that I mentioned earlier.

So next we'll discuss the accident conditions and there are also two routes here so - which depend on the availability of data. You can perform a structural analysis, which possible data that can be used is the Argonne National Lab pinch test or the Oak Ridge National lab bend test, and the bend test will be elaborated more by Michelle Bales in her presentation.

Then there's the analysis route which is, you know, just assuming a value of failed fuel. In this case, we chose 100 percent, which is obviously the most founding value. And that 100 percent would also be for the confinement, thermal shielding, and criticality analysis, and that will also be discussed more by John in his presentation.

So that's the storage. Next we'll discuss the transportation route. In this one also, the similarity is that, you know, you can either can the fuel or have it uncanned. And then a difference isn't the time that it's been in dry storage, but whether or not the fuel has been. So there is a path for fuel that has been in dry storage or fuel that would be directly shipped from the spent fuel pool.

So this is - the canned fuel route is exactly the same as the storage. They demonstrate the integrity of the can and then do the bounding analysis assuming the fuel is configured to the can and then - confined to the can, and then the direct shipment from the pool route.

So for this route, the applicant can determine the maximum and minimum cladding temperatures to verify the ductility of the cladding. And to do this, the applicant should have data to defend their DBTT values to indicate whether or not hydride reorientation has occurred, and to use a temperature code which should accurately predict lower cladding temperatures to be more conservative.

And if there is no data to defend the DBTT, or if the DBTT limit has been exceeded, the applicant can follow our next approach which is the fuel that's been in dry storage.

MEMBER SKILLMAN: Let me ask this. This goes back to Dr. Rempe's question about knowing what the temperature is. To succeed in the sequence that's shown on the left, you need to know the temperature.

MS. AKHAVANNIK: Yes.

MEMBER SKILLMAN: Is there a canary test? Do you know what a canary test is? They used to use a canary in the mine to determine whether or not there was -

MS. AKHAVANNIK: Oxygen?

MEMBER SKILLMAN: - oxygen.

MS. AKHAVANNIK: Okay.

MEMBER SKILLMAN: Is there a canary test that could be used to understand the temperature instead of having a requirement for a very sophisticated or a very high tech detector?

Is there something that could be used that is a surrogate or a dummy that would be a practical indicator of whether or not there has been this hydride reorientation? Is anybody looking at something like that?

MS. AKHAVANNIK: I'm not aware of anyone looking at some sort of, like, test that would kind of maybe make it easier.

MEMBER SKILLMAN: A go or no-go, something that says, "Golly, we know the temperatures have been at a level where hydriding is very likely," or ultimately an indicator that would suggest, "There is no way. The temperature was never great enough to even raise the question." It seems as though an awful lot of the logic here is understanding that ductile to brittle transition.

MS. AKHAVANNIK: Yes.

MEMBER SKILLMAN: And that's so prominent in all of this. It seems, at least in my mind, to beg the question, isn't there an easier way to make that determination?

MS. AKHAVANNIK: I'm not sure if you can simplify it since there are different kinds of cladding types. I'm not sure how different their DBTTs would be. I think it's personally more complicated than being able to maybe have, like, an indicator that would - maybe for all of the cladding types.

I understand that that would be the best way. It would be, you know, just the most efficient thing to do, but I'm not sure how plausible that would be. And I personally am not aware. I'm not sure if other people would be.

MR. RAHIMI: I think you're exactly right. I mean, you put your finger on the - how to predict accurately the temperature of the cladding. How do you know the temperature of cladding? And that is the subject of really our ongoing research we have right now at Sandia.

We're making a mock-up, you know, and determining how accurately you can, you know, predict the temperature of the cladding. So there is research, a lot of research at EST focused on it in terms of knowing the cladding temperature accurately.

In this case, you are - I mean, you are interested in maximum, what does the maximum go to when the hydride becomes reorientation. You're also interested in minimum because that's where the ductile to brittle transition happens.

So on both ends, you'd each have a good capability in terms of predicting the cladding temperature. And we do have right now, we started a test at Sandia. Actually, we started a couple of years ago.

But this particular one, we're going to look at above-ground system, below-ground system in terms of the entire heat transfer, how accurately it can predict the cladding temperature.

MEMBER REMPE: Now, is that the BWR test at Sandia you're talking about?

MR. RAHIMI: That's the BWR test. That's right.

MEMBER REMPE: And it will encompass the conditions one might expect during the drying process?

MR. RAHIMI: That one, no. I guess to answer your question, no. I believe that it is during storage in terms of the capability of how accurate you can predict. No, it's not focusing on the drying.

MEMBER REMPE: I appreciate more details about that test, but I still think from what I've read, and correct me if I'm wrong, that the drying is where people believe that the temperatures will be the highest.

MR. RAHIMI: That's true.

MEMBER REMPE: Then I guess - okay, we talked about the low burnup test where they went to 415 degrees C. And that was just a measurement in a guide tube, so I don't know what the cladding temperature is.

But say it's 100 degrees higher, that it's up to 500 degrees or 515. Can it go above 570 degrees C with high burnup fuel? And then I start thinking about the skip tests when they start seeing things going pop really quickly, and are we anywhere near the regime so that this hydride thing is not the concern of interest?

Are we getting in - do you have any confidence that I don't need to worry about some of the things we've seen with other transients for other purposes? And I'm kind of looking at Michelle when I say that because I know she's been involved with some of the following of the skip tests, and how do I know I'm not in that regime?

MS. BALES: Yes, I'm familiar with the failure modes at high temperatures and high pressure, but unfortunately I'm not familiar with the kind of analysis that is done for the casks. So although I am aware of where the failures occur, I can't speak to the analysis and how accurately the temperatures are known in a cask.

MEMBER REMPE: Correct me if I'm wrong, isn't the skip phenomenon starting to occur at temperatures as low as 570 C?

MS. BALES: Well -

MEMBER REMPE: Because I remember seeing a paper from Studsvik on that topic.

MS. BALES: But I think that the - I guess I might be mixing up the programs, but the programs that I'm aware of at skip are all, like, in water. It's all reactor kind of conditions. And some of them are subjecting the rod to a power transient, so you also have, like, a fuel swelling.

I mean, there's a lot of different things going on in those tests, and some of those phenomena might not also be occurring in a spent fuel cask. So I'd have to look at it more to see how it translates.

MEMBER REMPE: It's just a question I was having when I was looking at this. Yes, you're right, they were in water, but it's a transient and the temperature got to this temperature, and suddenly you have other phenomena.

And I just would like some confidence that I don't need to worry about that other phenomena. And so, I think the cladding temperature is an important parameter we ought to have a bound on.

MS. BALES: Yes, I think the key difference, if it's the power transients that I'm thinking of, would be the fuel's behavior because the fuel is in a power condition so it's a higher temperature, and that's not the case for the spent fuel conditions. So -

MEMBER REMPE: Okay.

MS. BALES: That might make a big enough difference to a lot of the concerns, but I'd have to look at it more.

MEMBER REMPE: Yes.

MR. RAHIMI: I should maybe mention again that yes, during drying as we discussed earlier, the demo that the industry and DOE are planning to do is to measure the temperature, cavity temperature, you know, during drying at all times.

MEMBER REMPE: Yes, but again, in the low burnup tests, which didn't have water when they started by the way, it was just a dry one, they had issued this and they got up to 415. So I'm just kind of wondering what's going to happen with the high burnup and how do you know what the cladding temperature is?

I think we should maybe go a little bit beyond getting data similar to the low burnup tests and maybe - I appreciate what you're saying. It's just not practical to do it during the burnup, but I think there are some other opportunities.

MR. CUMMINGS: Let me clarify and provide some additional information. Keith Waldrop, who is the EPRI project manager, has been texting me, and he's listening on during this. He said there will be benchmarking of the thermocouple lances.

And I don't know all of the details, but they'll basically benchmark it. They'll put it in a similar sort of configuration to determine what is the difference between the actual fuel cladding temperature and the thermocouple measure temperature. I don't know the details of how they're going to do that.

MEMBER REMPE: Okay, we need other details, yes.

MR. CUMMINGS: But certainly as I offered before, we can get EPRI to come in and talk about exactly the details of the demonstration program. So that is a concern for the purposes of the demonstration program.

And understanding that, you know, how you take that measurement from the cladding from the thermocouples and get a reliable, you know, estimate of the, or calculation of the cladding temperature is something that is one of the key aspects of this project to ensure that we're getting the right, I don't want to call it a correlation, but the right transference of the measured temperature to the cladding temperature.

MEMBER REMPE: So I'd like to see those details and hear more about it please because I think it's important.

MR. CUMMINGS: We'll be happy to work with Chris Brown to work on getting a date where we can get

EPRI to come.

MR. RAHIMI: Gordon?

DR. BJORKMAN: Yes, Gordon Bjorkman again. It's important to point out that the brittle ductile transition that we saw, that curve, that's only a problem when it comes to the pinch mode. That is the mode where you pinch and ovalize the cross section. That's when the radial hydrides come into play.

For the other modes, the bending modes which would be associated with the side drop, or the bending that would go on in the buckling analysis, the pinch mode is not invoked, and therefore the brittle to ductile transition is not an issue.

To get to the pinch mode, you have to have a very severe accident because the cladding had to collapse upon itself in a side drop. Grade spacers have to basically start to crush. So to get to the pinch mode is a very difficult place to get.

So typically we would not see that mode in our normal accident - or our hypothetical accident conditions.

MR. RAHIMI: Thank you, Gordon.

MR. LOMBARD: I might add a couple of things. The ISG-11, Rev. 3 provides what we feel are conservative bounds for drying temperatures.

And what we're hearing from the industry as more operating experience is gained, we're hearing that even though heat loads for systems are certified to certain levels, what they're actually loading is lower, in some cases much lower than that.

So they're seeing temperatures that are much lower than that, and hopefully during the demonstration project we'll see that. As you may know, during the demonstration project planning they tried to get up to, I think, if my memory serves me right, 37 kilowatts is the certified heat load of that system, that TN32 system. It couldn't get up to that heat load. I think they only got up to 33 or so.

So it's interesting even though heat loads are certified at a certain level, they're having trouble getting up to those levels. So we feel that ISG-11 has some conservatism in it. The actual operating screenings also show additional conservatism.

MEMBER SKILLMAN: I believe that the comment that Gordon just made is very, very important, at least in my judgment. What he said is the ductile to brittle transition really gets called upon only when that clad is being pinched.

Now that pinch load only comes with a

certain spectra or spectrum of accidents, and it's got to be a crushing load on the fuel assembly. And so, while 71.73 identifies what your transportation accident requirement bounds are, it seems like what Gordon just mentioned gives great credence to the notion of a probabilistic approach to this because of the very low likelihood of having that pinch load.

If you think about the accidents that can happen, there are darn few that would cause, if you will, lateral compression onto the fuel assemblies. So if that - if the point that Gordon just made is not highlighted somewhere, it may be lost in translation and the benefit of that information will not be available to industry. It seems like that is a very important point.

MS. AKHAVANNIK: And that is in our RIS. A few slides ago in the background section, I had, like, one slide on the pinch mode. And we do have, like, a paragraph or so that kind of describes that the pinch mode would be the one that you need to consider.

MEMBER SKILLMAN: Okay.

MR. RAHIMI: Yes, and that is a subject - I understand that Dr. Rempe was asking in terms of, okay, the prediction of this temperature. That's true. Even hydride reorientation happens, but like what Gordon is saying, it doesn't come into play really, only under pinch modes.

And actually, our test that Michelle Bales is going to talk about next, is confirming that. If indeed this doesn't come into play under bending, under vibration, that's what the tests are confirming. And then we have a plan to do the test, exactly what Gordon mentioned.

Okay, say the high burnup, with hydride reorientation, pinch them. So we're going to confirm every step of the way indeed, it's only under that condition as Gordon mentioned and David mentioned that you get, you know, the fuel assembly might see 50, 60 G under a 30-foot drop, and that's not enough, you know, to get it even to the pinch mode.

But we're going to confirm in the test even if it gets to that point because of the fuel pellets providing such a stiffness, you know, you don't have a hollow tube, because Argonne did the pinch test. They did confirm that's - it comes into play but it was with a defueled cladding simulated. But now we're taking the actual fuel with the fuel pellet in there providing stiffness and even doing the pinch mode. Even if it comes into play, we're going to confirm it's still - so we are confirming really the bend, the vibration, the behavior.

MEMBER SKILLMAN: Thank you.

MR. LOMBARD: If I may clarify too, on the testing we're doing at Sandia National Lab in concert with DOE, it's really to validate our computational fluid dynamics models. It's not necessarily to validate cladding temperature, but just to validate the CFD models that we're using.

CHAIR BALLINGER: We're getting a little bit - we're not that far.

MS. AKHAVANNIK: Well, we're almost done, so. The next approach is the fuel that's been in dry storage, so first we'll discuss normal conditions of transport. And similar to storage, there's also a need for confirmation built into this approach.

So there's the test data, then the analysis route. And the test data would assume that data is available to perform a structural analysis. As we were just mentioning, you could use the Argonne pinch test, or the Oak Ridge National Lab vibration test, or any other data really that the applicant can have.

And the analysis route, instead of assuming one percent, we give the value of three percent, and that's also just taken from our low burnup containment analysis values. And they would do that also for - assume that fuel failure for criticality, shielding, thermal and containment, and these will both be discussed further in John and Michelle's presentations.

But no matter which of these approaches that you take, there needs to be confirmation of the fuel condition prior to and after transport, and that's for 71.55(d)(2). So this confirmation can be done in multiple ways.

Again, we're not expecting anyone to open a canister or a package, but something that someone could use the results in the demo cask after it's been transported as a form of confirmation, or performing gas sampling or dose measurements.

So the last approach is the hypothetical accident conditions. And again, this depends on the availability of data, so are you going to go the test data or analysis route? The test data past could use the Argonne bend test, or Oak Ridge bend test, or any other data the applicant may have.

If fuel can be reasonably expected to reconfigure, then safety consequence analysis should be performed for that route. But for the analysis path, 100 percent, fuel failure is a bounding value, and that would, again, be done for thermal, containment, shielding and criticality.

And if the applicant feels that they can come in with another value, they have - you know, they can feel free to justify that.

So those are our approaches. And just so we can get to the path forward, we are planning to issue guidance, as Meraj mentioned, you know, through our SRPs that would expand on the RIS with greater technical detail to implement the approaches.

And we're kind of just waiting for - to get - you know. For example, you know, we got this recently. We're waiting for the consequence analysis. You know, we need those pieces to be able to write a good guidance.

So that's currently on hold also because we are - we're working to harmonize more with NUREG-1927, Rev. 1. We want to make sure we're consistent with each other. And also, we have received comments on the RIS that we are working to consolidate.

And at that time, we'll also decide - when we've harmonized with 1927 and we've gone through the comments we've received on the RIS, we decide if we want to issue the RIS or not.

CHAIR BALLINGER: So the issuance of the RIS at all is not a done deal?

MS. AKHAVANNIK: I mean, I think we'd like to issue it, but we have received comments. And I think it also kind of depends on how exactly we want to - like, we may find that oh, if we just work on a new reg, that would be a much better document to issue than the RIS.

And if we can see that, oh, we've gotten some of the data and issuing the new reg won't be that far off, it's - we kind of have to weigh the pros and cons of issuing the RIS at that point after we get - consolidate our comments and also with 1927 for our consolidation with that.

CHAIR BALLINGER: Thank you.

MR. RAHIMI: This - the issue already drafted for us has been very helpful to the vendors. I mean, since we've had a number of pre-application meetings with vendors and they appreciate that very much seeing the big picture, the path, you know, these are the possible ways. And so, it depends, you know, on what kind of feedback we're getting, you know, from the applicants.

MS. AKHAVANNIK: That concludes my presentation.

MR. RAHIMI: So -

MS. AKHAVANNIK: Next up is Michelle.

MS. BALES: Okay, good morning. My name

is Michelle Bales. I work in the Office of Research. And today I will be presenting results and the strategy of a mechanical testing program of mechanical testing on high burnup fuel, especially for properties important to transportation applications.

On the next slide I'm just reiterating the slides that you just saw from Huda, and I wanted to revisit them to point out that the information that you will see here is part of the technical basis that supports these test data paths that were identified.

The research program that I'm going to talk about started with some fundamental questions. The first one was we wanted to understand how the presence of fuel impacts the flexural rigidity or the bending stiffness of a fuel rod.

So this is in comparison to a structural analysis that would just look at cladding properties to determine the fuel assembly's structural response. We wanted to understand how high burnup fuel will change the bending stiffness in a structural analysis.

The next one was to -

MEMBER SKILLMAN: Excuse me.

MS. BALES: Yes?

MEMBER SKILLMAN: Excuse me, Michelle. When you say that, I think what you mean is how the pellets in the clad for the high burnup fuel affect the flexural rigidity.

MS. BALES: Yes.

MEMBER SKILLMAN: So you're really saying, hey, what is the dependence on the pen stack -

MS. BALES: Yes.

MEMBER SKILLMAN: - on the physical properties -

MS. BALES: Yes.

MEMBER SKILLMAN: - of the clad and pen itself?

MS. BALES: Right, so this - what we're looking at is the structural response of the system.

MEMBER SKILLMAN: Bingo.

MS. BALES: The fuel and cladding system together.

MEMBER SKILLMAN: Thank you.

MS. BALES: We also wanted to know how the presence of fuel pellets impacts the failure strain of cladding. And we wanted to know how many cycles to failure high burnup rods could experience at a range of elastic stress levels.

And then finally, we wanted to understand whether radial hydrides will impact the bending stiffness or fatigue life of high burnup rods in comparison to high burnup rods that only have circumferential hydrides.

I want to point out a couple of challenges that we faced because this really was important to our test design. We really wanted to test this mechanical property of the as irradiated fuel. We didn't want to use more - some of the traditional tools of the mechanical testing trade, reduced gauge sections or pre-notches.

We didn't want to dictate where the failure would occur with some of these methods. So - and also we had a small amount of material so we had to design a system that would be able to measure the properties that we wanted with a small amount of material.

And also, all of this testing has to be conducted in a hot cell, so time was also a very sensitive matter, and we wanted to create a test where we could test - not accelerated testing, but that we wouldn't have - that we were conscious of the time that it would take to run the test.

What we found as we started was that many of the standard measurement devices and mechanical testing equipment for fatigue and bending stiffness were not really compatible with the material that we wanted to test and the test environment, so we had to develop something new.

On the next slide you can see an image of the device that was developed. This is taken before it was put in cell, and you can see - I'll show another picture that you can see a little bit more of the detail.

But the device is called the Cyclic Integrated Reversible-bending Fatigue Tester, which is CIRFT for short, and I'll refer to that name later in the presentation. And the same device is able to measure the properties we were interested in for the static and dynamic conditions.

I want to point out a couple of unique features of the test device and measurement equipment because it makes a difference as we go forward what we were able to measure.

I also have a sample from the - as we first started, we did a lot of testing on surrogate material so that we could understand how the equipment behaved and validate the approach. So this is one of the first samples that was tested.

You can see the image of this system in the upper lefthand corner. Basically we have grips that are added to - this is the surrogate for the high burnup rod, and then there is an epoxy layer in between the high burnup rod and the grips.

And this grip design was integral to creating a uniform bending moment in the two-inch section between the grips, and also to ensuring that the failure would not occur at the grip locations, but rather in the center wherever the weakest point in this two-inch segment was. So I will pass these around if you want to take a look.

In the lower lefthand corner, there is an image of the testing device shown from above, and the green arrows indicate the loading arms and their direction path, basically horizontal to the image.

And their horizontal motion in this u-frame design creates a bending moment on the rod which is in the lower part of the device indicated by the red arrow. And as I said, the grip design allows for motion in this device so that there is no axial load, but just a pure bending moment on the sample.

In the upper righthand corner you can see a different view of the device and also the three LVDTs are indicated. We used three LVDTs to measure the curvature of the sample directly, and this allowed us to know the bending that was - that the rods were being subjected to directly from measurements.

So it wasn't derived from the displacement of the loading arms, and therefore the compliant layer, we didn't have to make a calculation or any assumptions about the compliant layer's effect.

Okay, on the next slide I have a couple of things to say about the irradiated material that we tested. All of the samples that we tested were from the same father rod campaign. It was PWR fuel irradiated in the U.S. It's Zirc-4 cladding, an older vintage Zirc-4 cladding so the oxide layer thickness was relatively high. The hydrogen pickup was relatively high, and the cladding thickness was also relatively thick.

In this particular pellet fuel design, the pellet height was shorter than what we typically see today. And what this means is that in the two-inch gauge section, we typically saw about seven pellets, which I can get to a little bit later. The pellet-pellet interface, the number of pellet-pellet interfaces that we had was significant.

In the first phase of the testing which is now complete, all of the rods that we tested were characterized by circumferential hydrides or just the condition as irradiated.

The second phase we are in the middle of now. And in that phase, we are testing material that has been subject to hydride reorientation and is characterized by radial hydrides.

MEMBER SKILLMAN: Michelle, can you give us an idea of what the radiation level was on that little piece of fuel?

MS. BALES: So yes, I forgot to mention that the burnup range was relatively high, 63 to 66 on the segments that we tested. We tested from different parts of the axial length, and there is a little bit of variability in the burnup. But generally, the rods were rod average 63 to 66.

MEMBER SKILLMAN: And what was the radiation level of that piece?

MS. BALES: In terms of?

MEMBER SKILLMAN: REM.

MS. BALES: REM? I'm not sure. I only know about - I only know in terms of the burnup level, so that's typically what we used to characterize the burnup.

MEMBER SKILLMAN: Okay, thank you.

MS. BALES: Okay, so in the program, as I mentioned, we have two phases. The first phase we had four static bending tests, and then 16 vibration fatigue tests at a range of bending moment amplitudes.

The second phase we're going to focus

really on comparing a couple of samples to the data that we already have. So we're conducting one static bending test and three vibration fatigue tests on samples that have been subject to reorientation.

CHAIR BALLINGER: How did you arrive at the number one?

MS. BALES: Because we are very limited on material and that's all we have. We really only have four samples remaining that we can test, and so we've divided them one to static and three to dynamic so that we could look at a range of amplitudes.

CHAIR BALLINGER: Because where I come from, anything less than three is -

MS. BALES: I agree, and I think that in this case we were definitely limited by the material.

CHAIR BALLINGER: Easy to do with one sample, yes.

MS. BALES: I think that I can address that a little bit in the next slide where I start to show the results because we do see a lot of consistency in the four repeat tests of the static behavior.

So we're really looking to see if this next sample with reoriented material has statistically different behavior than the four that we've already tested.

CHAIR BALLINGER: And when you say reoriented, will that be quantified?

MS. BALES: Yes, we'll take metallography before and after to understand how extensive the reorientation was. So going into the results, on the next slide we have an image that shows all four of the static bending test results. I'll say a couple of things about this.

Number one, if you're familiar with low displacement curves, you'll notice that these rods didn't fail because we see an unloading path in the image. The load displace - sorry, the displacement that is possible in this device is limited by the loading arms.

And what we found is that the loading arms at their maximum displacement we still didn't see failure in this rod. So in that sense, if we could go back, we would change some of the characteristics of the device to have a longer loading arm so that we could actually capture failure.

But what we see is that - or what we did with results after they were subjected to the maximum displacement on an unloaded, we subjected them to high amplitude fatigue testing to actually fail them, and we saw the peak bending moment approximately around 80 to 90 MPa - I'm sorry, meters, for these samples. So they weren't far from failure when - on this first static loading.

But the other thing that you can notice from these curves is that the behavior is relatively similar for these four samples. The elastic modulus was similar. They all experienced about one to two percent strain without failure.

And on the next slide I can show you one of these curves in a little bit more detail. Because Oak Ridge really looked at the slopes and the different regions of the curve to try to understand what might be going on as the bending moment increased, and they really saw two separate elastic moduluses.

They see a region below about 20 Newton meters that's characterized by one elastic modulus and then they see some change in the elastic modulus from there all the way until plastic behavior begins.

They have some speculations in the new reg report, I think on page 27 and 29, about what this change in slope might be attributed to. Perhaps a fuel cladding bonding is breaking down or some other structural change is taking place. I think a lot more work needs to be done to really understand that from a mechanistic point of view.

In the new reg report, these parameters, EI-1 and EI-2, were characterized for each static rod so you can kind of compare them and look at how they relate to each other. Then we have the plastic region and then the unloading slope was also quantified and compared to EI-1 and EI-2.

Okay, and the next slide. I mentioned at the beginning that one of our goals was to understand how the structural response of a fuel clad system, a high burnup fuel clad system, compared to cladding properties alone.

Originally, what we really wanted to do was defuel a high burnup fuel rod and test a rod with fuel pellets in bending and without fuel pellets in bending. However, there was a couple of challenges to this.

One is that we couldn't defuel a segment that was six inches long at Oak Ridge with their current tools, and then the other is you have some challenges bending an empty rod into a large displacement. So we ended up approaching this analytically.

So we have high burnup fuel - sorry, high burnup cladding properties from the Pacific Northwest. They are the values that are used in our FRAPCON codes, and we made an assessment of a bending load through using those properties, and compared that analysis to the measured behavior.

So we do see an increase in stiffness due to the fuel which is what we expected. But again, we were really looking to quantify that. And we saw that approximately one-and-a-half times the bending stiffness was seen when these results were compared that we can contribute presumably to the fuel itself.

Okay, on the next slide I'm about to talk about the dynamic testing, but before I do, I just want to highlight the region - the bending moments that we used in the dynamic testing relative to the static behavior. We were really looking at the lowest region of the elastic behavior. We tested in dynamic modes from about 5 to 35 Newton meters.

MEMBER SKILLMAN: Michelle, would you explain why you chose that region please?

MS. BALES: Yes, originally we were looking at a much wider portion of the elastic curve. We were going to test at, like, 80 percent of the yield stress. But we found that even at 35, that's sort of where we started, we had much higher cycles to failure than we expected.

And so, we were more interested in characterizing the cycles to failure, the X-axis on the cycles to failure graph, so between 1,000 and one million cycles, and so that kind of dictated the bending moments that we were interested in.

MEMBER SKILLMAN: Thank you.

MS. BALES: So as you'll see on the next slide, the results that we obtained even at 35 Newton meters and a relatively low elastic modulus, we were seeing about 1,000 cycles to failure. And then as we continued testing at smaller strain amplitudes, we saw predictably decreasing - or increasing cycles to failure.

A couple of things I want to point out while we're on this curve is that the behavior - we were kind of surprised at the - how well the data behaved relative to a single power-law curve. Even though the material that we tested was from the same father rod, there was a lot of variability in the hydrogen content and oxygen content.

We also know that high burnup fuel has a lot of localized features that could be controlling failure. So the fact that we saw a relatively well-behaved cycles to failure curve was a bit of a surprise.

But nevertheless, we also - well, not nevertheless, another thing that we saw was we tested some rods at very low amplitudes without failure. We tested to 10 million cycles, in one case 20 million cycles, and then we terminated those tests because it's very expensive to run tests that run for that long. And we presume that this about 0.1 percent strain could be declared a fatigue limit because we saw so many cycles without failure for some of these rods.

On the next image - let me see if there was anything else I wanted to tell you about that one. I don't think so.

CHAIR BALLINGER: How does that compare with the sort of - and I should know it by reading it - the estimated number of cycles, if you will, or the history during transportation? Are we way, way, way out of the bounds of anything that would occur in transportation with that fatigue limit?

MS. BALES: So, I would love to answer that question, but really the focus of this work was to characterize the mechanical properties, and that information is combined with information about transportation loads and transportation cycles to actually determine if there is failure or not.

And so, that work - I don't have a lot of information to present about that. It's a DOE program. But there is a lot of work ongoing to understand exactly what loads would be seen, what number of cycles, so that we can compare that information to these measured properties and determine if there's failure.

But I can say that there is some - the information that is available now suggests that we would be really low on this curve in real transportation.

Okay, on the next slide I have added some images of the fracture surface from a number of data points, and the reason I have done this is because I want to point out that almost all of the rods failed at a pellet-pellet interface.

And so, I don't know if it's obvious from these images, but if you look really closely you can actually see a number stamped on the top of the pellet. So we're pretty confident that we're seeing a pellet-pellet interface, the top of a pellet in almost all of these tests.

MEMBER SKILLMAN: Michelle, please explain what the image is presenting to us. Is this the fracture surface that's down within the epoxy region of the sample that you showed us? In other words, the shear was at the buckling location where the pin was, if you will, bending at its fixed point? Is that what we're seeing?

MS. BALES: No, so there's only one sample that had a fracture right at the grip location. That's this one. But I agree, otherwise you can't really tell in this image where the fracture is relative to the grip section. And there are images in the new reg that are from the side where you can clearly see that the fractures occurred in the middle of the span in almost all of the cases.

MEMBER SKILLMAN: Thank you.

MS. BALES: The exception was for a couple of claddings that -

CHAIR BALLINGER: I can now rationalize why you got such nice behavior. You're really not doing a bending test. You're doing a tension fatigue test at that pellet-pellet interface.

So that's pretty much you're doing the testing on the cladding with the pellet stiffness there, so that's kind of - you're probably in the same shape as if you did the, if you did just a straight pull-pull cladding test.

MS. BALES: There is some speculation that that's really dominating the behavior, that the localized cladding strains resulting from the pellet-pellet interfaces is really controlling the failure.

Okay, so I won't speak too much about the

DOE program. However, I do want to mention that after the NRC completed our dynamic testing, the DOE's Used Fuel Disposition Campaign came in at Oak Ridge and also continued some testing on other fuel designs.

So they looked at other cladding materials as well as MOX fuel that they had available. And what they were trying to do is determine whether the property that we were measuring was fuel design dependent.

So the DOE has done - the Used Fuel Disposition Campaign has a lot of discussion of this comparison, and they have publications and ongoing work to try to understand this behavior, so I'm not going to try to explain the differences.

I wanted to include it in this presentation to acknowledge that even though our data set is kind of limited, there is a supplemental effort going on with the DOE to really look at a larger amount of data to get more statistically significant results, and to also understand if this behavior is fuel design dependent.

Okay, the NRC's program is - there's also some ongoing testing that we are sponsoring. And as you have heard, this is really in the realm of the reoriented material and understanding if reorientation makes a difference in this property.

So we are conducting fatigue tests on high burnout fuel segments that have been subjected to radial hydride reorientation. The samples that we have available, the four total samples, those are from the same father rod as the previous testing that we've done.

And we're going to evaluate the impact of radial hydrides really by comparing these four tests to the data that we already have on rods characterized by circumferential hydrides.

And as Gordon mentioned, we believe that the bending moment will put - because both circumferential and radial hydrides are parallel to the loading that is seen in bending and fatigue, at least in the bending fatigue mode, that we don't expect a big difference in the behavior.

But we are - this is a confirmatory test program to make sure that we really understand the phenomena and that we're not going to see something unexpected.

Right now the equipment buildup and the procedure development to actually induce reorientation is nearly complete at Oak Ridge. We're just installing the equipment into the hot cell to start for the first time subjecting high burnup rods that have fuel still in them to hydride reorientation.

So the previous work at Argonne also did reorientation treatment of cladding, but in those cases they were defueled. So this is the first time where the high burnup rods will - sorry, the high burnup fuel pellets will still be in the cladding samples during the reorientation treatment.

So as I mentioned, the equipment buildup and the procedure development is nearly complete, and the testing will be completed this summer. And we're expecting to complete all four tests by the end of the summer.

So there's a couple of documentation notes that I want to make. There's a large number of publications, journal articles, presentations, letter reports, and task reports that Oak Ridge developed for describing the equipment device - the testing device, discussing surrogate material testing, and the things that they learned from testing hydride material.

They had some samples where they had pellets - pellet simulates and some where they just had a single ceramic insert so that they could try to understand the difference between pellets and a single ceramic, and also a discussion of the testing protocol. I have - one of my backup slides provides a lot of those references.

Most recently, we have completed a document that captures all of the phase one testing, and that is the one that Meraj had held up earlier. So all of the results of the circumferential hydride samples are captured there.

I wanted to point - if you are looking for documentation on the DOE testing program, I would direct you to the Used Fuel Disposition Campaign's task leaders and to their publications. They've also published a number of papers and presentations on their work. And that work is still ongoing so you can expect even more as their work continues.

Phase two testing that the NRC is sponsoring will be reported in a future publication so that people can make use of the comparison.

Okay, so in conclusion I just want to say that a unique testing device has been developed to measure bending stiffness and fatigue behavior of high burnup fuel in both the cladding and fuel cladding as a system.

Five static tests will be run in NRC's program. Four have been completed, and one will be completed on a rod that has been subject to hydride reorientation. And the static results to date demonstrate that the presence of fuel does increase the bending stiffness relative to calculations using cladding properties alone.

There are 19 dynamic tests that will be completed. 16 have already been completed, and three more remain, and those are going to be on rods that are - have hydride reorientation. And the dynamic results to date demonstrate that high burnup fuel can experience a large number of cycles without failure, and an effective fatigue limit can be interpreted from the available data.

And then finally comparison of as-irradiated reorientation tests is going to help us to address whether radial hydrides impact the bending stiffness and fatigue life of high burnup fuels.

And that's the last slide that I have. I have a couple of backup slides in case there is questions, but at this time I can take any questions.

CHAIR BALLINGER: I have one, I have one about one again.

MS. BALES: Okay.

CHAIR BALLINGER: What happens if one goes wrong? Is there a backup plan? I mean there is a lot hanging on that one.

MS. BALES: Yes, well, so I haven't even described -

CHAIR BALLINGER: What if one is 50 percent different than what you expect?

MS. BALES: Well, you have to remember also that the nature of the NRC's research programs are to understand what the phenomenon might be, and where there is concern, and where there might not be concern.

But in this case, if we saw something that was, it was either unclear or there was a difference but we think it's experimentally driven, then that would prompt additional - either additional research by us or additional questions and partnership with the DOE.

So we don't know until we see the results, but if they are exactly in line with the results that we have to date, we might make different decisions than if they were significantly different from the results that we've measured so far.

CHAIR BALLINGER: See, in the experimental world, if you get exactly what you expect for one test, that's also meaningless because it could be fortuitous.

MS. BALES: Yes.

CHAIR BALLINGER: You could be fooling yourself.

MS. BALES: Yes, and I agree that there's a lot of things that are going on in these tests. The reorientation itself, we're going to measure it to confirm that the hydrides reoriented.

But they are subject to a temperature transient and a pressure transient that the other rods were not subject to, and we won't know for certain if the behavior that we see, if it is different, if it is a result of the reoriented hydrides or possibly the -- annealing the cladding experience to the temperature transient.

So we really acknowledge the number of challenges with this low data set, but unfortunately this is all of the material that we have available and it's very - we have to do the best with what we have and - So anyway, it's really a function of the material that we have available, and so we're trying to do the best with what we have.

But if there is something that makes us question the results, you know, we'll have to think about that at the time and decide if that means that we should do more testing on other materials or try to approach it analytically. There's a lot of options that we would have if we found different results.

MR. RAHIMI: Yes, I think that as Michelle mentioned, the DOE is going to do a similar test. Is

DOE going to do the hydride reorientation tests under the spent fuel disposition?

MS. BALES: I'm not sure. I haven't heard that, but I don't see why they wouldn't. I think that the capability that's being developed at Oak Ridge to do the reorientation is relatively new, and I wouldn't be surprised if other parties go to Oak Ridge to capitalize on that capability that's now there.

CHAIR BALLINGER: I'll ask our NEI folks.

MR. CUMMINGS: I'm sorry, could you repeat the question?

MS. BALES: Are you planning to do any testing on reoriented cladding material at Oak Ridge after the capability has been developed there?

MR. CUMMINGS: I'm not aware of any plans right now for EPRI or anybody else in the industry to do tests there.

PARTICIPANT: I can add to that a little bit. You know, there is a sister rod characterization program that goes with the high burnup demonstration program, and there will be a variety of testing that's performed on those types of rods as well. So some of those tests could be used to supplement where there's gaps in the data if it's determined that there is a lot of hydride reorientation going on.

Remember in the beginning of this we talked about that this is not a for sure phenomenon that's occurring, this is a - it's been shown to happen in some instances, but it's not really a - it is temperature driven.

And if we're not getting to the temperatures that everybody thinks causes hydride reorientation, then I don't know if you want to really put a lot of effort into these very expensive tests where it's a phenomenon that isn't occurring.

CHAIR BALLINGER: Okay, Pete, are you still there?

MEMBER RICCARDELLA: I am, I am, I've got a couple of questions.

CHAIR BALLINGER: Good, shoot.

MEMBER RICCARDELLA: Okay, first, Michelle, what's the test frequency you're using?

MS. BALES: One hertz.

MEMBER RICCARDELLA: One hertz, and is that -

MS. BALES: Oh, no, sorry, I'm sorry, it's five hertz. Sorry, I misspoke, it's five hertz.

MEMBER RICCARDELLA: Five hertz, okay, and is that typical of what the kinds of vibration frequencies you expect in transportation?

MS. BALES: So at the - one of the initial characterizations that we did was trying to understand if this behavior would be frequency dependent.

So we have an assumption that the fatigue life in this is not dependent on the frequency, and therefore the testing that we did at five hertz was balancing what we expect in transportation with the need to have an efficient program in a hot cell.

MEMBER RICCARDELLA: Okay, and are there similar data for low burnup fuel that you could put on the same curve that we can see how they compare?

MS. BALES: We have not tested any low burnup fuel in this device.

MEMBER RICCARDELLA: So nobody's done a fatigue - no one's developed a fatigue curve for low burnup fuel?

MS. BALES: Not in the same manner.

MEMBER RICCARDELLA: I'm sorry, you broke up.

MS. BALES: Sorry, no, the answer is no, not in the same device, or, I'm sorry -

MEMBER RICCARDELLA: I understand not in the same device, but I mean -

MS. BALES: Not even in another device.

MEMBER RICCARDELLA: It's an S/N curve.

I mean, we don't have an S/N curve for low burnup fuel?

MS. BALES: That's correct.

MEMBER RICCARDELLA: Okay.

MS. BALES: Maybe Meraj can answer this or somebody else from NMSS, but the assumption - even though the fatigue behavior has always been written into the regulations as one of the aspects of normal conditions of transportation, before there were arguments made about how much - how far the loads that were experienced, how far they were from the expected yield strength.

And so through an argument that the loads were so much less than the yield strength, the licensees have argued that vibrational fatigue was not an issue at play for low burnup fuel.

And the question that prompted this for high burnup fuel was more an acknowledgment of the possible decrease in cladding properties and also some of the localized features that we see in high burnup fuel, whether they would change the argument for just saying our loads are so much lower than yield that we don't expect fatigue.

MR. RAHIMI: I want to confirm Michelle's answer. To our knowledge, similar tests have not been performed on low burnup fuels.

MEMBER RICCARDELLA: Okay, and just a final sort of reply or response to Ron's comment about the one test, you know, this is a - there is static testing and of course, the fatigue testing, and I think the main focus here is the fatigue testing, which you are doing three tests, not one.

And just sort of a related question, you will get some static information like the slope in the low portion of that curve from the dynamic tests, right?

MS. BALES: In the NUREG report, there is some discussion of what information we can discern from the dynamic results because they are measured continuously. So in principle, we should be able to back out some more fundamental or static properties, but that proved to be a little difficult.

So I think that the static tests are really good for bending moment and definitely for maximum bending moment. The dynamic test, it's a little more challenging to process the amount of data that we have and how frequently it was collected to say that we know something about the elastic modulus.

MEMBER RICCARDELLA: Well, are you going to do the static test before the dynamic tests on the radial hydride fuel?

MS. BALES: Yes.

MEMBER RICCARDELLA: So if you got something really strange, I presume you could make a different decision about what to do with those remaining three samples, right?

MS. BALES: Yes, the way that we've been running this program is we have identified different kind of check-in points, and so when those check-in points come, I get NMSS staff on the phone, research staff on the phone, Oak Ridge staff on the phone.

We share what's been produced to date and we talk about the strategy to confirm that we still want to move forward as we had planned, and there has been a number of instances where we've changed our mind once we've seen the data.

So certainly after the static tests we'll have a call to discuss what we've seen and what it means for our dynamic tests. And then we're looking at running three tests at different loads in dynamic mode, so we would also probably discuss after each one of those tests where we want to run the next test based on the results so far.

MEMBER RICCARDELLA: Okay, thank you. I appreciate it. It was a very impressive program.

CHAIR BALLINGER: Questions from the colleagues before we take a break? Okay, let's adjourn until about 16 minutes of.

(Whereupon, the above-entitled matter went off the record at 10:29 a.m. and resumed at 10:43 a.m.)

CHAIR BALLINGER: We're back in session. I don't know about that part. I guess it's John.

MR. RAHIMI: I guess before John starts, Dr. Ballinger, I wanted - I know you asked a question about the curve that Michelle provide in terms of asking what in a typical transmutation the number of cycles that you would see and I would like Gordon to speak to that - to answer your question.

DR. BJORKMAN: Yes. Typically, in a cross country trip by rail or by truck you'd be very hard pressed to get above a million cycles. Ten million cycles would be extremely difficult to get to that number.

And the only way to get to that number is if actual vibration frequency of a rod is fairly high in the 20 to 30 hertz range. So and typically at those frequencies the amplitudes are very, very low. So the actual bending moment is very, very low in order to get that much fact fluctuation.

It's only at lower frequencies that you get the higher amplitudes. And so we don't expect - I mean, we expect, based on the S/N curve that we're seeing that depending upon what fatigue damage law you want to use that you are not going to get failure in fatigue mode traveling across country. At least that is what we suspect, based on the data we've seen so far.

CHAIR BALLINGER: So that's like - what you're saying is we're below the fatigue limit?

DR. BJORKMAN: You're below the endurance limit or you're at the bending moment and stress levels that you're going to get at the higher frequencies. You're going to be well within the endurance limit.

CHAIR BALLINGER: The endurance limit?

DR. BJORKMAN: Well, yes. The endurance limit being the lower limit on that curve.

CHAIR BALLINGER: Okay.

DR. BJORKMAN: Which was the .1 percent strain, I believe.

MR. RAHIMI: Thank you.

MEMBER SKILLMAN: Gordon, I'd like to ask this question. For a truck, what would be the appropriate input frequency to the cask? Wouldn't it be some multiple or combination of a wheel harmonic at 60 or 65 or 70 miles an hour, 80 feet a second divided by the diameter, that type of - that type of approach?

DR. BJORKMAN: That would be the input

that you would expect to get to the connection to the cask - from the truck bed to the cask - and then you've got to go through all of the other internals of the cask to actually get to the fuel assembly. Yes, that's what we would expect.

MEMBER SKILLMAN: Okay.

DR. BJORKMAN: That's sort of the answer. It's how many turns of the wheel, those kinds of things that -

MEMBER SKILLMAN: At speed - whatever that speed might be. Let's hold that thought. So now we're transmitting six, seven, eight hertz up through the truck bed into this massive cask.

How does one determine, if you will, the amplification or the dampening that occurs in the cask?

DR. BJORKMAN: What we really want to look at is in the cask itself we are going to have some damping. Now, the damping will be very low. We expect to get higher damping in the rod.

We haven't done any damping on fuel rods as such but I would expect that just as concrete has a higher damping than steel - and concrete is a composite material much like a fuel rod, a spent fuel rod, brittle - a brittle material surrounded by a more ductile outer coating.

So it will behave more like a concrete structure. I would expect the damping would be relatively high. But if you're inputting the frequency at, let's say, eight hertz now that's not the natural frequency of a fuel rod.

The actually frequency of a fuel rod is slightly higher. So at eight hertz it would depend upon what the response of that rod is going to be in terms of what the amplitude is.

But at eight hertz you're not going to accumulate a million cycles. I mean, you just can't, you know, as you go across the country. But, you know, these are things that will all come together but the key piece here is - key piece here is that we finally now have this S/N curve, the stress to failure given number of cycles.

That's the key piece that we need to fit into the rest of the piece and the rest of the piece will be what is the - what is the vibration mode - what is the actual rod seeing from the truck all the way into the cask and those are studies that some which have been done but others will be done to get that information.

MEMBER SKILLMAN: Thank you, Gordon.

MR. RAHIMI: So with that, I guess we're ready to start. John?

MR. SCAGLIONE: All right. I'm John Scaglione from Oak Ridge National Laboratory and today I'll be talking about some work that we did that's been documented in NUREG CR-7203.

Essentially, this complements the information we saw earlier today and it looks at trying to provide an understanding of what are the impacts if we did have some kind of geometry change inside the canister systems that could be associated with clad and integrity issues or drops in accident sequences. Next slide.

The - so Huda showed you this earlier and this here shows the highlighted boxes here on the analysis side for storage and next one is the - for transportation and I'll talk about some of the different types of analyses we did that could be used or fits within these analysis sequences.

Next. So basically we did a consequence assessment for a number of hypothesized geometry changes.

Essentially, we had three major reconfiguration categories. We had reconfiguration associated with cladding failure.

Then we had a reconfiguration associated with where the rod or the assembly deforms but the cladding did not fail because we already covered cladding failure in the first one. And we also accounted for changes in the fuel assembly axial alignment without cladding failure.

If you look at the figure on the right here, this shows you a schematic representation of how a fuel assembly sits within the storage participation package. Essentially, there is a neutron absorber plate panel that's inside the basket.

Some of them are longer than others and some of the newer basket designs are actually full length. They accommodate a variety of assembly links and in order to do so they usually use what's known as a fuel spacer.

That's the green rectangular representations on the bottom and the top of that. These fuel spacers are typically designed to withstand the - they have the structural integrity to withstand the nine meter drop or the 30-foot drop test.

So that keeps the fuel within its location within the basket structure provided the rest of the fuel assembly remains intact. Now, the evaluations that we performed we looked at four technical disciplines - criticality, shielding, containment and thermal.

The criticality and the shielding analyses were done with the scale code system and the thermal analysis was done with COBRA-SFS. Containment was based on the derivations from the NUREG CR-6487 and the A2 values provided in 10 CFR Part 71.

Some of our key analysis functions are that the all-criticality calculations were performed fully floated with water so that's an important assumption there because without water we really have no criticality concern.

And the - all of our fuel assemblies were considered to behave in the same manner. So, for example, if I had 42 rods that were breached in one assembly, we assumed that the same 42 rods were breached in all of the assemblies.

And for each of the different technical disciplines we did tailor the parameters that we were interested in to understand what was the largest impact with respect to that - what was of interest for that particular discipline.

Our results were provided as a - the relative change from the intact configuration so what we have here is we have a hypothesized or a generic - it's a fake cask that we model that's representative of existing storage in transportation packages and we loaded it with a representative 17 by 17 fuel assemblies for the PWRs and 10 by 10 assemblies for the BWRs.

So what our starting frame of reference would be may be different from existing packages out there but what we do is we calculate what's the relative difference if there was some type of reconfiguration. And these did account for burn-up credit so they are representative of burn-up credit casks out there.

MEMBER SKILLMAN: John, for these - for these assemblies - 17 by 17 and the 10 by 10 - are you assuming five percent to 35?

MR. SCAGLIONE: We did a variety of enrichments and burn-ups. Five percent was one of the enrichments. But other ones were - we looked at different enrichment burn-up combinations that you might see in a burn-up cask.

So, for example, you might have a 3 percent at 35. Five percent might require, like, 45 or 50 in order to meet your initial loading conditions.

MEMBER SKILLMAN: Thank you.

MR. SCAGLIONE: Next. All right. So the - we'll walk through some of the cladding failure configurations here. Essentially, as I mentioned, the first one was - well, we had two sub-classes within the cladding failure configuration category.

Looked at ones where we had breached spent fuel rods, where there was some amount of breaching to allow some particulate to escape, and then we looked at damaged configurations where we allowed all of the fuel to move and be relocated.

So the damage would be considered part of the - on the hypothetical accident side where the breaches would be more in line with the normal conditions aside for either the storage or transportation part.

So, for example, in the thermal what we would be interested in if you have clad breach then you're looking at what's the impact that the back fill gas is having on your system thermal properties. For the criticality it's looking at the - essentially these fuel assemblies are under moderated systems.

So if you start removing fuel and replacing it with water you can cause an increase in radioactivity. So we looked at configurations associated with that.

For the shielding, we looked at moving the source term to different regions within the canister system and for containment we looked at the fraction of failed fuel rods. In addition to the high burn-up fuel we also looked at the effects that the rim effect could have.

And then on the damaged side it's just - we allowed the larger range of degrees of freedom. For thermal we looked at - once you lose your cladding integrity in the thermal then you're concerned with your temperatures at the - like, of the other components within the system. So, for example, your neutron absorbers, your canister surface temperatures, things like that.

And next slide. So for the rod assembly deformation configurations, these are the ones where we do not allow cladding breach and so we thought about what kind of configurations do we need to think about here.

So we looked at ones that could be from a side drop or from a potential end drop, and as you can see the - from a side drop you're really going to get a compression of the fuel assemblies within the basket structure and from an end drop you can get where the fuel assembly buckles it can either be spread out or become tightened, and the pitch from a criticality standpoint the larger you spread out the pitch the larger the increase you get on that.

If you compress the pitch you actually have a decrease in criticality potential. For shielding, the end drop really had no impact as bounded by our moving the source up or down because the way that the source is described within the basket itself it doesn't matter if it's - the lattice is close or far or spread apart.

And for the horizontal drop though we did look at the effect of compressing the source against the sides of the basket and you can see two representations there where it's either flat against it or stored within, like, the V if it was on a - the basket was, like, a little bit rotated.

And these do have a small effect because it allows different streaming pads up through the ends of the canister system and it puts the source closer to one side versus the other.

For containment, on the - since there's no clad reach in this one we looked at the effect of crud spallation. We varied that from .05 to 1.0 and there was a - it's the same configuration for the vertical drop systems.

And for the thermal we looked at the effects of pin pitch contraction and pin pitch expansion because that can affect the flow rates within the void regions of the fuel assembly.

Next. For the changes in axial alignment, essentially we moved the fuel assemblies to the top of the canister system or to the bottom of the canister system. This is essentially the same for all of them.

What this does is this checks to see if depending on how our outer neutron shield is configured you might have a region that you could expose the fuel and then within the fuel basket region if you have the fuel - the actual active fuel region that gets outside of the neutron absorber envelope then that's something that would be of concern as well.

Next. So on some of the results from the criticality evaluations we saw was a - basically the highlighted yellow one is what is considered to be probably the most realistic or reasonable reconfiguration or impact on K effective.

It was a 4.91 increase in K effective for PWR fuel and 2.4 for BWR fuel. What we did for this PWR configuration is we assumed that we had essentially - I think it's either 42 or 44 rods removed from the lattice configuration.

They were the highest radioactivity rods in that lattice and then we had the material redistributed outside the neutron absorber envelope and near optimum packing traction to maximize K effective.

So this is also a highly unrealistic case to have the fuel actually get distributed like that and have every single fuel rod that's breached and removed from the lattice be the most reactive fuel rod in that lattice.

The majority of the configurations would show that the - you actually have a decrease in radioactivity for most of the time. But because we were interested in trying to see what we could do to maximize it so that's why the configuration is modeled that way.

For the damaged fuel scenario, this is also a very conservative rebounding approach that was used to understand the impacts on K effective for this.

Essentially, we tried to get the highest K effective response we could because it was - we just wanted to see so what's the worst that could happen. You know, it's a - if you could live with that one then there's nothing else to do.

But essentially it's - we did a lot of simplifications to make the system as high a radioactivity as we could, and I'll talk a little bit more on that case that'll give you some insight into how unrealistic that case really is.

And then the rod assembly deformation case we looked at where we had different degrees of pin pitch expansion. We looked at different locations of the assembly up and down it, having different amounts of pin pitch contraction and expansion, and our maximum delta K was 3.9 for that, for the PWRs, 2.8 for the BWRs and then 13.3 for unchanneled BWR fuel.

Others very little unchanneled BWR fuel out there that's actually in storage in transportation packages and some of these would need to be reassessed on an individual basis where you can actually bring in the true basket dimensions to see what is the maximum allowable of a pitch expansion that could be in place there. But for our hypothetical BWR cask configuration we showed a 13.3 percent change.

And then for the changes in axial position, essentially this is where K effective behaves linearly and the more fuel you'll have outside the neutron absorber envelope the higher the K effective.

Typically, these - the amount of space that's above and below the fuel assembly that there could be movement within is one to two inches and these results here show that it's less than a 1 to 2 percent change in K effective for - when it goes within one to two inches.

But this is also a system and assembly

specific design. That's what's going to control how much movement there could be.

So those were something that would be - need to be looked at to make sure that it still - they got the spacers and there's only so much movement possible.

Let's move to the next slide. All right. So this is our hypothetical bounding criticality analysis for damaged fuel.

We had it just - the fuel is rubbleized and allowed to be distributed throughout the entire canister cavity or the entire basket cavities and the - so while outside the neutron absorber envelope and we removed all of the hardware that you see in the middle there.

Essentially, we did not account for guide twos. We do not account for the nozzles, spacer grids or the cladding. So what we did is we take fuel pellets and distribute them in different size lumps throughout the system to get the optimum fuel to water ratio to see how high could we make K effective go for this configuration.

So this is - essentially you've got floating fuel in water at a perfect optimal H to X ratio for this configuration so that is not a credible configuration but it does - it is a bounding line.

The - another thing that we actually maintained was the burn-up profile. So we - although this fuel might have been represented at 45 or 50, we did a number of sensitivity calculations so there's a variety of burn-up enrichment combinations. The lower burned ends are what's outside the neutron absorber envelope so that's also going to increase reactivity.

Next. So we also looked at the consequences of geometry change with respect to dose for storage casks. So the way that this - there's really - there's no actual requirement for storage casks other than your site boundary dose limit.

But so what we looked at here was the one meter from a storage cask to see what the change is and what the dose change would be at, let's say, at the site boundary. So it was - we used 100 meters from the array configuration to represent a site boundary dose limit.

And for the - we saw here for this configuration this is with actually - for the damaged fuel we had a 4.1 increase and a 9.2 increase for the BWR.

This was actually at the vent location where you have the most streaming. And then we had very small increases for the - at the site boundary of 1.8

and 2.4 for the damaged fuel.

This is allowed to be distributed within the entire canister system. So typically when you're in a vertical system like this and you have damage the fuel will be at the bottom but the results shown here were for if we just let it be uniformly distributed within the canister system.

And then we have a change in axial position that's - when you move the fuel slightly down to the bottom that caused an increase in the streaming dose at the bottom storage vent locations.

CHAIR BALLINGER: So this is still full of water?

MR. SCAGLIONE: No, there's no water in the shielding. So that's why we tailored the analyses to make sure that they were representative of what's important. So for criticality you fill it with water and for shielding there's no water.

MR. RAHIMI: Let me interject. I mean, the reason for the assuming water is mainly focused on transportation because under Regulation Part 71 you need to assume optimum moderation. But the storage dry - that's the way it's stored.

MEMBER SKILLMAN: Let me just make sure this is clear in my mind. What I see you presenting here is for the damaged to fuel, if the undamaged radiational level meter from the cask was 3 MR per hour for the PWR it would be approximately 12 or 13 milligrams per hour.

MR. SCAGLIONE: That's correct, except that this is actually only at the vent region.

MEMBER SKILLMAN: Yes. Okay.

MR. SCAGLIONE: Okay. In the middle there was essentially no change.

MEMBER SKILLMAN: No change. Yes. Thank you.

MR. SCAGLIONE: Okay. Next. All right. So we also looked at the consequences for transportation purposes. So and these were concerned with the - there's a number of requirements in the 10 CFR 71 but for the most part we're concerned with the dose up to two meters for normal conditions of transport and does at one meter is for hypothetical accident conditions.

So for the - we assumed 25 percent failure of the fuel in these lines which is - or that's what the results are being shown here.

We have different numbers in the report that you can look at, because the RIS indicated that 3 percent failure for transportation and we're looking at 25 percent for BWR and 11 percent for BWR.

So this is a - the results we're showing you here are much greater amount of failure than what the RIS is stating and what we're seeing here on the right is that there is very, very modest increases in the dose rate at the - for the - at the 2 meter and the 1 meter surface.

The - for the first ones here we looked at the different numbers of rods missing and where the fuel is distributed to.

We have - at the top it was 1.1 for the PMB, actually a slight decrease for the BWR radially and then a slight decrease for the PWRs at the bottom, and then the other numbers are almost nearly the same.

This is where the fuel is redistributed to the middle of the fuel assembly region. Now, on the next one on the bottom there we looked at - let's say we redistribute this fuel to the bottom region of the fuel assembly, so what's the impact?

So the bottom dose rate goes up and you can see that the - for the PWRs it went up to 2.54 and the BWR went to 3.97. The reason that there's a large difference between the PWR and the BWR here comes from the way that the fission source distribution for our nominal system was provided.

The PWR is essentially a lot more flatter and cosine shaped and the BWR one is more middle peaked. So that's why when the middle comes down to the bottom you see a larger increase in dose down there.

For the pin pitch contraction models, this is where they're flattened against the side or in the V. The - you can see that at the top we get a changing dose of what - goes from 1.4 and 1.5. This also a very small increase in dose.

This is primarily due to the neutron streaming because the fuel is no longer doing as good a job at self-shielding itself so therefore you get more streaming.

And then we looked at changing axial position and this one here, depending on where we shifted it, either to the top or the bottom, you can see what the maximum increases were and they're also very small.

This just gives you an illustration of how our bounding shielding analysis model looked. You go from the top plot here shows you how the nominal configuration looks and then for the - when we go to our bounding model we actually allow the source to redistribute outside the basket region.

So it comes a lot closer to the canister surface so that's why you get an increase on the surface radially and then for the - where it was homogenized down to the bottom you can see that it's just - all of the fuel is allowed to be laid down at the bottom.

So these are also very unrealistic configurations of what they were meant to be bounding.

Next. All right. So this is where we looked at the effects on containment analyses. So what we found out overall was that the - it's really - because of the constant decay of the source over time the impact of fuel failure may be of secondary importance, especially when you start looking at 60 years or so down the road.

One of the main contributes to the consequence or the containment is the crud and that's because it has Cobalt 60 in it. So once you start getting out to the 40-, 50-year time frame it's pretty much decayed away to almost - there's really not that much left.

Therefore, it's no longer planning an impact on the containment analysis and the allowable release rate increases with increasing decay time, and the greatest sensitivity to allowable leakage rate was really from the mass fraction of fuel released as fuel fines.

If you look at that plot on the bottom you can see the curve kind of goes and all of a sudden there's a drop. Well, that drop is where started doing sensitivities on the actual mass fraction of fuel released, and the - there was a variety of sensitivity analyses that were done to look at different release rates and fuel fines.

Currently, NUREG 1617 gives you a table that says these are the values to use for normal conditions and these are the values to use for hypothetical accident conditions.

But when you start looking at high burn-off fuel there's - we've done a number of sensitivity analyses to see what if there was some changes in that and how does it impact the overall system.

And essentially what we've seen that really it's with the increased decay time you can essentially have the same - you can accommodate a much greater number of cladding breaches.

For example, on the top plot there you can see the .03 value is the starting point from the NUREG 1617 but as you go out to the right, let's say you start at the 1.0. You get a negative four failure there.

So you can have, like, .1 after 40 years. If you get out to a hundred years so your fraction is increasing as you go out and you still have the same - what was originally allowable.

CHAIR BALLINGER: Can you explain to me what allowable - allowable against what? Can you restate that?

MR. SCAGLIONE: Yes. Basically, there's a series of formulas and tables in 10 CFR 71 and based on the fuel fines, the release reductions what you calculate is a number essentially that says this is my allowable leakage rate.

CHAIR BALLINGER: This is to the environment?

MR. SCAGLIONE: Yes.

CHAIR BALLINGER: Okay. So this applies to breach of the canister as well?

MR. SCAGLIONE: Now, see, there's a little question or kind of a - basically, for welded systems they're considered leak tight so there is nothing coming out of it.

But for bolted canister systems, sometimes, depending on how the seal, this is a test against what's - they can measure from - on the seal if they're below their leakage rate.

CHAIR BALLINGER: Okay. But what I'm trying to get at let's say we had a welded canister that did have a leak like a stress crack, for example.

MR. SCAGLIONE: Yes. Yes.

CHAIR BALLINGER: These numbers are applicable then?

MR. SCAGLIONE: I would say they are but it's - I think that that's an area for discussion.

MR. RAHIMI: Yes, let me explain. One, the canister for transport, let's say, is put into overpack, the overpack is your containment barrier in this case.

The closure system of the overpack needs to be tested to the allowable recreating Part 71.51, which tests into the minus 68 to value. That's where the allowable comes from.

So you could - for all practical purposes for transportation if you've got, you know, a crack in your canister, your containment, you know, boundary is the transportation overpack - your seal.

CHAIR BALLINGER: Yes. Okay. I'm understanding that. What I'm saying are these numbers applicable or do they have any relevance to the pad - to the cask sitting on the pad at the IFSI. In other words, are these allowable leak rates are appropriate for a cask sitting on a dry storage pad?

MR. RAHIMI: Yes, because if it is the

welded system canisters you automatically is leak tight. That's the definition.

CHAIR BALLINGER: No, no. I'm assuming that the canister leaks.

MR. RAHIMI: Okay.

CHAIR BALLINGER: Okay. So something happens to that canister on the pad.

MR. RAHIMI: Okay.

CHAIR BALLINGER: And there's a crack somewhere. Are these numbers - do they have any relevance to that situation even though they're for - calculated for an overpack and all this kind of stuff for transportation.

MR. RAHIMI: Yes. These numbers - these are for transportation. For the storage system what you have is a site boundary dose in the regulation.

CHAIR BALLINGER: Okay. So that's the site - that's the -

MR. RAHIMI: The site boundary dose. Yes.

CHAIR BALLINGER: Okay.

MR. RAHIMI: Site boundary dose, 25 millirem for your - at the site boundary dose. That's what's the requirement.

MEMBER SKILLMAN: John, I'd like to ask

this question. In your first bullet and first sub-bullet, crud is important in calculation of allowable leak rate. How does the cobalt get out?

MR. SCAGLIONE: Oh, get out?

MEMBER SKILLMAN: Yes. How does it leak?

MR. SCAGLIONE: It's - I don't think that - it doesn't actually leak but it's - you take a penalty for it in the formulas that are dictated on how you calculate your allowable - your useable A2 value.

So it's - really, there's a certain amount of crud and because of that the - you have to account for it in your calculation. That's - I'm not sure how it would actually leak out because there's a number of other - the only stuff that should leak out are the respirable or the very light - the gaseous materials.

But the other materials are - go into this calculation for the - what's your allowable leakage rate. So it's just - it's part of the formula for how you calculate.

MR. CUMMINGS: Let me - let me add to that. Let me add to that.

MEMBER SKILLMAN: Absolutely.

MR. CUMMINGS: Kris Cummings, NEI.

MEMBER SKILLMAN: Let me finish. Where I was going with this is I understand this real well.

Cobalt is really bad news but it's two gammas. It's a 1.17, it's a 1.33. This is a 5.2 year half-life and after about 35, 40 years it's gone.

But when it's there it's deadly. But the way this is presented it's presented in the term of a leak, and having dealt with this quite thoroughly a number of years ago I'm looking at your slide and I'm saying to myself how in the world does that get out of there.

That would have to be some form of a particular leak or you didn't de-water - it didn't de-water as much as you had intended it to de-water and it comes out with some fluid leaking somewhere.

So what I really think you're saying here is there's a handbook or cookbook that says here's how to either consider or not consider Cobalt and after 40 years you don't have to consider Cobalt.

MR. CUMMINGS: Right. In confinement analysis you take a percentage of the Cobalt 60 that is in the crud. You assume, one, that it falls off the cladding.

You take some conservative estimates of that and then you make the assumption that that is in an aerosol form which can get out of the canister through any size leak. So there is no consideration of gravitational settling, the fact that it's a particulate versus, you know, in an aerosol form. So it is a very conservative treatment of Cobalt 60 inside the canister.

So your case in point, exactly, is that it is a - what I would consider an over conservative simplification simply to ensure that you do a conservative estimate of either the release. And that's fine because in most cases you don't have a problem meeting the 25 millirem.

You can do this very conservative calculation even if you have an assumed leak rate. But in reality, the Cobalt doesn't get out because it sets to the bottom and even if you have a leak very little of it actually comes out of the cask. It's an artifact of how you do that recipe.

MEMBER SKILLMAN: Okay. So as Dr. Ballinger said, it's a stylized calc and you just live with it.

MR. CUMMINGS: Yes.

MEMBER SKILLMAN: Got it. Thank you.

MR. SCAGLIONE: Next. Okay. So I'll talk about some of the - what we saw with our thermal analysis results.

Now, to give you a little background on the source term here is that this was for five weight percent enrichment, burned a 65 gigawatt day burn-up.

So that's a high burn up fuel, and as such that makes - you have a high discharge heat load. So for looking at the - to put it into perspective, for a decay time between 20 and 60 years you have about a 220 degree change in your cladding temperature from the time it was - we have gone into the canister system until the time it's - after about 20 to 60 years.

For a horizontal cask system, you have - it's a 226 degree differential, and then once you get to the - in the 40 to 60 years you actually - it's kind of plateaued out and I'll show you the curve on the next slide here.

But essentially you have a steep curve in the beginning and it starts to plateau out over time so that the change in temperature isn't as great. But in that first part there's a large drop in your overall thermal output. And we looked at the effects of insulation.

Those are actually very small. It was like having an on or off. It causes a 10-degree change on your cladding temperature for a vertical cast system, 8 degrees for horizontal.

When we had a failure of one assembly where we allowed the gas to be released from that assembly it shows that you actually decrease for the vertical cask system and you had a slight increase for the horizontal cask.

For the failure of all of the assemblies we allowed all of the gas released. It shows you that you have a lot of - a larger decrease for the vertical cast system and a - you have an increase for the horizontal cask system, 42 degrees there.

But if you compare that to your 226 degree change then it's very small. For the damaged spent nuclear fuel configurations, we allowed the fuel to collapse and form a particle bed at the bottom of the canister basket region.

We see a change in the - 14 degrees for the other fuel assembly cladding temperatures for the vertical system, 3 degrees for the horizontal cask. I should note on the last one because we lost a cladding now we are focusing on what's the change in temperature to the neutron absorber material instead because we are no longer concerned with cladding temperature.

CHAIR BALLINGER: So these temperatures - these numbers are relative, right?

MR. SCAGLIONE: Yes.

CHAIR BALLINGER: For example, 3 - is that significant?

MR. SCAGLIONE: No. That's a -

CHAIR BALLINGER: Okay. Is 4 significant?

MR. SCAGLIONE: No.

CHAIR BALLINGER: Is minus 8 significant?

MR. SCAGLIONE: No.

CHAIR BALLINGER: Is minus 51 significant?

MR. SCAGLIONE: Depends on how close you are to the limit in the beginning but I would say at this time period it's not significant.

CHAIR BALLINGER: Okay. So the uncertainty is plus or minus 50 degrees?

MR. SCAGLIONE: I wouldn't say it's plus or minus 50 degrees but it's a - so what do you think is plus or minus 50 degrees?

CHAIR BALLINGER: I don't know. I'm just trying to get a handle on minus 221 degrees.

MR. SCAGLIONE: This -

CHAIR BALLINGER: Which digit - which digit is significant?

MR. RAHIMI: Yes, I think so. The minus 221 - what John is showing is the temperature drop.

CHAIR BALLINGER: Right. So you

calculated a temperature drop.

MR. RAHIMI: Yes.

CHAIR BALLINGER: So it's minus 221. Is the one significant? What's the - what's the uncertainty on the 221?

MR. RAHIMI: The -

CHAIR BALLINGER: Because that has bearing on whether or not you get to the MBT - not MBT, ductile to brittle transition temperature, right?

MR. RAHIMI: That's right. Actually, that's a good point, that you can get some idea about if you assume that when you loaded the cask you were, you know, close to 400 degrees and 221 degree drop, that takes you in that zone, ductile to brittle transition, if you - yes, thinking about that cladding. But the temperature - he's reporting this is a temperature of the poison, right? The borale?

CHAIR BALLINGER: Oh, okay.

MR. SCAGLIONE: Well, it's the cladding, but once we lose the cladding integrity then it's for borale.

MR. RAHIMI: For the borale?

MR. SCAGLIONE: Yes.

MR. RAHIMI: So those are the temperature drop that you're reporting for the borale?

MR. SCAGLIONE: Only where there's a star.

MR. RAHIMI: Oh, where there is a star. But the 221 can we use that as a temperature drop in the cladding?

MR. SCAGLIONE: That's the temp -

MR. RAHIMI: That is the temperature drop?

MR. SCAGLIONE: Over decay time that's the temperature drop of the cladding.

MR. RAHIMI: Yes. So you're right. IN terms of the - if somebody wants to know after 20 years. That's why, you know, what I showed everything we're talking about is beyond 20 years. That is when your temperature drop is significant enough it takes you to ductile to brittle transition.

MR. SCAGLIONE: Okay. Okay. So now when we get to the - towards the bottom here we're looking at failure of all assemblies. So we're no longer concerned with the cladding temperature because we've already got our fuel is failing.

We look at the effect on the borale temperature and we can see that there was a - it was 127 degree increase in temperature when we have all of our fuel failing and when we start to get - we look at the - we can become concerned with the seal temperature on the canister system because that's going to determine how well that it maintains it containment function.

We see that the way that our - we've approximated this is we looked at the change in the lid temperature. We don't have - this is a hypothetical cask. We don't have an actual seal on it or a seal design.

But if you look at the delta T that the lid experiences you can estimate what the seal might have as a delta T and we saw that to be 19 degrees.

For the rod assembly deformation, it was 51 and 12 for the two systems, and for the change in axial position it was very small changes.

So essentially what you're seeing here is that the main takeaway is my fuel is - the thermal output is decreasing significantly over the first 40 years or so and if my fuel starts to become reconfigured or change shape the relative increase is very small compared to the original decrease in heat load or temperature that we've already dropped.

So even though I report it as a fuel temperature here, all of the other temperature - all of the other components would experience similar delta T's over that time period.

So because it's always the same thermal -

really, it's your thermal output that's going to drive the temperatures.

Let's go to the next slide here real quick. Okay. So this kind of helps put it in perspective maybe. The - in the first 20 years the heat load is at 48 percent of what it was at the time five years after discharge.

So most fuel isn't able to go into dry storage five years after discharge, especially fuel that's at 65 gigawatt day per metric ton burn-up because they wouldn't be able to meet the - some of the other requirements that are necessary to meet the storage function there.

But after it reaches the 20 years the thermal outputs drop to 48 percent. After 40 years it's at about 25 percent of its heat load limit and then it pretty much plateaus off.

Next. All right. So overall the results of this study gave us an understanding of the - what kind of changes we could expect to see from the nominal intact configuration versus if there was some degree of reconfiguration occurring.

For all of the scenarios, the ones that involve cladding failure had the largest impact on the technical disciplines. Criticality was for all intents and purposes less than 5 percent increase for the - what would be considered plausible.

Shielding we had less than a 3X difference for the PWR fuel and that's after assuming 25 percent of all the fuel was redistributed to a different location. That's a very small impact.

For BWR fuel had a 4X difference and that was where we considered 11 percent redistributed BWR fuel. And for containment and thermal basically what we see is that these are really - because of the decay over time they become of secondary importance.

It should be noted that the safety impacts of fuel reconfiguration are system design and content type and loading dependent. So there will be differences, you know, based on, you know, one type of assembly and one kind of canister system versus another.

But for the most part, this is what is showing you what the relative change is expected to be in that ballpark.

That is pretty much it.

MEMBER POWERS: Well, I don't think I understand quite your bold red statement at the bottom. What are you trying to communicate to me? It seems to me that everything you've shown here on the face of it seem to be fairly bounding assumptions of pretty mild behavior.

But you have this caveat they're very sensitive. Are you saying that you didn't bound it here?

MR. SCAGLIONE: Well, we didn't try to bound everything. What we did was we -

MEMBER POWERS: Well, what are you trying to communicate to me?

MR. SCAGLIONE: Basically, what I'm trying to communicate here is that there will be differences. If you look at the actual -

MEMBER POWERS: Differences I don't care about. I mean, if it's mild and it becomes more mild I don't care.

MR. SCAGLIONE: Okay.

CHAIR BALLINGER: Let me put it in MIT speak. Do we have a problem?

MR. SCAGLIONE: No. I think that these results show that there is no problem.

MEMBER POWERS: Well, then I don't - really don't understand the last sentence.

MR. RAHIMI: Okay. It depended. What John and the team did they took a generic GBC - generic cask - a 32 assembly cask. What we get at that application is different.

I mean, right now we're getting, you know, 37 PWR, 89 BWR cask system. The design is different. The criticality safety control is different. So based on his design, so he showed that generally for the credible scenarios you're talking about less than 5 percent delta K increase.

But the worse scenarios that you show - you saw it was up to 35 percent, 22 percent, and those were very, one could argue, not very credible scenarios.

CHAIR BALLINGER: In fact, I think some of his words were equivalent to, this is crazy.

MR. RAHIMI: Well, he used non-mechanistic, not the crazy - not the word crazy but used the non-mechanistic term and that's what we're to ask Oak Ridge to look at because we wanted staff to have a reference. The entire range - look at the entire range and see what are the consequences, you know, with respect to all for discipline.

Now, having all that information the NUREG we're writing we're pulling the, you know, credible scenarios and we're saying okay, if you analyze - if you don't have any test data about the cladding and you want to do analysis - just go fuel base analysis, these are just some of the, you know, credible scenarios.

You should look at consequence analysis.

So what they=ve done, they provided the complete scenario, the complete range, and we're going to take that and these are just some of the conclusions they reached, you know, based on credible scenarios less than 5 percent effective. Shielding, we're talking about less than three times, assuming 25 percent of the fuel rods, the rubbleized, you know, broken.

Are you talking about your doses will go up three times, and if it's, you know, 11 percent redistribution against four times. And the containment in thermal - I mean, their conclusion - their finding was there is this - it is such a rapid, you know, exponential decay, you know, that's when you really drive your system.

You know, a system - you know, 20-year old, 40-year-old system, I mean, you can easily meet, you know, all the thermal and containment requirements.

CHAIR BALLINGER: But if I look at this slide I read the first three bullets and I say I don't have a problem. But then I look at this thing in red.

MR. RAHIMI: Yes.

CHAIR BALLINGER: Which, like Dr. Powers was saying, kind of mitigates against the first three.

And I just don't see it.

Mb: Meraj, maybe I can add something. Because we worked on this - similar sentences appearing in the forward and in the front matter to the NUREG and so because we talked a lot about this I can point out that the purpose of this study was really to look at how one would perform these analyses and so the cast designs that were available at Oak Ridge were these generic designs but we did not intend the work to encompass all possible scenarios and all future cast designs.

And so this caveat appears to caution the reader that this is a method but not a source of quantitative values that other people can cite for any cask design because -

MEMBER POWERS: The problem lies in the very sensitive term there. Nothing that was shown said very sensitive. In fact, shows very smooth behavior.

And so but the caveat that appears here on the slide and appears in your documents seems to suggest that there's some sort of a cliff edge, in fact, has been discovered but none is revealed in the document.

And so one is left with the nagging feeling that something has been hidden from me, and what could that possibly be. That's where the difficulty lies.

If you'd said gee, we've done finite number of calculations on some specific things and we have no reason to think they're applicable to other configurations and geometries or other accidents then I would have walked away and said fine.

But it communicates to me that there's something unrevealed that causes results to become wildly different.

MR. RAHIMI: Yes, we'll make sure and we'll modify, you know, that. But I don't know if - we'll look at the NUREG, you know.

CHAIR BALLINGER: But, you see, the point is that amongst us we kind of understand what you're saying now. But to somebody that's not us that's reading this, they see something like that and they - it raises, you know, this kind of red flag in their minds.

And so if it's not really correct in the sense of its implications for the analysis, it probably shouldn't be there. Or change the words, like Dr. Powers was saying, to make it more reflective of what items - the three bullets ahead mean.

MR. RAHIMI: Right. Yes, maybe I'm too close to it because to me, you know, that statement goes back in explaining, you know, if somebody asks, you know, what about those, you know, 35 percent, 22 percent increase for PWR or BWR.

What about those, and to me, you know, sensitive to modern assumption that's what that word is referring to, that -

CHAIR BALLINGER: Those by themselves are almost not credible, right, some of those - some of those configurations that you analyzed are not credible. But when they get put in writing they suddenly become credible in quotes.

MR. LOMBARD: To tell you the truth, we did wrestle with that quite a bit with this analysis and it's kind of our equivalent of the core on the floor exercise or analysis on the reactor side.

But we did want to do it just to get an idea of what is the worst case improbable type events that could occur and what would be the consequences.

CHAIR BALLINGER: But what would be the most credible case as compared to these cases.

MR. LOMBARD: I understand.

CHAIR BALLINGER: Is that in here? I didn't read that - in the document.

MR. RAHIMI: In the - in the document I think the first line what John has listed, you know, less than 5 percent, those are really the credible cases. Criticality less than 5 percent -

CHAIR BALLINGER: Okay.

MR. RAHIMI: - that's K effective, those - what he cited those bullets - sub-bullets, those are for the credible scenarios.

CHAIR BALLINGER: Okay. Thank you.

MR. RAHIMI: All right. Okay. I guess these -

CHAIR BALLINGER: Before we go to Kris, Pete, do you have any questions? Earth to Pete.

MEMBER RICCARDELLA: Yes. No, I was on mute. Yes, no questions or comments. Thank you.

CHAIR BALLINGER: Thank you very much. I guess we can shift -

MR. CUMMINGS: Do you want me to do it from here or -

CHAIR BALLINGER: It's probably better to do it from there.

MR. CUMMINGS: Great. Thank you.

Well, that, I think, is - is that better? That, I think, is actually a great lead-in into the industry's comments on the risks itself.

I had a chance to finally look through the consequence analysis last night and, you know, certainly, being a nuclear engineer and I focus mostly on the confinement, the criticality and the shielding and my takeaway was they did a whole lot of things to fuel assemblies that aren't reasonably credible and it was kind of a no, never mind in the end.

But that's certainly my perspective on it. But given that, I wanted to talk a little bit about the role of risks and our concerns with it and getting back to some themes that I've talked about before in front of the ACRS, which is a risk-informed management framework and ensuring that we apply that in this - in this perspective.

Next slide. Before I get into the industry comments overview, Gordon, I wanted to address one of your questions, which was how, I guess, imminent or prevalent is this issue of high burn-up fuel.

So just to give you specifically some numbers, as of January this year we have 450 canisters that contain at least one high burn-up fuel assembly and in those 450 canisters there's a total of 7,000 assemblies that have - that are high burn-off fuel.

Now, certainly, a lot of those canisters have a mix of high burn-up and low burn-up fuel. But that gives you some numbers in terms of specifically what we have right now in dry cask storage, and then certainly as we go into the future we're seeing a lot more utilities having to load greater percentages of high burn-up fuel because they're starting to mix their high burn-up fuel and their low burn-up fuel or they're just running out of the lower burn-up stuff.

So they're loading more and more and you've seen that also in the - in some of the applications to the NRC, increasing the heat loads to accommodate a greater percentage of higher burn-up fuel and shorter cooling time fuel.

So I just wanted to be able to give you some of those numbers that we have at NEI to be able to address that.

So in terms of the industry comments, I'm just going to go through kind of a high-level view of our comments on the risks that we felt like new requirements are being stipulated, this doing analysis certainly in areas for storage where, you know, you have these, you know, scenarios of large amounts of damage to the fuel assembly where there are no stresses in storage that can cause this amount of damage to the fuel assembly and even in transportation, as you've heard earlier, it's really only in the side drop to transportation that you have a potential impact here.

A lot of - a lot of the discussion is focused around these laboratory experiments that are not representative of spent fuel. You look at the Argonne data it was on defueled cladding and so it doesn't take into account the fact that the pelvet is in there.

It provides some support and certainly for high burn-up fuel with the pelvet cladding bond that would provide some additional support.

CHAIR BALLINGER: But they are doing some of that now?

MR. CUMMINGS: They are doing some of that with respect to the bending fatigue tests. They're not doing that with respect to the pinch load tests.

The next set of tests that they're doing at Argonne, which are, again, the same sort of pinch tests, are still with refueled cladding but now at a lower temperature. So it's great that they're doing that.

The concern still is that you're not capturing the fact that there's - that there's fuel in that and that's just that Argonne can't take fuel. Their license limits them from taking fuel. So it's not possible for them to do fueled cladding pinch tests.

Again, like I said before, insufficient stresses in storage and transportation to cause significant fuel reconfiguration. There's some additional clarification that's needed that this is really only applicable for license renewal, not in the initial license period.

The NRC has stipulated several times that high burn-up fuel, if you meet ISG-11 Rev. 3 that you are - you are in a safe configuration and then it's really only applicable to the accident conditions of transport.

The risk is premature simply because we do need to make sure that we take a risk-informed approach to the licensing process and certainly a greater indication of relying on ISG-24 as the principal basis for storage and transportation of high burn-up fuel.

The basic underpinnings before we started talking about high burn-up fuel was the Idaho demonstration and they went in there, they looked at some fuel assemblies.

They took pictures of it. They certainly didn't do nearly the level of destructive and non-destructive examination that's being proposed for this demonstration program and that's provide the level of confidence and reasonable assurance that the fuel will remain in its as-loaded configuration during storage and transportation. Those fuel assemblies were transported in that Idaho demonstration program.

Next slide. So I want to go back and I just want to talk about a little bit with the regulatory requirements. In 72.122(h) it specifically has qualifiers that cannot lead to gross ruptures of the fuel or that would not pose operational safety problems.

So next slide. So how do we meet those regulatory requirements in storage? We have an inert environment. That's why it's there is to prevent some sort of degradation occurring.

There's limited or not residual water that's established via the drying process. The basket and canister themselves are designed to prevent significant fuel movement.

So even if you do have an event, an external event - a natural hazard, something beyond design basis - there's not - you're not having this fuel assembly move meters or being able to pick up large amounts of momentum that could cause significant forces to be exhibited on the fuel assembly - the limitation of the peak clad temperature below 400 degrees itself.

Realistically, we believe that it's much lower and in some of the initial best estimate calculations that have been done for this demonstration program they're finding that those temperatures of 320 degrees C, that's the peak cladding temperature during the vacuum drying operation.

MEMBER REMPE: So why did they get higher temperatures in the low burn-up test?

MR. CUMMINGS: Well, that depends on how you do the vacuum drive. They may - if you take the - it depends on the operational steps.

So if you just draw a vacuum as fast as you possibly can and leave it for a long period of time, then absolutely you can drive that temperature higher and I think that was the intent of that test in the Idaho demonstration was to drive it to a higher temperature.

However, we, from a regulatory perspective and our operational perspective, we want to maintain that temperature as low as possible and so through the operation of doing basically drying cycles, so you vacuum dry for a while, you bring it down in a slow manner, you have a controlled process to ensure that you don't violate that 400 degree.

MEMBER REMPE: But the high burn-up will have some - oh, I'm sorry. The high burn-up test will have some temperature measurements but in the industry today do they have any sort of measurements to confirm that they're doing this?

MR. CUMMINGS: In terms of the cladding

temperature, no. Again, it's done through reliance on the design basis licensing calculation. So, you know, to -

MEMBER REMPE: Do they even have anything at all, any sort of -

MR. CUMMINGS: In terms of the measurement.

MEMBER REMPE: When they're drying in the canisters do they have any sort of measurement of temperature for the standard operational procedures?

MR. CUMMINGS: I believe they measure say, for instance, the - I want to say the gasses but once you get to a vacuum you're not measuring that anymore. But in terms of cladding temperature there's not.

MEMBER REMPE: There's nothing -

MR. CUMMINGS: There's not a direct measurement because you can't -

MEMBER REMPE: I understand there's no cladding but, I mean, they don't even have anything else is what I - except for the gases that they pull off.

MR. CUMMINGS: Right. I can check on that and get back to you in terms of exactly what sort of temperatures they make or take.

MEMBER REMPE: Yes.

MR. CUMMINGS: But I can check on that.

MEMBER REMPE: Okay. Thanks.

MR. CUMMINGS: And get that back to you. And then, again, natural events failed to cause significant stresses and then, again, the confinement boundary itself prevents a water ingress.

So even if you go into, you know, these scenarios of the fuel falling apart, certainly in storage there's no way water can get into it. In fact, for leak-tight casks they are certified to not leak under all conditions - normal, off normal and accident conditions.

So if the helium can't leak out, water certainly cannot get into the canisters during storage. Next slide.

For transportation, again, there's the same sort of qualifiers in 71.55(d)(2). Again, substantial alteration needs to be prevented under normal conditions of transport.

And again, an important thing here is that this is applicable to normal conditions of transport.

Next slide. Again, a lot of the same reasons. I won't reiterate them here. I think the one difference, obviously, with transportation is that there are impact limiters on the transport overpack that reduce the stresses both on the package and on the contents during hypothetical accident conditions to prevent that substantial alteration.

Specifically, transport applications in terms of how they analyze the fuel, it's typically limiting the G load on the fuel itself to some agreed-upon level with the NRC.

I've heard 60 Gs before. I've also heard 80 Gs. So to some extent, it's dependent upon the interaction with the regulator.

Next slide. So some of the ongoing research, and you certainly heard about it from the NRC perspective, there's also some Sandia studies on loads during normal conditions of transport.

They've also got a fuel assembly shaker table experiments that are looking specifically at the types of stresses that you would see on the fuel assembly cladding.

What we've seen preliminarily from those Sandia studies, getting to some of the discussions we've had about how it relates to the fatigue analysis is that the amount of vibration that they see during the transports that they've done are significantly lower than the number of cycles that are included in the fatigue transport.

So there's at least some initial

indication that you're just not getting enough cycles in the transport cycle to lead to degradation of the fuel during normal conditions of transport.

Obviously, there's the DOE EPRI demonstration program which we certainly believe will provide another level of verification for high burn-up fuel.

As we've discussed before, we'd be happy to try to get EPRI - to have EPRI to come and discuss that. They certainly discussed it with the NRC already and Dominion has come in for their pre-application meeting and will be submitting an application for the modifications to the cask, I believe, in September. And then, as I mentioned, the Oak Ridge fatigue testing, which you've heard about.

Next slide. So the main point I wanted to make was the risk is premature for many of the reasons that I've talked about before.

I think another thing to note is that the first high burn-up fuel was loaded into dry cask storage in 2004 and so the period of extended operation would not be until 2024. So we have, at this point, a good eight, nine years before we get to the period of extended operation for dry cask storage.

There's currently no location to transport fuel so there's not a, from my perspective, a driving force to address this for transport.

And then also the DOE EPRI high burn-up research and development project will garner vast sampling in the 2007 - 2017 time frame and that will give us, again, some initial indications from that program about the cladding integrity after the drying process and -

MEMBER REMPE: So could you elaborate more about the gas sampling? It's my understanding it's just during the drying process and on - before it's transferred to the pad. Is that correct? Now, are they going to take it out - any gas sampling when they're out on the pad or not?

MR. CUMMINGS: Well, I should really defer to EPRI or Dominion to answer that. But my understanding, and I'll leave that as my understanding at this point, so take that with a grain of salt, is that they will take some gas sampling in the building after they've drained it, dried it, back filled it, and then they will take some periodic gas sampling on the pad.

MEMBER REMPE: Okay.

MR. CUMMINGS: But it's -

MEMBER REMPE: That would be a good thing to get clarified because -

MR. CUMMINGS: - periodic, not every week, maybe every couple years. So that's my best understanding. I will let EPRI correct me if I'm wrong -

MEMBER REMPE: Okay.

MR. CUMMINGS: - at the - when you - when they discuss that.

MEMBER POWERS: Let me pursue a little bit this question of risk informing this regulation or this regulatory area.

We've seen a transportation risk assessment that summarily I will characterize as saying that in transporting fuel we've got no risk.

We see now this mechanical analysis, which, again, summarily I would say, a very low risk here. Its risk - they've been a viable mechanism for spent fuel storage.

MR. CUMMINGS: Right.

MEMBER POWERS: I mean, if you're - if I'm dealing in risk metrics for transportation on the order of ten to the minus nine and I'm dealing with similarly low values here for on-site storage, don't I get beyond the bounds of credulity if I try to use risk here?

MR. CUMMINGS: Well, I think if you look

at this and you try to go back to the reactor site and look at it in terms of the quantitative health objective, you'd look at this and you'd say this risk is so low we can kind of say this is beyond the risk that we would need to look at or have an explicit either analysis on. We're certainly an advocate of that. If you can change to the next slide.

The question feeds exactly into my next slide, which is -

MEMBER POWERS: A wonderful straight man.

MR. CUMMINGS: If you keep doing the risk analyses and you see that the risk of storage and transportation are very, very low, well beyond what's associated with the reactor and so that's certainly an areas that in our discussions with the NRC about defense in depth and risk informing the regulations with respect to dry cask storage and transportation, it's well overdue.

It's well overdue in terms of the stuff that the NRC regulates. It's well overdue in terms of, you know, the amount of effort that goes into, you know, showing that these systems are safe.

We know that they're safe. They're designed to be that way. They're over designed to some extent, and that's fine.

But how we then incorporate that into our regulatory interactions with the NRC is where we're looking to see some improvement and we've had those discussions with the NRC on multiple occasions on how we can do that.

MEMBER POWERS: It seems to me, and in fact I am fantastically excited about all the work that's been reported here to us, I guess I think this is the technical bases for reexamining how we regulate this area. We've got a lot of empirical data that you've assembled that says gee, there's just not much of a problem here.

I've done everything I can think I can do and I just don't see a lot of problems, given that I've taken all these precautions beforehand.

And so, you know, I think it's one of looking at it and saying okay, how do we economize on resources both from the agency and from the licensee and still provide what looks to be a fantastically good protection of the public health and safety and preserve that.

And it just does not seem like risk is the vehicle that I want to use because it requires a lot of hypotheses and what not to eventually get to a result that is below the level of credulity that I have for our ability to resolve things.

And so I don't have an answer. Fortunately, I get paid just to ask questions and not paid to provide answers.

MR. CUMMINGS: Well, if I go back to the last - the last read, you know, statement on the NUREG, you know, I see that and I read that as well, okay, great - the NRC, you know, contracted to have Oak Ridge go do this study but, however, at the end of the day they're still saying well, every cask vendor needs to go out and do these same calculations themselves, and that's a lot of, from my perspective, kind of wasted resources to be looking at these scenarios that are very unlikely and that, you know, are making assumptions such as the breach of the confinement barrier and having water get into it.

That's, again, a kind of another non-mechanistic unrealistic scenario certainly for a storage cask. In transportation, it's done because it's in the regulations.

We're required to do it because it says assume fresh water gets into the package. But, again, if you look at the transportation risk studies they show that - I want to say non likely scenario. It's a practically impossible scenario to have that occur.

CHAIR BALLINGER: Now, this annual cancer risk that you're showing up here is that on the assumption that you get zero leakage from the canister during storage?

MR. CUMMINGS: These were - no, they would have assumed some level of leakage of radioactivity from the canister.

CHAIR BALLINGER: They probably had the vacuum technology or whatever it is?

MR. CUMMINGS: Either that or it might have been at the design basis leakage rate which would have been ten to the minus six or ten to the minus five.

CHAIR BALLINGER: So there's already - they're already assuming a de facto failure?

MR. CUMMINGS: Yes. Correct.

CHAIR BALLINGER: Although failure is not an option?

MR. CUMMINGS: Correct.

MEMBER POWERS: I think what they end up doing is just what he said. They take the design basis leakage. It's not a failure. It's -

MR. CUMMINGS: Right.

MEMBER POWERS: - it's what you can reliably and consistently measure in difficult circumstances.

MR. CUMMINGS: Right. Yes, you've got - you've got some of the first welded systems that actually were not tested to leak tight. They were tested at five times ten to the minus six or something equivalent to that. There's some - there are ones that I think were slightly higher than that. So it assumes that. Now -

MEMBER POWERS: Well, you do it. You go in and you say how - what's the leakage on this. Well, it's less than my leak detection rate. Therefore, I take my lead detection rate as the leakage.

MR. CUMMINGS: Right. Right.

MEMBER POWERS: Because -

MR. CUMMINGS: But are those -

MEMBER POWERS: - I'm not going to kill myself.

MR. CUMMINGS: - are those leaking more than the ones that were tested to leak tight? No, it was just a standard that was applied at that point. You could probably go back and test them at leak tight and they would be leak tight. They just weren't licensed that way.

CHAIR BALLINGER: My point is we're spending a lot of resources, as Dr. Powers has said, on ginning up or designing and producing inspection techniques to go in and look at the canisters themselves to verify that we don't have any leaks.

MR. CUMMINGS: Right. And in the case of those inspections for the case of, like, CISCC or things like that, the industry is supportive of that, you know, to make sure that we're going out there and if there is a potential issue that might have an impact on the canister boundary integrity, the confinement barrier, then it's prudent to have some, you know, understanding of when and if that might occur.

But then, you know, if you take that to the next step of what are the consequences of it, then that's where you get to the well, it's kind of not much of a consequence even if you had that occur.

But our licensing basis is our confinement boundaries intact and if we found that wasn't the case we would have to go out there to put ourselves back into our - into our - you know, into compliance with our license.

CHAIR BALLINGER: But isn't it - it's a comparison of - let me try to put it this way. Doing some kind of probabilistic analysis of a situation of everything, calculating what the site boundary is, first is spending a lot of resources to inspect canisters and then doing the same analysis anyways.

MR. CUMMINGS: Right. Right. All right. Next slide.

So, again, I also wanted to point out that there is a link to retrievability. The NRC a few years ago issued a Federal Register notice asking for stakeholder input on retrievability.

The regulations themselves don't talk about fuel assembly versus canister retrievability. If you go back to the revision zero of ISG 2, I believe it was, retrievability was based on a canister-based approach.

It then switched in the early 2000s to the NRC requiring it to be a fuel assembly basis. There's now some effort within the NRC to go back to the canister-based approach.

That, we feel, is inappropriate use of risk management to go to canister-based and a revised performance-based and risk-informed definition for canister-based retrievability really needs to be established and we look forward to those NRC efforts that are underway to allow that in the way that it was allowed previously.

Next slide. So, in summary, you know, what I want to leave you with is that we think there's a lot of additional work going on that will help to inform this process in high burn-up fuel in the next few years that we think will really actually make the risks in the end not needed.

Returning to a canister-based retrievability definition is consistent with the risk-based framework and to really put a finer point on it, we really need to adhere to the actual words in the Code of Federal Regulations - no extra regulatory requirements.

What we've gone to or what we're seeing now in the regulatory framework is that we have to maintain cladding integrity or we have to maintain that the fuel assembly stays in exactly the same pristine condition of when it was put into the cask and that's not what the regulatory requirements say.

Some finer cladding integrity loss, even distribution of fuel pellets, as we saw from the Oak Ridge analysis has a no never mind on the safety analysis.

You really have to have a gross loss of the fuel assembling and falling all over the place into little itty bits and pieces to have, you know, some sort of impact and really the current past designs are designed to prevent the fuel assembly from being damaged.

So we agree achieving or having the goal of cladding integrity is a valuable one and we will continue to try to assure that.

But if you don't have that, that doesn't mean that you have a public health and safety issue.

So that's all I had. I'm happy to answer any questions.

CHAIR BALLINGER: Any questions around the table? Pete, any questions from you?

MEMBER RICCARDELLA: No, I'm good. Thank you.

CHAIR BALLINGER: Thank you. Okay. The bridge line is open. Is there anybody out there? Can you speak up? Do you have any comment?

MS. GORTON: My concern - my name is Patricia Gorton. My concern is the connection you were having about fuel distribution, you know, under ideal circumstances and the tests that were performed by Argonne, I think, can be allowed. I'm sorry. I'm confused on who performed it.

Anyway, there was a lot of discussion about making sure that the fuel under ideal circumstances and this was the basis upon which an opinion is formed is that the fuel distributions are equally, you know, distributed at the ideal position and as there's no, you know, certainty that that ideal position is guaranteed.

So I wanted to ask, you know, what assurances are there that, you know, if in reality the fuel baskets contain material.

CHAIR BALLINGER: We thank you for the - for your input. We - I apologize. There's some kind of noise on the line. We can only take comments and if you would like to communicate and ask a question you can communicate with Chris Brown here on ACRS staff and if you like I guess you can comment. His email address is christopher.brown@nrc.gov.

MS. GORTON: All right. Thank you.

CHAIR BALLINGER: Thank you. Are there any other folks out there?

MS. GILMORE: Yes, this is - go ahead, Marvin.

MR. LEWIS: My name is Marvin Lewis. Look, your emphasis on so-called outlandish health effects or outlandish requirements or whatever, I hate to tell you this.

I live in northeast Philadelphia. I live within a mile of where a train went off the tracks because people were shooting at it and this is not the Wild West. Thankfully, there was a television camera or some kind of camera inside the cabin.

We know what has happened. And what I'm trying to explain to you, whether you want to believe it or not, although all you do is have to go to Fukushima in Japan about, what, 50 or 60 miles north Tokyo and you will see outlandish and unusual things do happen. And I take great offense.

I remember you are supposed to be protecting me and you're saying we don't have to worry about outlandish numbers. I say look at Fukushima. Look at northeast Philadelphia. Thank you.

CHAIR BALLINGER: Thank you, Marvin. It sounded to me like there was another person.

MS. GILMORE: Yes, this is Donna Gilmore from California. I have a comment - number one, a comment on the NEI presentation with their confidence level. I see it was assumed that there - that they know a breach in the welded canisters was the assumption and given that the data that the NRC and others have on the potential for stress corrosion cracking, a lot of that data is in marine environments.

We could be looking at welded canisters that are already cracking and I don't see any analysis that take that into consideration or if he's going to do these slides he ought to at least put that on his slide that he assumes that they're totally intact because based on the data, especially the data at the Koeberg plant in South Africa where they have the same conditions at San Onofre.

They had a through wall crack in 17 years on a tank that has a similar - with a similar kind of component and it was a .6 inch through wall crack. And I know I can't ask questions but I would like to know where that - where the 2004 high burn-up fuel was.

And, again, regarding the previous slide presentation, the - I want to make sure you're aware that this new Holtec UMAX system that has 37 fuel assemblies there was a recent report out about the effect - the problems with different wind situations affecting the ability to cool.

For example, there was the underground system. If there was no wind the cooling that was expected isn't happening and I can provide information about that if you're interested. And let's see - where is the other one?

And I'll send this in an email but I'd like to know what the cladding out that was used in that earlier test was. And Mark Lombard's statements about everything trying storage and transport doesn't seem to be based on actual data.

And I just wanted to mention I know the emphasis on cracking and coastal environments but they have told me that there's a lot of different things that can cause these thin-welded canisters to start cracking and since no one can inspect to see what the - you know, inspect for cracks, nobody really knows what's going on in those canisters.

And at Diablo Canyon we had a two-year-old canister that already had temperatures low enough for moisture to initiate the cracking process. But we don't know if that's happening. Anyway, those are my comments.

CHAIR BALLINGER: Thank you. Thank you. Is there anybody else out there?

MR. HOFFMAN: This is Ace Hoffman. Hello?

CHAIR BALLINGER: Yes, sir.

MR. HOFFMAN: Yes, I have two questions. First of all, does the analysis include large tsunamis, earthquakes, jumbo jets crashing into the dry casks, and asteroids, for that matter, in terms of how they might be breached?

And the other question is when you talk about rubbleized contents - up to 25 percent of the contents being rubbleized at the bottom of the canisters, the internal canisters, what is the effects of the gamma distribution?

It's going to be completely different with the fuel completely relocated, and then over time it's going to irradiate the weld area and so forth, it takes so much. And has that change in configuration been taken into account not just for potential for the criticality events and if a jumbo jet does land on it but also just over time it becomes - degrading the outer container. Thank you.

CHAIR BALLINGER: Thank you. Kris is going to be very busy. Anybody else out there?

Well, that's next. Okay. Can we close the bridge line? Okay. Comments from the floor. Yes, sir.

DR. EINZIGER: Robert Einziger from the NWTRB. And this is directed to Mr. Scaglione.

On I think it's very fine print - I think it's on slide 13 where you're looking at the consequences for containment.

It looks like from that one view graph that the difference between the allowable leakage for the non-rim region and the rim region is about a factor of two, which would account for the difference in the radio nuclei content that's expected in the rim or in the body of the fuel.

But that's sort of a minor effect when looking at the difference between the rim and the body of the fuel. The rim is made up of many fine particles in the micron to sub-micron size range, which if that rim is fractured you're releasing a lot of respirable-size particular ready that will remain in Brownian motion. It's acceptable for release from the cask should a - should a cask breach occur.

Now, there's a couple lines of thought on that. There's the land line coming out of Germany and Spino's calculations using micro hardness that says the rim is going to fracture just the same as the body of the fuel so that shouldn't make a difference.

Lately, that approach has been coming under a lot of discredit and scrutiny. The other school of thought from admittedly a lot of just anecdotal information is when you try to handle fuel that has the rim region that all you get is this stuff just flakes off and all.

And so I'd hope that in the future presentations that you make - of course, I'm doing this as a comment as opposed to a question - that you would explain how you take into account the fact of the difference in the behavior of the rim - possible difference in the rim region because it could make a difference of almost four orders of magnitude in the type of release rate you have.

Similarly, with the crud a question was asked how does the crud get loose. Well, the crud comes off in flakes but it's a flake that's made up of many fine sub-micron-sized particulate which when it drops it fractures so you also have material that can get into Brownian motion.

I'd also like you to consider when you look at the volatiles and gas release, the fact that if the fuel is being hit with an impulse and the fuel fractured, gases and volatiles that have been trained in the fuel themselves will be now available that could double or triple it.

All in all, I think that in your presentations to make these results with respect to consequences valid you have to really delve into the assumptions that went in behind them. Thank you.

CHAIR BALLINGER: Anybody else? Sir?

MR. SCOTT: Can you go back - can you go to the NEI slides, about the third one from the end? This is Harold Scott from the Office of Research.

I want to just make a comment about the Argonne marine compression test. You can see in the picture there what it looks like, and it is true that there's not an insert like there's be a pellet. But the strain at fracture was only, like, 1 percent or less. So you don't have to squeeze it down very far to actually get a failure and I'm not sure even if that pellet how much compression is in cladding.

The other comment had to do with another source of improbability is the pressure in a rod. These marine compression tests during the hydride reorientation were stressed at over 100 MPA stress and if you look at the distribution of pressures in rods that are going to be in the cask there won't be very many at that high a stress, particularly as the temperature drops over time. Thank you.

CHAIR BALLINGER: Thank you. Other - thank you. I guess now we can go around the table, and with Pete on the phone, and any comments? Remember, one of the things we're trying to do is to make a determination as to whether or not we should bring this kind of discussion to the full - to the full committee. So if you've got any input on that, that would be great. Otherwise, we can wait a little bit. But I'm just looking at you directly.

MEMBER REMPE: I see that you're looking at me directly. I wanted to thank everyone for their time and efforts to give presentations today and I've learned a lot.

I - actually, I'm interested in some of the ideas that Dana has put forth about trying to look at regulation in a different manner. But I guess I would caution industry if that were to occur and to staff that we need to make sure that some of the statements we've heard are backed up with appropriate data that I believe it - I've mentioned the cladding temperature, the gas, even the comment about the moisture content - got updated to support that, if you want to go forward with this.

But so that was kind of my thoughts at this time. I'm not sure about a letter or anything but I don't think it would hurt to bring it up to the full committee. I think it's good to keep the full committee informed.

CHAIR BALLINGER: Dana?

MEMBER POWERS: Well, I think - I think we are succeeding here admirably on all quarters. We've devised a strategy for storing spent fuel on site that seems to be working extremely well, and in fact seems to be evolving to get better all the time.

And I think it's time that we think a little bit about how we respond to success and I'm not sure how to do it.

But my first thought in bringing to the full committee I think that we need to, first of all, raise this issue in connection with our research report to suggest where research should go in this direction. And Joy, that might be a vehicle for you to pursue in that.

I think we need to look at should we be considering more about the potential for focusing research on - or focusing our efforts on inspection and monitoring of these systems rather than characterizing what's going on inside because it looks like a lot can go on inside and not make a lot of difference and in fact, not much is happening inside. And so inspection and monitoring might be more of a focus on things and that leads, of course, to I've suggested thinking about in terms of regulating , because it looks to me like it is the one off event, something totally unexpected, something that we cannot include in our risk assessments because we just don't know about it, that's going to possibly be a vulnerability here.

Now, Bob raised one technical issue that arises surprisingly frequency when he pointed out things flaking off the rim or crud falling off and you've got agglomerates or particles that have at least in principle the potential for breaking in to respirable materials that can leak and, quite frankly, to an aerosol particle that's respirable, a crack that produces a ten to the minus fifth cubic centimeter per second lead rate looks like the Holland Tunnel.

So Bob's right, some microns can get out. The challenge -the technical challenge is how do you break agglomerates up into sub-micron particles? I don't think we understand that very well. We've done some research in that area and it can occur, but it's difficult, and so if I were going to pick an area to pursue I would jump on Bob's comments and try to understand those better and the analyses that Oak Ridge presented.

But I think for the committee itself it is this regulatory framework and like I said the vehicle for us to start is via the research report and then we can build upon that to go forward.

I do think we need to provide the commission some technical advice in this area because it is an area where they're under some pressure publically and some interest because it's going to be a while before a final disposition of spent fuel occurs, even given that there's activity in that area now with both respect to the Blue Ribbon Commission recommendation and even a resurrection of the Yucca Mountain site.

The commission still needs to know where to marshal its resources and what not. Fortunately, we're going to be - we should be able to report to the commission there's been a tremendous amount of success here. I think that's about all I have to say.

CHAIR BALLINGER: Thank you.

MEMBER SKILLMAN: I would complement the staff and NEI for a very thorough presentation. This was really good. Thank you.

I believe that the issue of the strength - the mechanical strength of the fuel is tied up in this temperature, understanding the temperature and I would urge there to be some consideration to some type of device that actually fields the clad at an appropriate location so that an individual who is out in the IFSI field can use a hand-held device to find out what the temperature is because that would put to rest an awful lot of questions about the condition of the fuel and its fragility.

With regard to informing the rest of our members, in my view this presentation closes a number of the questions that we had on the spent fuel studies and some of the other activities we've had over the last two or three years.

And so I think an information briefing would be very helpful just to bring the rest of the membership up to speed and it could be that as a consequence of that briefing we decide to do as Dana says - write a letter to provide some input to the commission.

CHAIR BALLINGER: I think that - one last thing from me is that we've had a tendency on this committee to hear half of the problem at a time. But it's inexorably - the high burn-up fuel issue is inexorably tied up with the canister viability itself. And so we've heard information about the - what's going on with respect to the canister via canister integrity and now fuel, and we haven't had a case where - probably just takes a lot of time to hear the full story.

Combine the canister integrity issues with the fuel issues themselves in one place where the - where the full committee can put two and two together.

So I think that's a consideration that you might think about. I don't know.

Again, we - it's been - we've heard Al and his - Al and company come and talk about canister integrity. Now, we've got this six-week delay or whatever - six-week hiatus and then we hear this, and the full committee hasn't heard either one, I don't think, together, right?

Anyway, so that's my comment, and I would also like to thank you folks for coming here with very excellent talk. We've had the advantage in some cases of having a few before this. So we're not completely in the dark when you talk about high burn-up fuel and that's a great thing too.

So I guess, unless there are other comments, we are adjourned.

(Whereupon, the above-entitled matter concluded at 12:26 p.m.)

Draft Regulatory Issue Summary (RIS)

Considerations In Licensing High Burnup Spent Fuel (HBF) in Dry Storage And Transportation

Huda Akhavannik
NMSS/DSFM/SFLB
HBF Taskforce PM

June 8, 2015

Overview

- RIS History
- RIS
  - Addressees
  - Intent
  - Background
  - Summary of Issue (Licensing Approaches)
    - Storage
    - Transportation
- RIS Path Forward
- Questions and Comments

RIS History

- Presented approaches at:
  - 1/24/14 NEI public meeting
  - 2014 RIC in March (poster)
  - November 2014 Division Regulatory Conference
- Issued RIS via FRN for 45 day public comment period (ended April 20, 2015)
- Discussed RIS comments at 5/18/15 NEI public meeting

RIS - Addressees

- Holders of and applicants for:
  - Part 71 CoC
  - Part 72 CoC
  - Part 72 General Licensee
  - Part 72 Specific Licensee

RIS - Intent

- Provide high level information on **some** approaches acceptable to the NRC for applications containing HBF
  - Developed based on HBF research and guidance to date
  - Developed based on approved and in-house HBF applications

RIS - Background

- License low burnup fuel using the basis in Interim Staff Guidance (ISG) – 11, Rev. 3 and confirmation from Idaho Cask Demonstration

- License HBF up to 20 years using basis in ISG-11, Rev. 3

RIS – Background cont.

- ISG-11, Rev. 3
  - Originally developed to limit formation of radial hydrides and to limit creep deformation to less than 1%
  - However, later research shows that radial hydrides may still form even if temperatures and stresses in ISG-11, Rev. 3 are not exceeded
    - Radial hydrides need to be considered for beyond 20 years in dry storage
    - Hydride reorientation

RIS – Background cont.

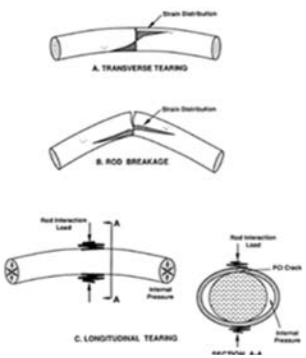
- Licensing HBF beyond 20 years
  - Hydride Reorientation
    - Occurs when hydrides in cladding go above a certain temperature and then cool below another temperature – ductile-to-brittle transition temperature (DBTT)
    - Affects temperature-dependent fuel cladding mechanical properties
  - What is impact on regulations?

RIS – Background cont.

- Main regulations impacted:
  - Storage:
    - 72.122(h) – protect fuel against gross rupture
    - 72.122(l) – ready retrieval of spent fuel
  - Transportation:
    - Fuel condition must meet CoC conditions during transport
    - 71.55(d)(2) – during normal conditions of transport, geometric form of content is not substantially altered

RIS – Background cont.

- Effects of hydride reorientation on regulations
- Hydride reorientation would only affect cladding integrity if there is a “pinch mode”:
  - Pinch mode occurs when inertia loads which result in a large tensile stress are perpendicular to the radial hydrides
  - Seen during the hypothetical accident condition 30 foot side drop in transportation regulations



RIS – Background cont.

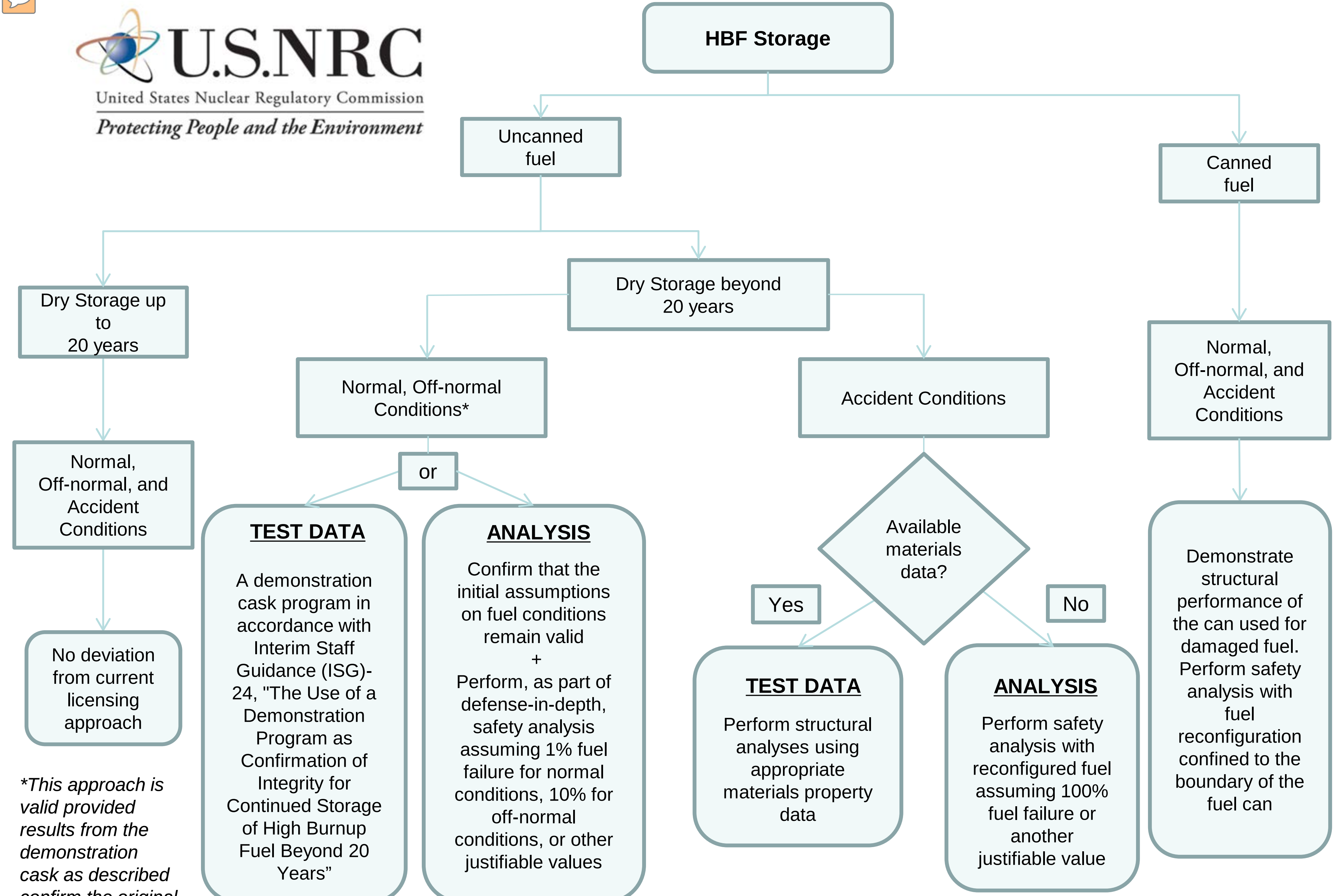
Theme of licensing approaches: we do not expect fuel to reconfigure due to hydride reorientation during storage or normal conditions of transport – we expect to get confirmation of this belief through current and future research results

RIS – Summary of Issue

- Licensing Approaches
  - Used pieces from previous HBF applications
  - Based on LBF but modified to account for need for confirmation. As we get more data, we expect to no longer need confirmation
  - Depending on data availability: “defense-in-depth” analysis route
  - Structure of approaches consider whether or not the fuel has been placed in damaged fuel cans and the length of time it has been in dry storage

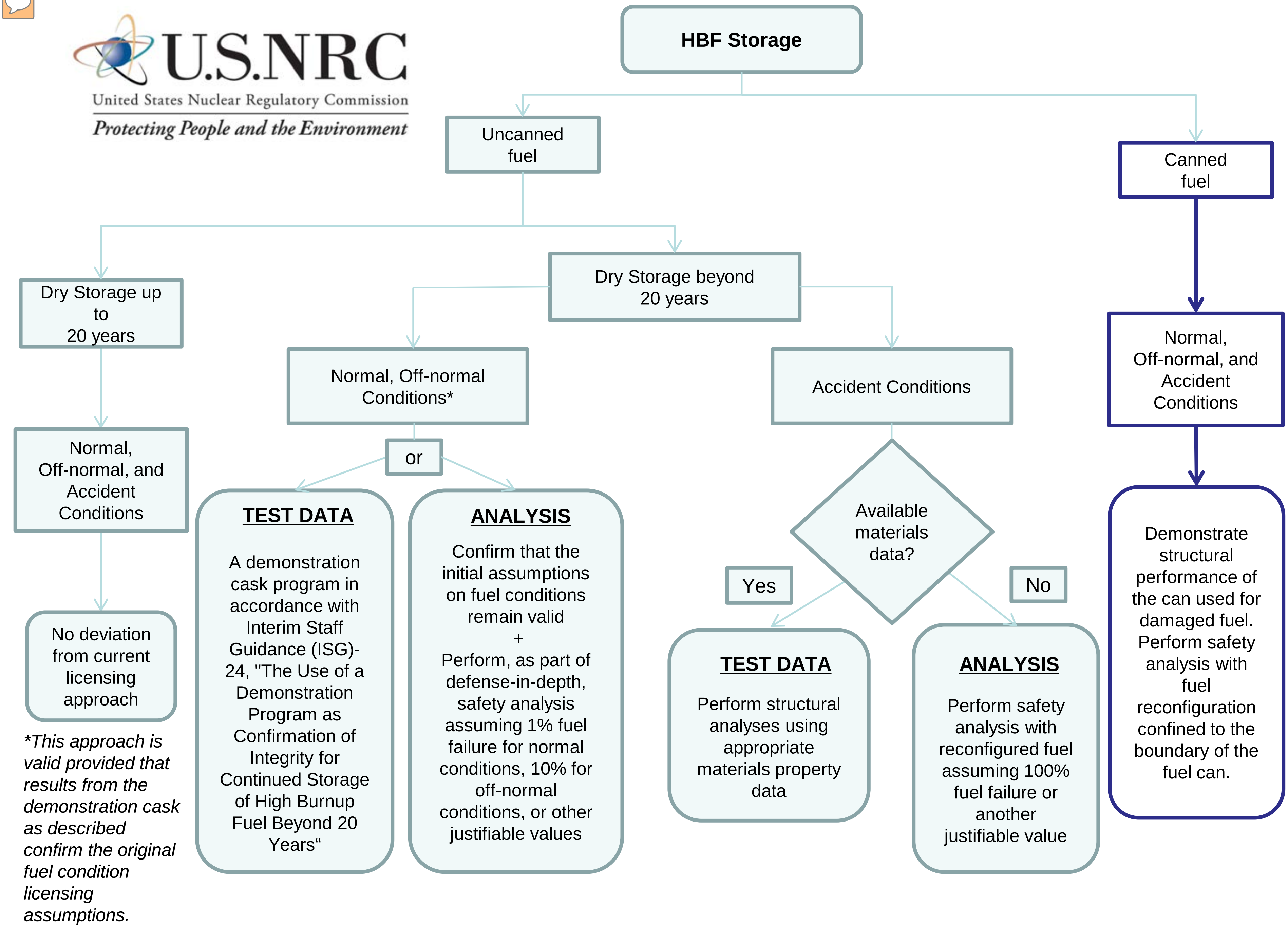
Licensing Approaches – Storage

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

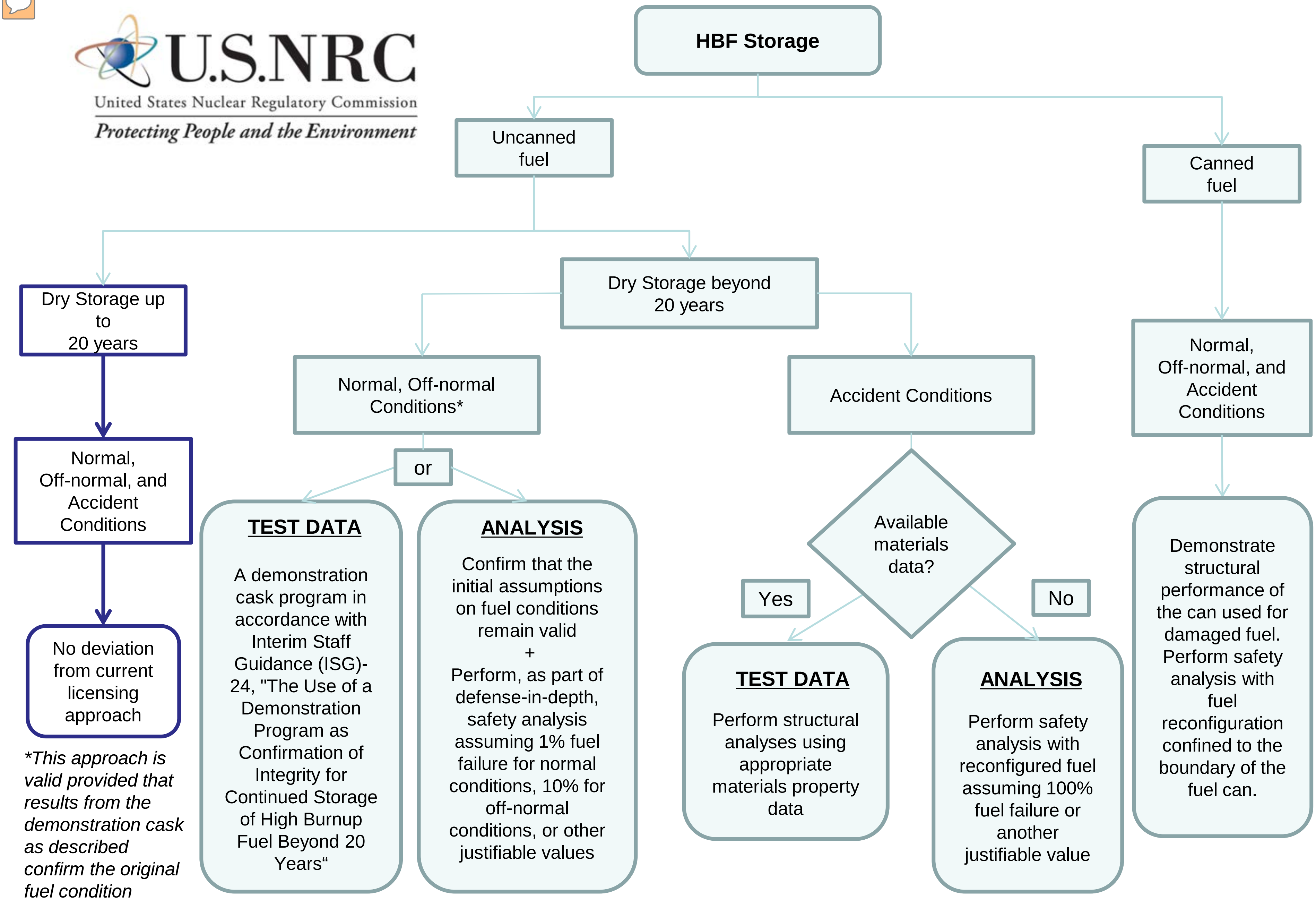


**This approach is valid provided results from the demonstration cask as described confirm the original fuel condition licensing assumptions.*

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

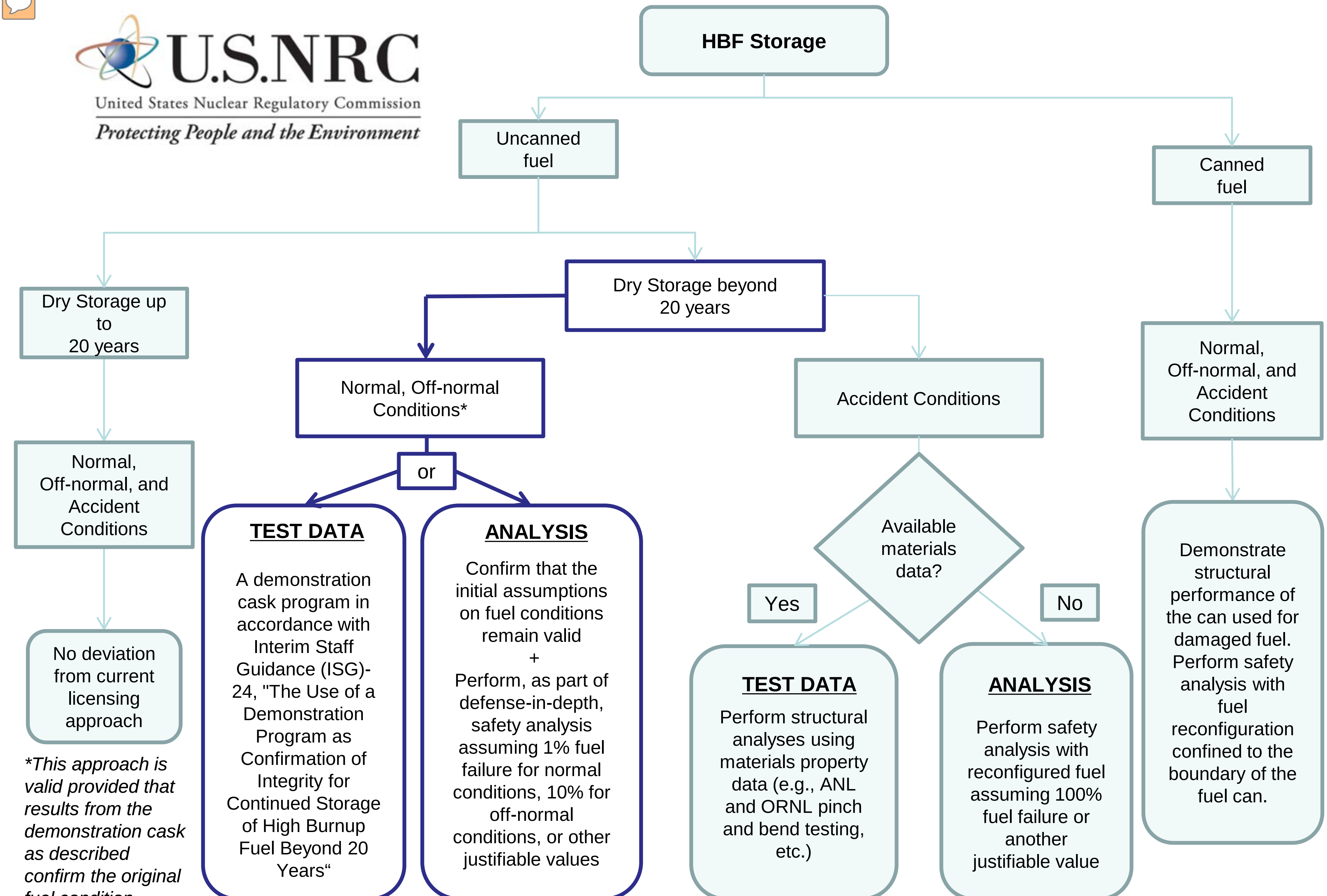


U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

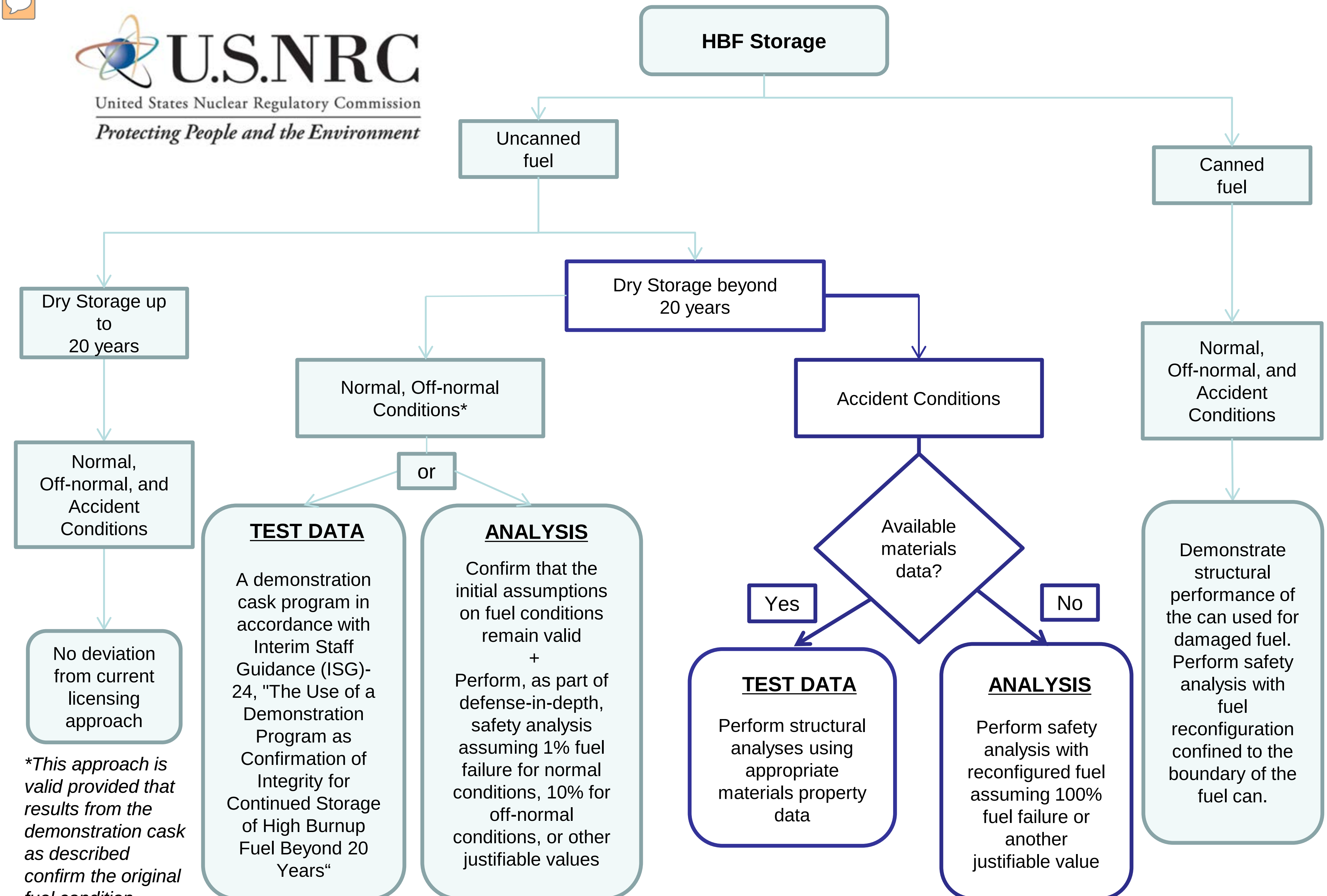


**This approach is valid provided that results from the demonstration cask as described confirm the original fuel condition licensing assumptions.*

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

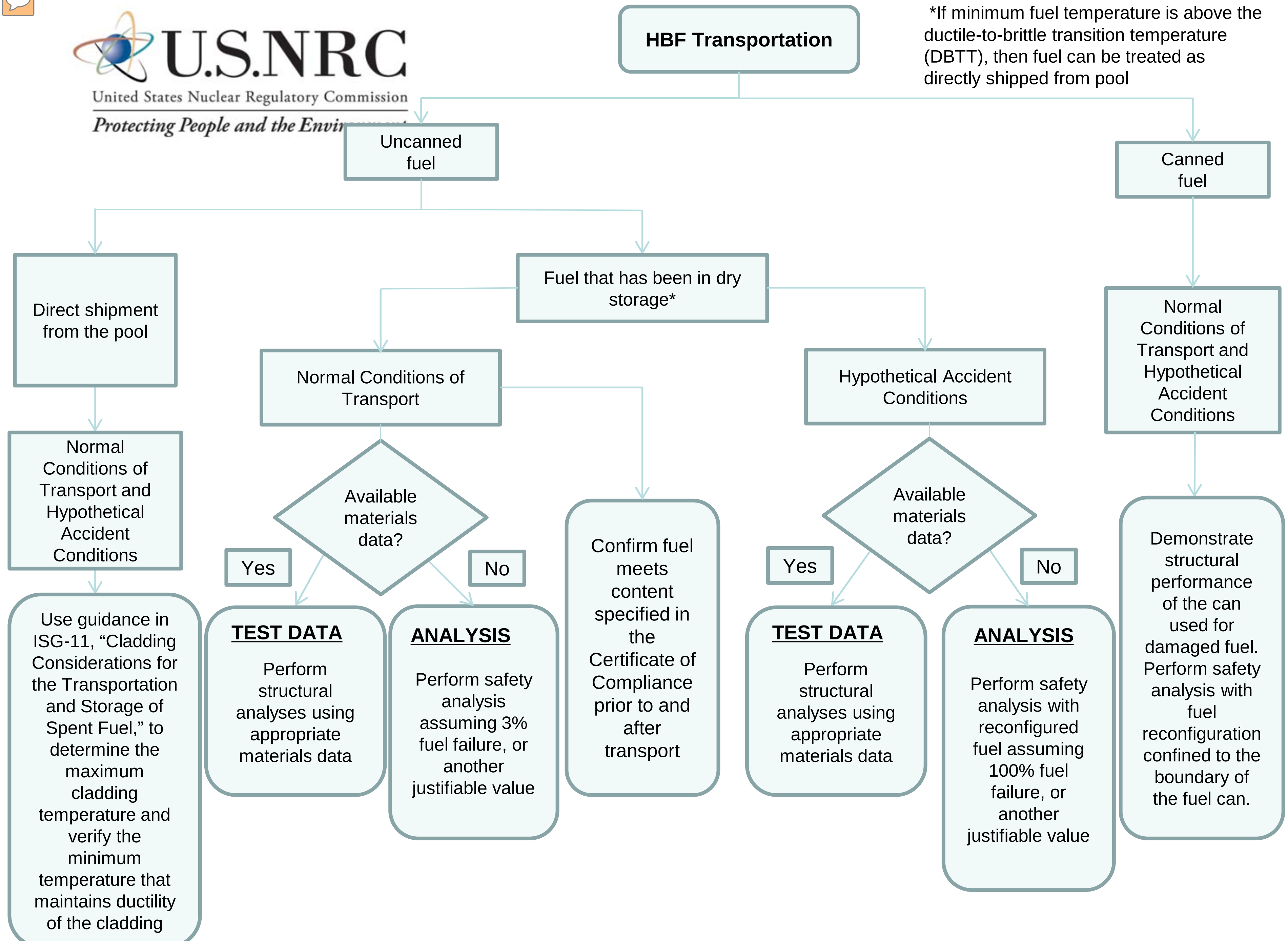


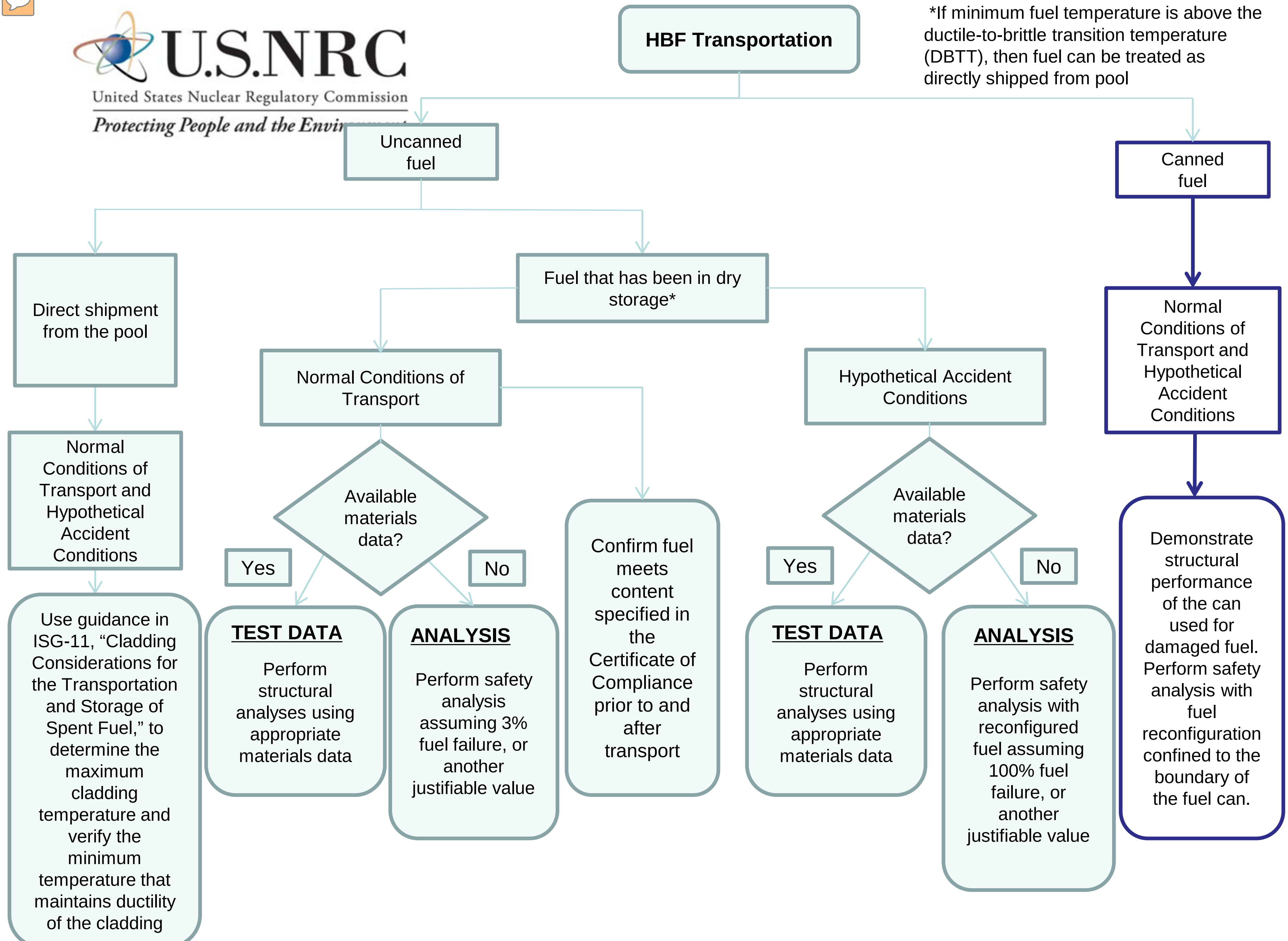
**This approach is valid provided that results from the demonstration cask as described confirm the original fuel condition licensing assumptions.*



**This approach is valid provided that results from the demonstration cask as described confirm the original fuel condition licensing assumptions.*

Licensing Approaches – Transportation


U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment
HBF Transportation
*If minimum fuel temperature is above the ductile-to-brittle transition temperature (DBTT), then fuel can be treated as directly shipped from pool
Uncanned fuel
Canned fuel
Direct shipment from the pool
Fuel that has been in dry storage*
Normal Conditions of Transport and Hypothetical Accident Conditions
Normal Conditions of Transport
Hypothetical Accident Conditions
Normal Conditions of Transport and Hypothetical Accident Conditions
Available materials data?
Yes
No
Available materials data?
Yes
No
Use guidance in ISG-11, "Cladding Considerations for the Transportation and Storage of Spent Fuel," to determine the maximum cladding temperature and verify the minimum temperature that maintains ductility of the cladding
TEST DATA
Perform structural analyses using appropriate materials data
ANALYSIS
Perform safety analysis assuming 3% fuel failure, or another justifiable value
Confirm fuel meets content specified in the Certificate of Compliance prior to and after transport
TEST DATA
Perform structural analyses using appropriate materials data
ANALYSIS
Perform safety analysis with reconfigured fuel assuming 100% fuel failure, or another justifiable value
Demonstrate structural performance of the can used for damaged fuel. Perform safety analysis with fuel reconfiguration confined to the boundary of the fuel can.

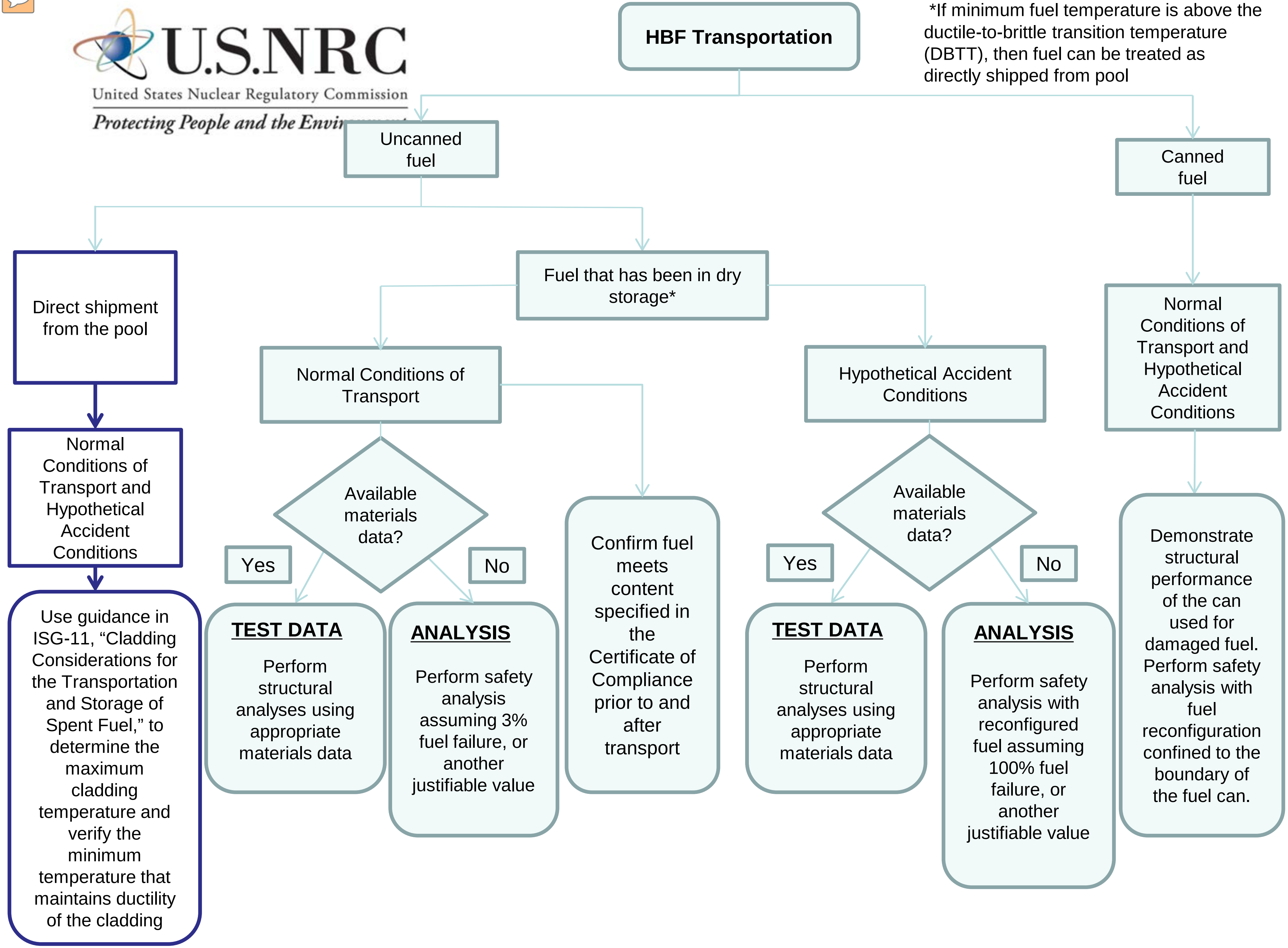


HBF Transportation
*If minimum fuel temperature is above the ductile-to-brittle transition temperature (DBTT), then fuel can be treated as directly shipped from pool
Uncanned fuel
Canned fuel
Direct shipment from the pool
Fuel that has been in dry storage*
Normal Conditions of Transport
Hypothetical Accident Conditions
Normal Conditions of Transport and Hypothetical Accident Conditions
Available materials data?
Yes
No
Available materials data?
Yes
No
Normal Conditions of Transport and Hypothetical Accident Conditions
Use guidance in ISG-11, "Cladding Considerations for the Transportation and Storage of Spent Fuel," to determine the maximum cladding temperature and verify the minimum temperature that maintains ductility of the cladding
TEST DATA
Perform structural analyses using appropriate materials data
ANALYSIS
Perform safety analysis assuming 3% fuel failure, or another justifiable value
Confirm fuel meets content specified in the Certificate of Compliance prior to and after transport
TEST DATA
Perform structural analyses using appropriate materials data
ANALYSIS
Perform safety analysis with reconfigured fuel assuming 100% fuel failure, or another justifiable value
Demonstrate structural performance of the can used for damaged fuel. Perform safety analysis with fuel reconfiguration confined to the boundary of the fuel can.

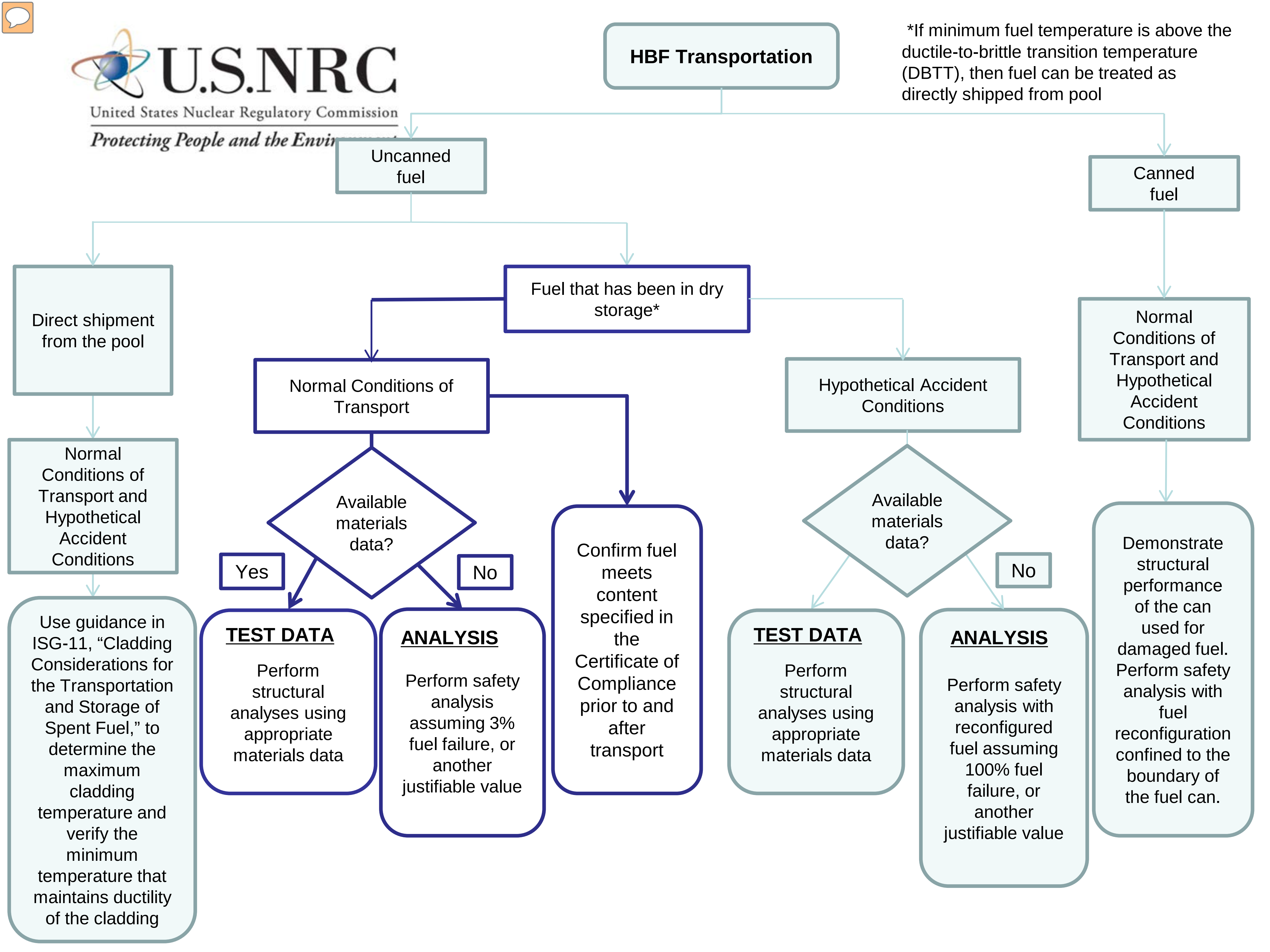
U.S.NRC

United States Nuclear Regulatory Commission

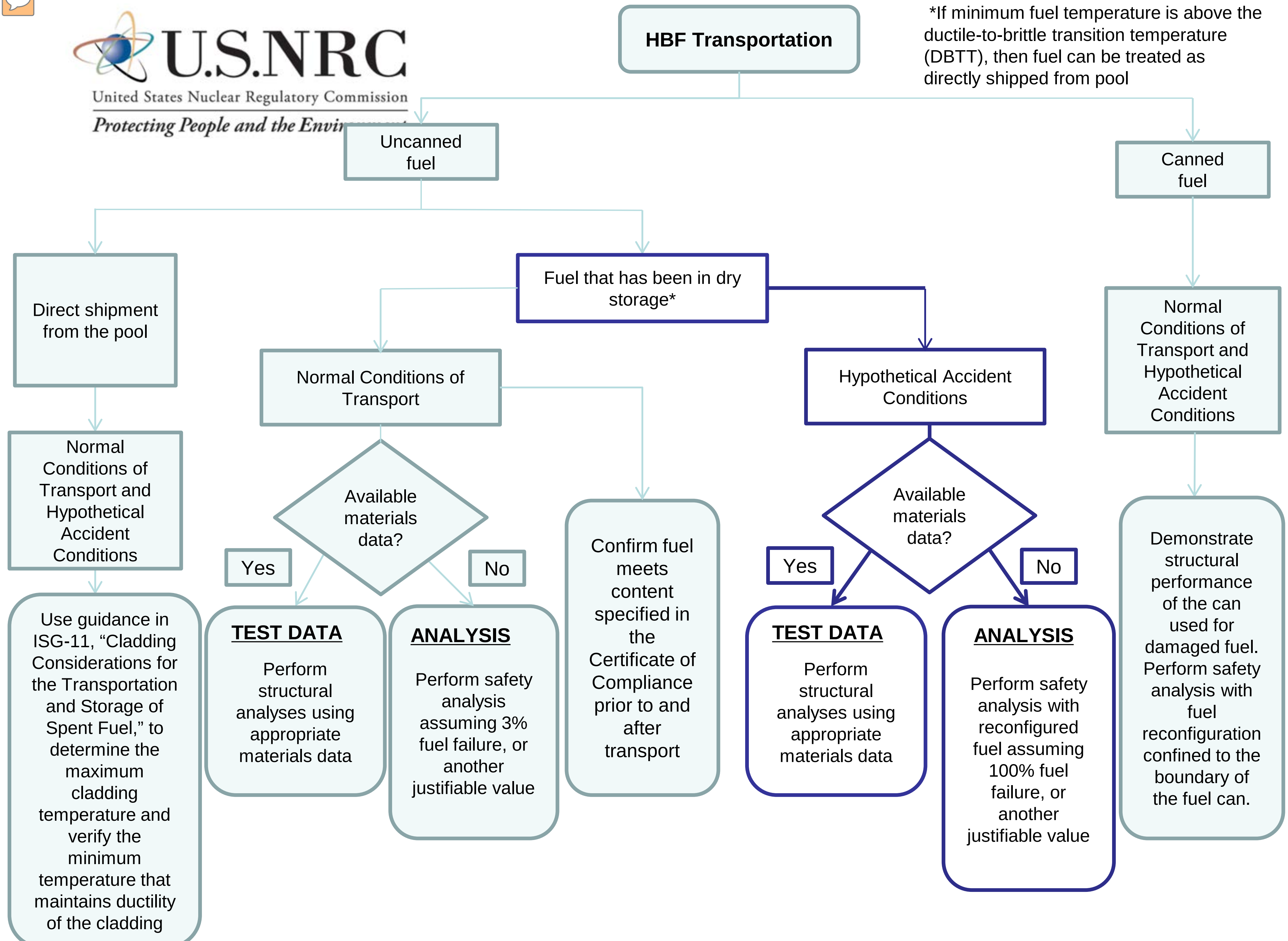
Protecting People and the Envir



*If minimum fuel temperature is above the ductile-to-brittle transition temperature (DBTT), then fuel can be treated as directly shipped from pool


U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment
HBF Transportation
*If minimum fuel temperature is above the ductile-to-brittle transition temperature (DBTT), then fuel can be treated as directly shipped from pool
Uncanned fuel
Canned fuel
Direct shipment from the pool
Fuel that has been in dry storage*
Normal Conditions of Transport
Hypothetical Accident Conditions
Normal Conditions of Transport and Hypothetical Accident Conditions
Normal Conditions of Transport and Hypothetical Accident Conditions
Available materials data?
Yes
No
Available materials data?
No
Use guidance in ISG-11, "Cladding Considerations for the Transportation and Storage of Spent Fuel," to determine the maximum cladding temperature and verify the minimum temperature that maintains ductility of the cladding
TEST DATA
Perform structural analyses using appropriate materials data
ANALYSIS
Perform safety analysis assuming 3% fuel failure, or another justifiable value
Confirm fuel meets content specified in the Certificate of Compliance prior to and after transport
TEST DATA
Perform structural analyses using appropriate materials data
ANALYSIS
Perform safety analysis with reconfigured fuel assuming 100% fuel failure, or another justifiable value
Demonstrate structural performance of the can used for damaged fuel. Perform safety analysis with fuel reconfiguration confined to the boundary of the fuel can.

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



Path Forward

- Drafting guidance that expands on RIS with greater technical detail to implement the approaches – currently on hold
- Decision on issuing RIS – after comment consolidation and ensuring harmonization with NUREG-1927, Rev. 1

RIS Questions and Comments?

Huda.Akhavannik@nrc.gov
301-415-5253

DOE/EPRI Demo Project

- Site-specific license at North Anna using TN-32 cask
- Burnup: 50-55.5 GWD/MTU
- M5, Zirlo, low-tin Zircaloy-4, Zircaloy-4
- Payload heat load ~37 kW
- Peak cladding best estimate drying temperature – 340°C
- Thermocouples and gas sampling (NDE)
- Future transportation of cask to offsite location for fuel examination

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

STORAGE AND TRANSPORTATION OF HIGH BURNUP SPENT FUEL

Meraj Rahimi

Chief of Criticality, Shielding, & Risk Assessment Branch

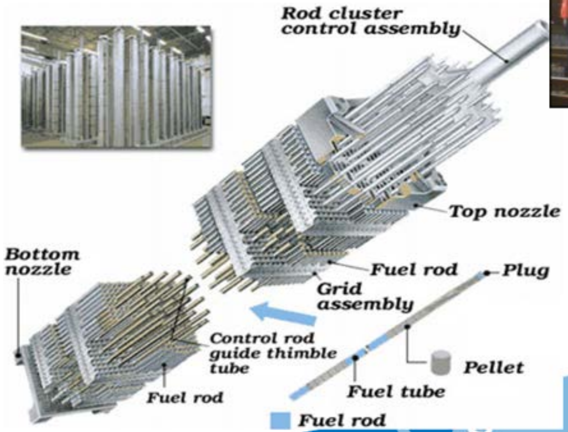
Division of Spent Fuel Management

Office of Nuclear Material Safety and Safeguards

U.S. Nuclear Regulatory Commission

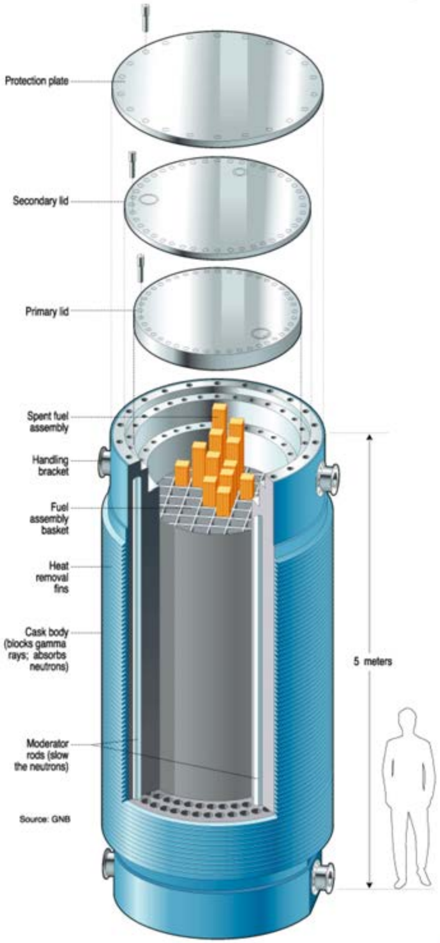
Background

- Historically, safety analyses for design of storage casks and transportation packages has relied on spent fuel cladding confining fuel in as-loaded geometry inside casks and packages



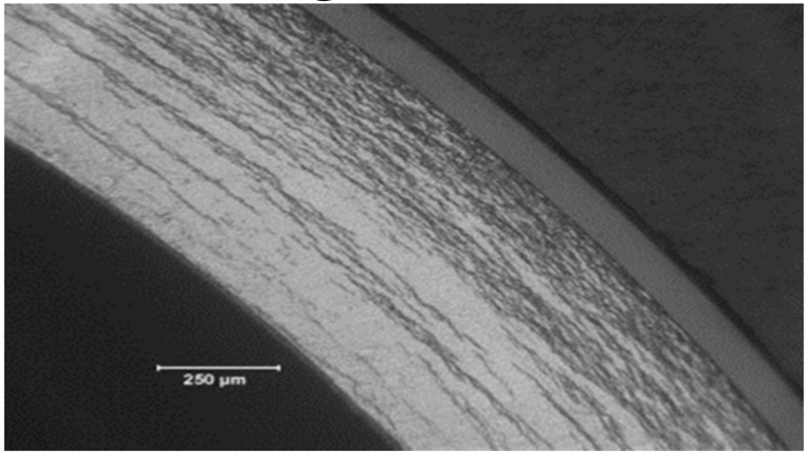
Background (cont.)

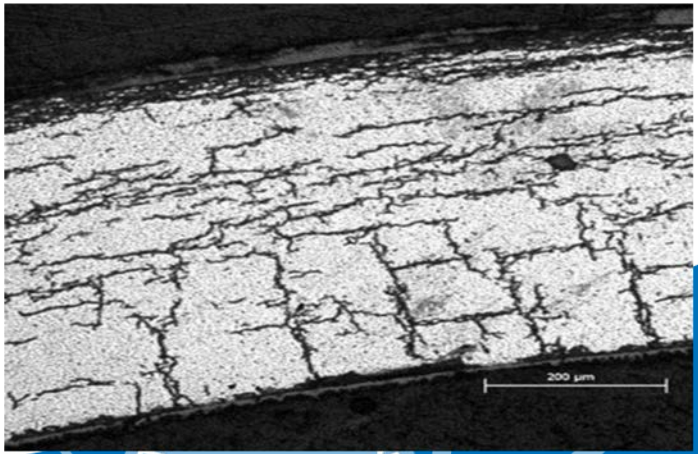
- Research (e.g., M.C. Billone, etl.) has indicated possibility of changes in high burnup (i.e.,>45 GWd/MTU) spent fuel cladding mechanical properties when subjected to cask loading conditions and subsequent long period of storage.



Hydride Reorientation

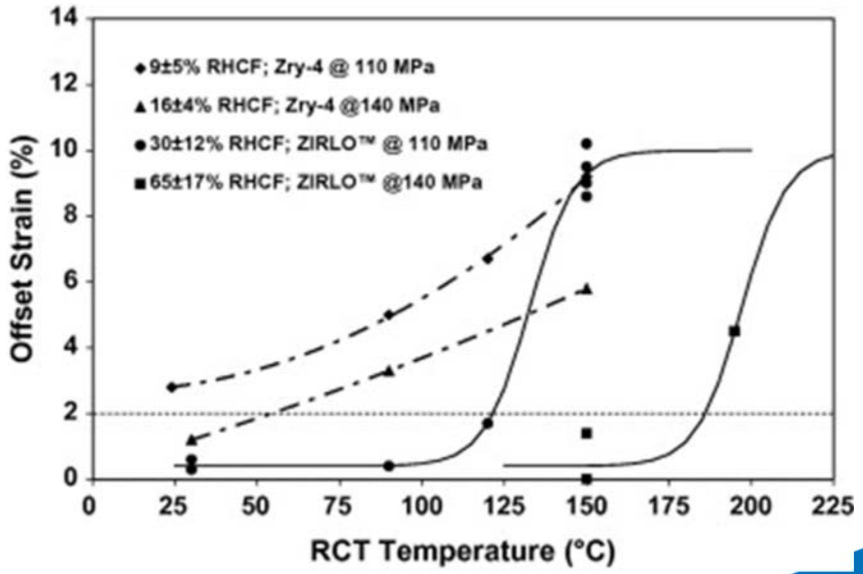
- During cask draining and drying, fuel temperature and fuel rod internal pressure increases causing hydrides in cladding to go into solution form and reorient from circumferential to radial directions during storage





Ductile To Brittle Transition (DBTT)

- Hydride reorientation results in a less ductile and more brittle of the cladding (DBTT) when the cladding temperature falls below a certain value after a long period in storage



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

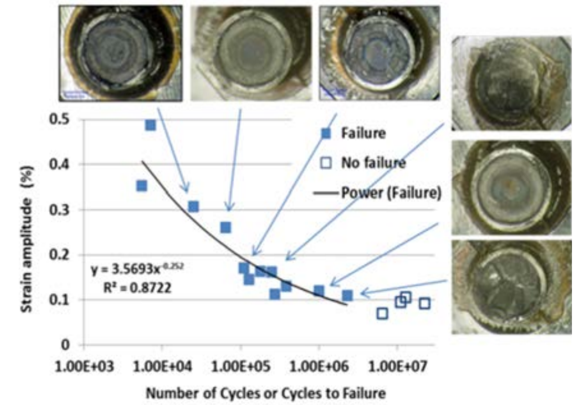
NMSS
Division of Spent Fuel Management

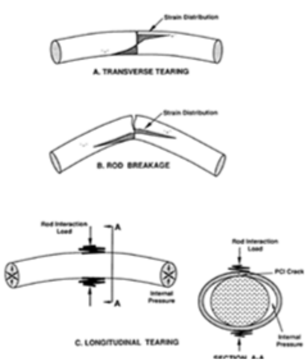
Design-Basis Loads

- Under design-basis loads for storage (e.g., seismic, cask tip over) and transportation (e.g., vibration, impact), high burnup fuel cladding integrity may be compromised

NRC-Sponsored Research

- “Mechanical Fatigue Testing of High-Burnup Fuel for Transportation Applications,” NUREG/CR-7198
- A Quantitative Impact Assessment of Hypothetical Spent Fuel Reconfiguration in Spent Fuel Storage Casksand Transportation Packages,”NUREG/CR-7203





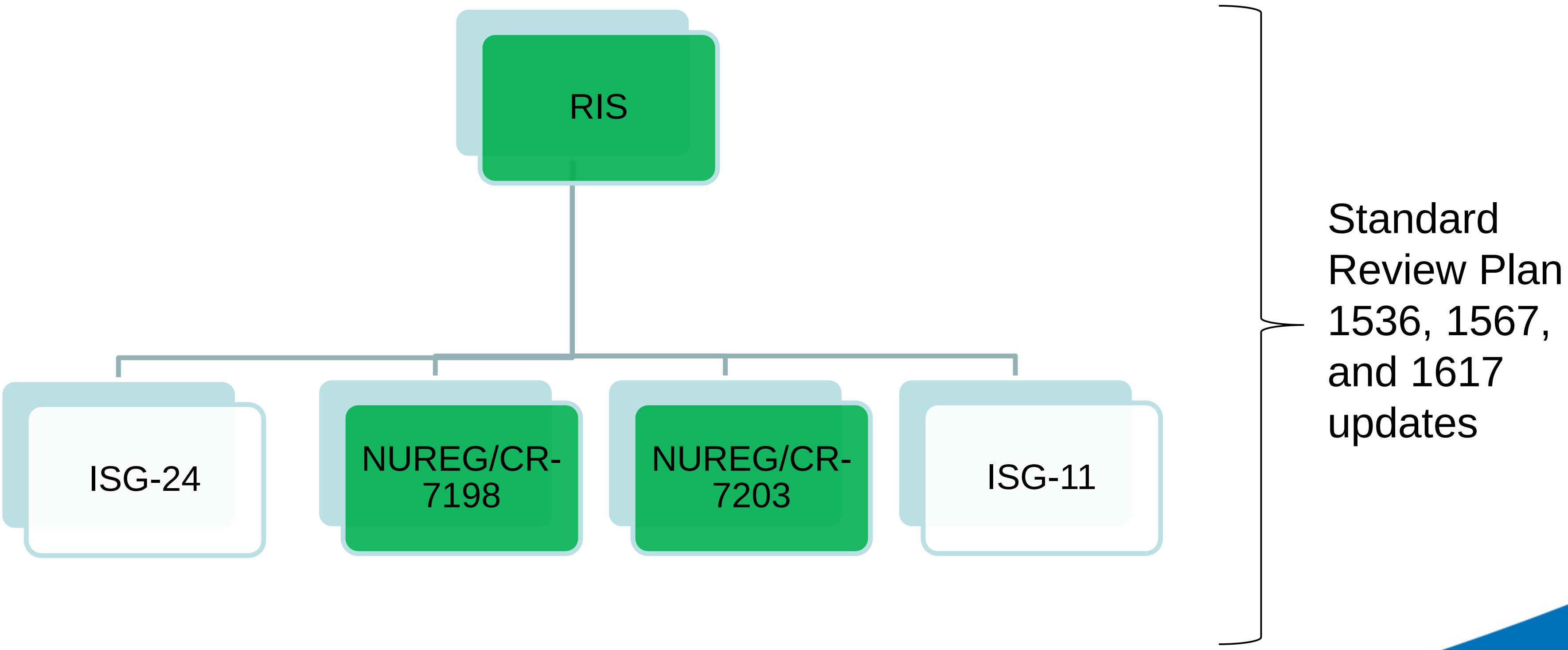
Interim Staff Guidance (ISG)

- ISG-11, Rev. 3
  - "Cladding Considerations for the Transportation and Storage of Spent Fuel"
- ISG-24, Rev. 0
    - "Use of a Demonstration Program as a Surveillance Tool for Confirmation of Integrity for Continued Storage of High Burnup Fuel Beyond 20 Years"

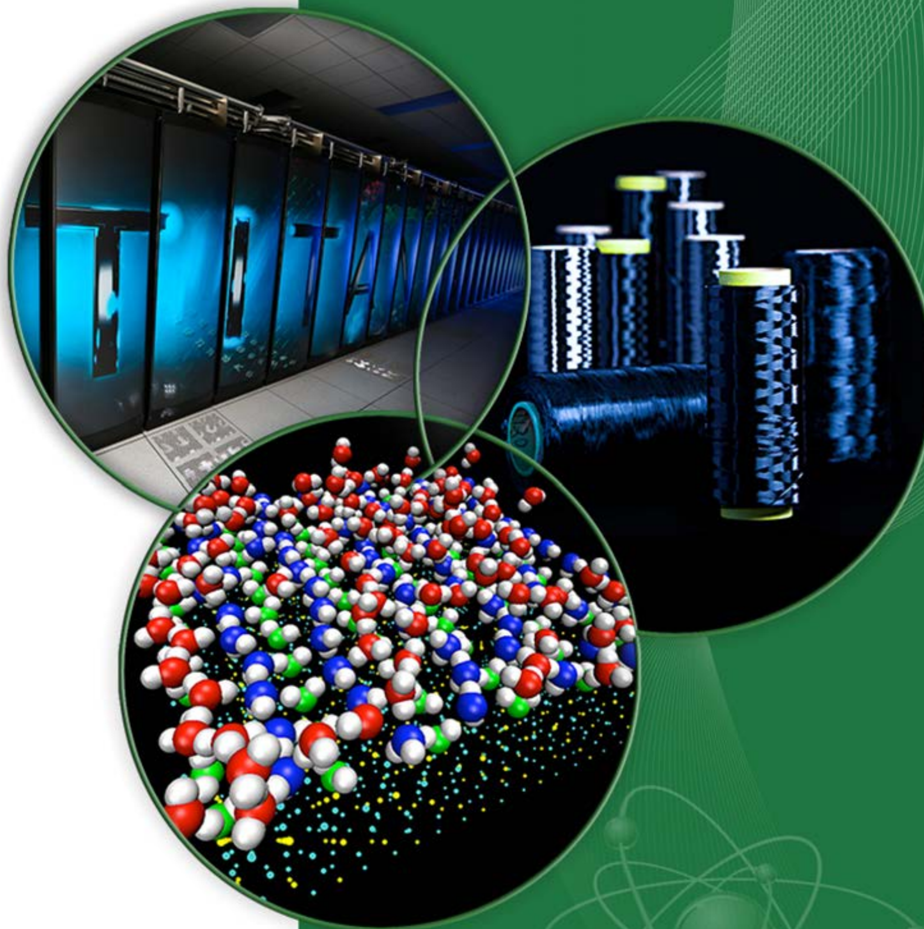
Draft Regulatory Issue Summary (RIS)

- Provides a road map on **some** approaches acceptable to the NRC for applications containing HBF based on the research and the guidance to date.

Guidance on Storage and Transportation of High Burnup Fuel



A Quantitative Impact Assessment of Hypothetical Spent Fuel Reconfiguration in Spent Fuel Storage Casks and Transportation Packages NUREG/CR-7203



John Scaglione

Oak Ridge National Laboratory

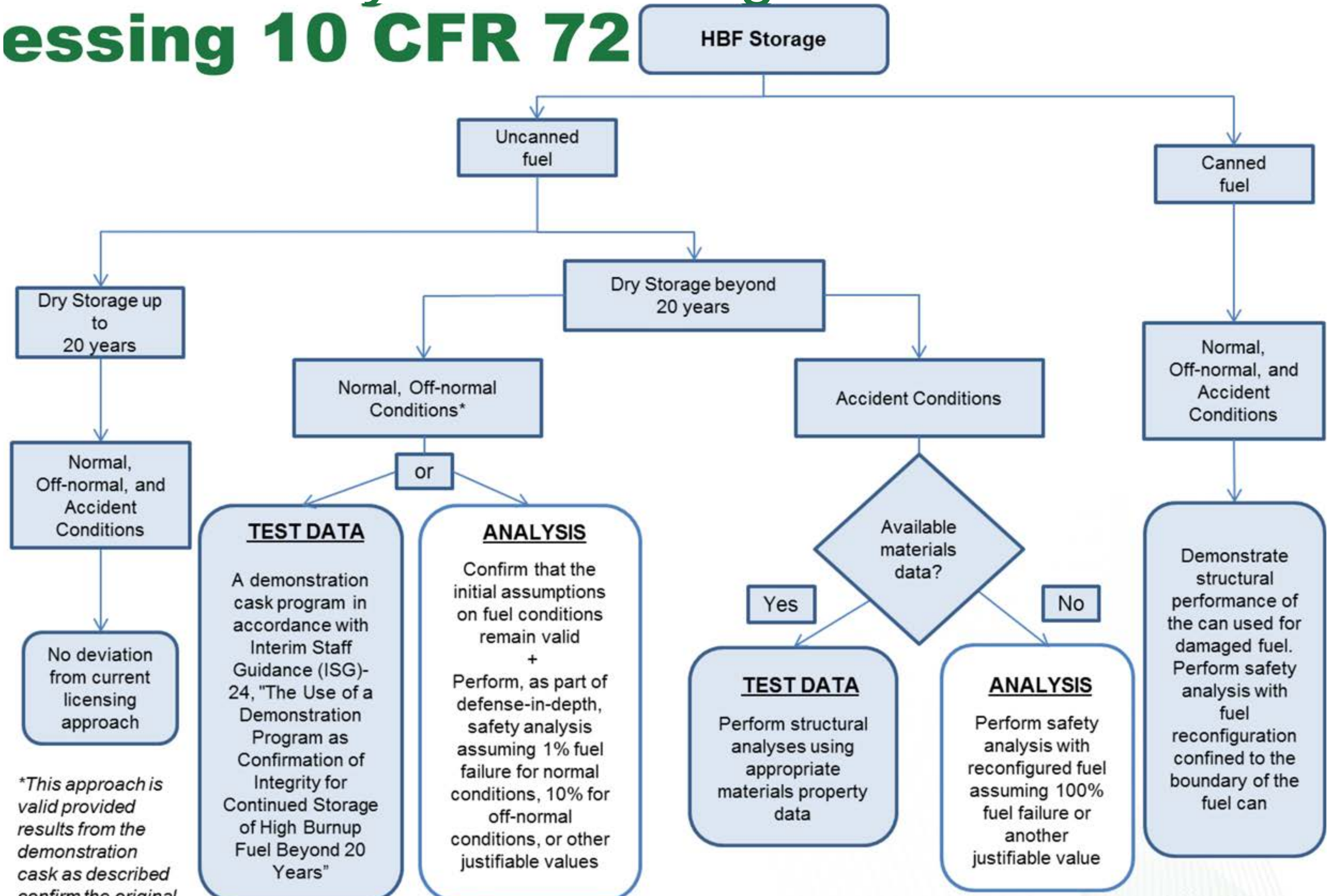
ScaglioneJM@ornl.gov

Advisory Committee on Reactor Safeguards Meeting
NRC Offices, Rockville, MD
June 8, 2015

ORNL is managed by UT-Battelle
for the US Department of Energy

OAK RIDGE
National Laboratory

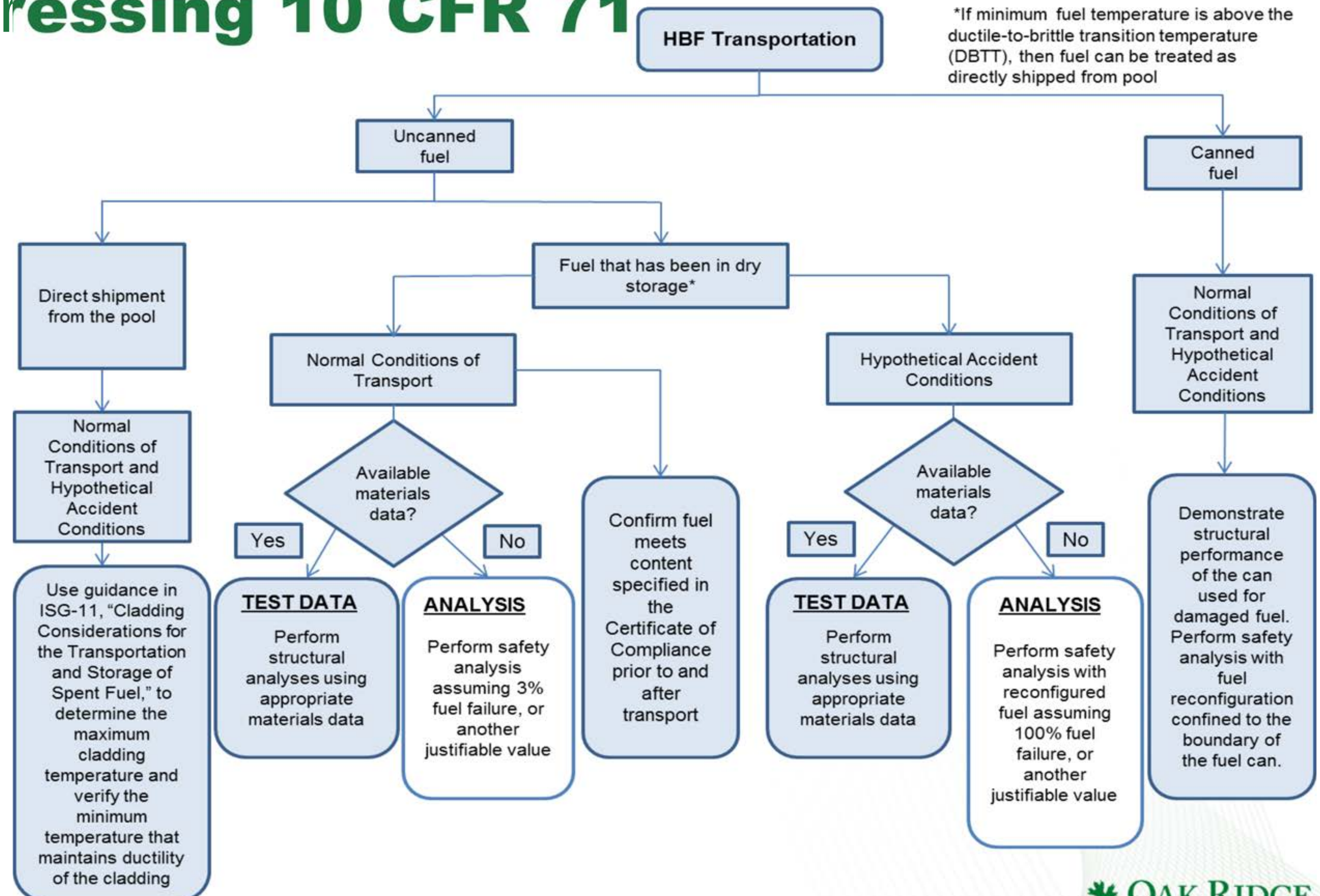
Where this work ties in with Regulatory Issue Summary for storage and addressing 10 CFR 72



**This approach is valid provided results from the demonstration cask as described confirm the original fuel condition licensing assumptions.*

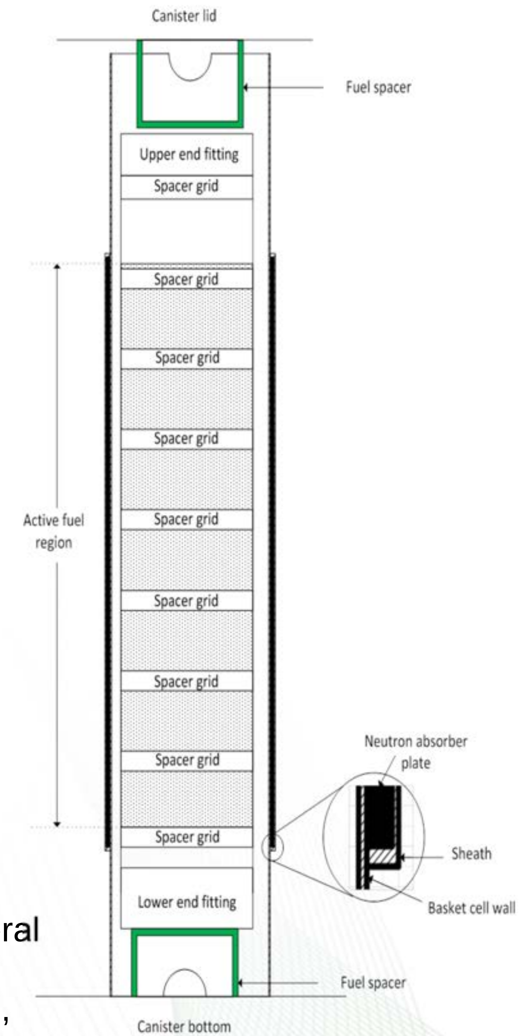
Oak Ridge National Laboratory

Where this work ties in with Regulatory Issue Summary for transportation and addressing 10 CFR 71



A consequences assessment to evaluate the impact of hypothesized geometry changes was performed

- Three reconfiguration categories
  – Cladding failure
  – Rod/assembly deformation without cladding failure
  – Changes in fuel assembly axial alignment without cladding failure
- Evaluations conducted in four technical disciplines
  – Criticality (SCALE code system)
  – Shielding (SCALE code system)
  – Containment (Derivations based on NUREG/CR-6487 and the containment acceptance criteria provided in 10 CFR Part 71)
  – Thermal (COBRA-SFS, thermal source term from SCALE)
- Key analysis assumptions
  – Criticality calculations performed fully flooded with water
  – All fuel assemblies have same reconfiguration in all basket cells unless stated otherwise (tailored to technical discipline considerations)
- Results/consequences developed were relative change between reconfiguration end-state from nominal intact configuration
  – (32) 17×17 pressurized water reactor (PWR) fuel assemblies representative of a Westinghouse (W) optimized fuel assembly (OFA) design
  – (68)10×10 boiling water reactor (BWR) fuel assemblies representative of a General Electric-14 (GE14) design
  – PWR and BWR models are representative of high-capacity-type casks/packages, referred to as generic burnup credit (GBC)-32 and GBC-68, respectively



OAK RIDGE National Laboratory

Scenario descriptions for cladding failure configurations

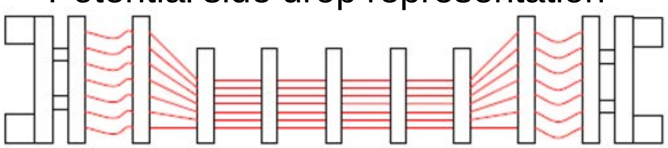
Technical discipline	Scenario	
	S1a – Breached spent fuel rods	S1b – Damaged SNF[a]
Criticality	Fuel particulate displaced from assembly lattice positions resulting in increased moderation	Geometry changes and modeling homogenous versus heterogeneous representations of fuel debris mixture
Shielding	Varied fraction of fuel redistributed to different canister basket cavity region	Regions within canister volume where fuel is redistributed
Containment	Fraction of failed fuel rods; in addition for high-burnup fuel, varying release fractions for the contributors to the releasable activity and pellet region from which the radioactive material originates	For high-burnup fuel, varying release fractions for the contributors to the releasable activity and pellet region from which the radioactive material originates
Thermal	Fraction of fuel rods experiencing cladding failure that releases fission product and rod backfill gases (varied from 0-100%)	The number of assemblies (1 or 32 (all)) and the packing fraction of the debris (0.612-0.313) to investigate the impact of fuel redistribution on component temperatures

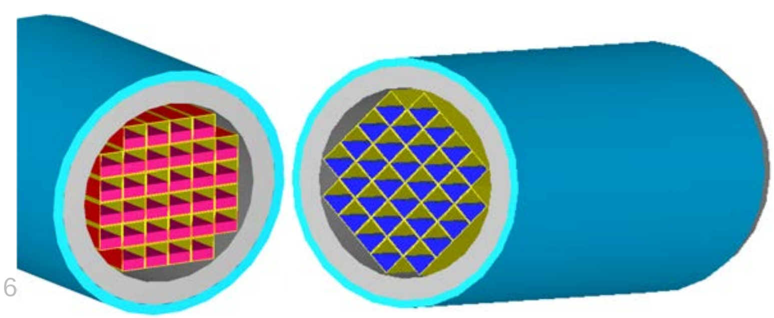
[a] Includes stylized analyses to bound impact (some configurations not credible)

Scenario descriptions for Rod/assembly deformation configurations

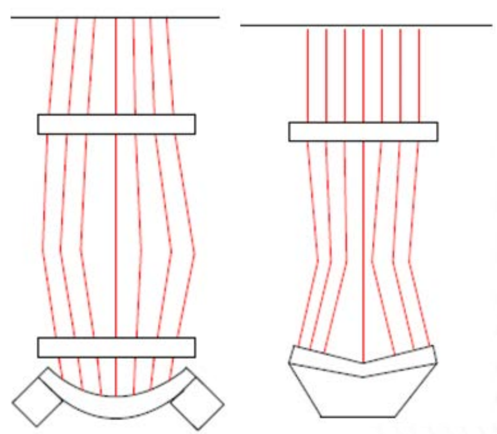
Technical discipline	Scenario	
	S2a – Side/horizontal drop	S2b – End/vertical drop
Criticality	Assembly pin pitch contraction	Uniform and non-uniform radial and axial pin pitch changes
Shielding	Source/fuel location	N/A – Bounded by Category 3
Containment	Fraction of crud that spalls off cladding (varied from 0.05 to 1.0)	N/A – Same as Scenario S2a
Thermal	Assembly pin pitch contraction	Assembly pin pitch expansion

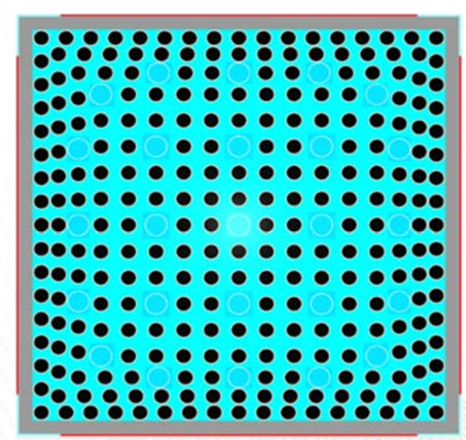
Potential side drop representation





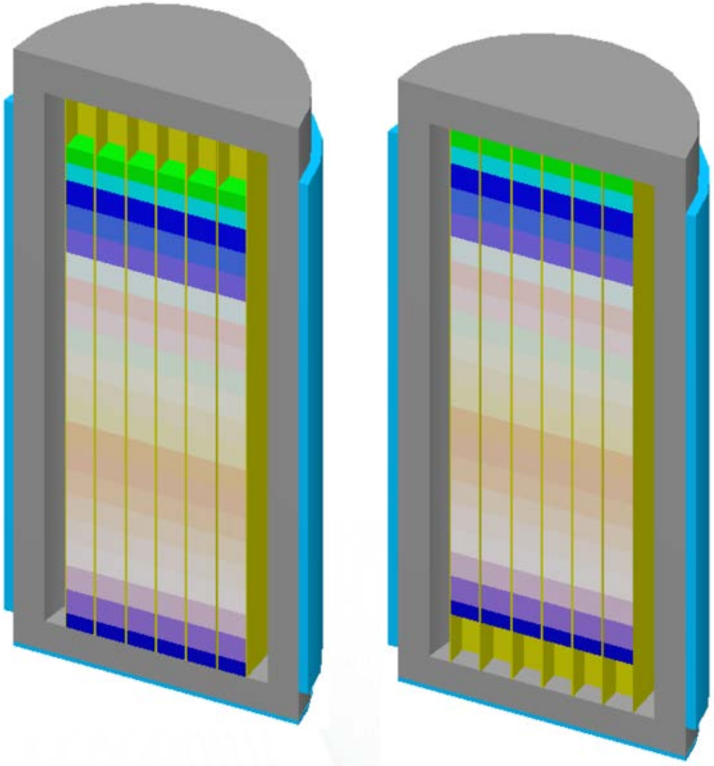
Potential end drop representation





Scenario descriptions for changes to assembly axial alignment

Technical discipline	Scenario S3
Criticality	Fuel assembly axial position (varied between canister base plate and top lid)
Shielding	Fuel assembly axial position (source shifted towards top lid or towards baseplate)
Containment	N/A (same as Scenario S2a where fraction of crud that spalls off cladding is varied)
Thermal	Fuel assembly axial position (varied between canister base plate and top lid)



Consequences of geometry change with respect to criticality (maximum $\%\Delta k_{eff}$ shown for configurations analyzed)

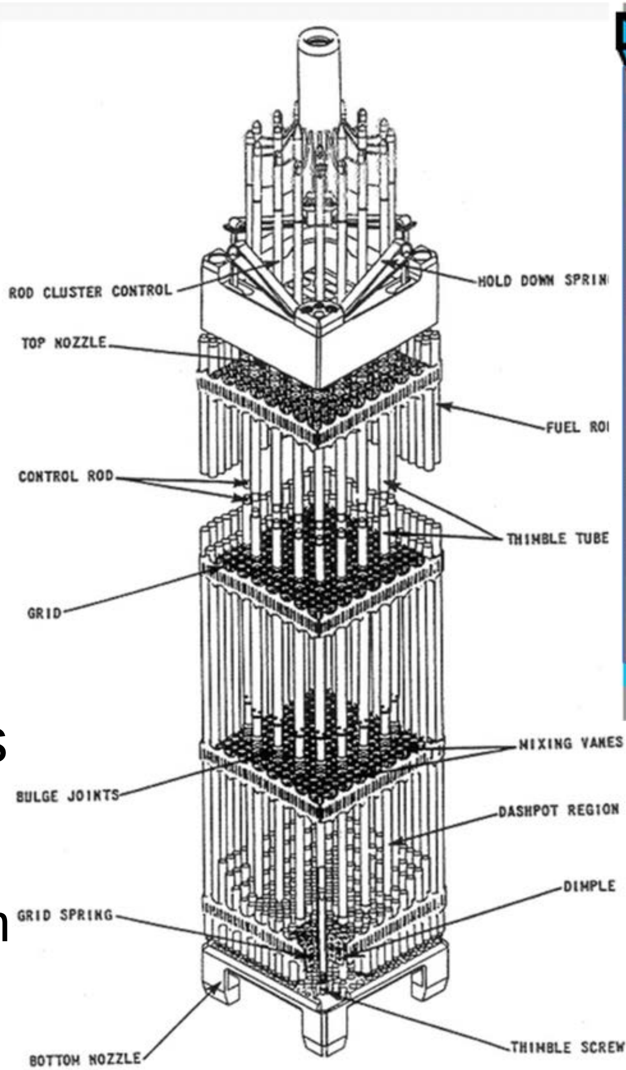
Scenario	Description	Relative change in k_{eff} ($\% \Delta k_{eff}$)	
		PWR	BWR
Breached spent fuel rods	Combination of multiple rod removal and rubble extended beyond absorber envelope (displaced fuel volume fraction=0.341)	4.91	2.4 (no displaced fuel modeled)
Damaged SNF	Uniform pellet array (near optimum moderation conditions)[a]	~22[a]	~35[a]
Rod/assembly deformation	Non-uniform radial pin pitch expansion	3.90	2.80 (channeled) 13.30 (unchanneled)
Change in axial position	Assembly shift exposing active fuel outside neutron absorber envelope (must be towards lid)	Linear with exposure length (<1.0 at 2 in.)	Linear with exposure length (< 2.0 at 2 in.)

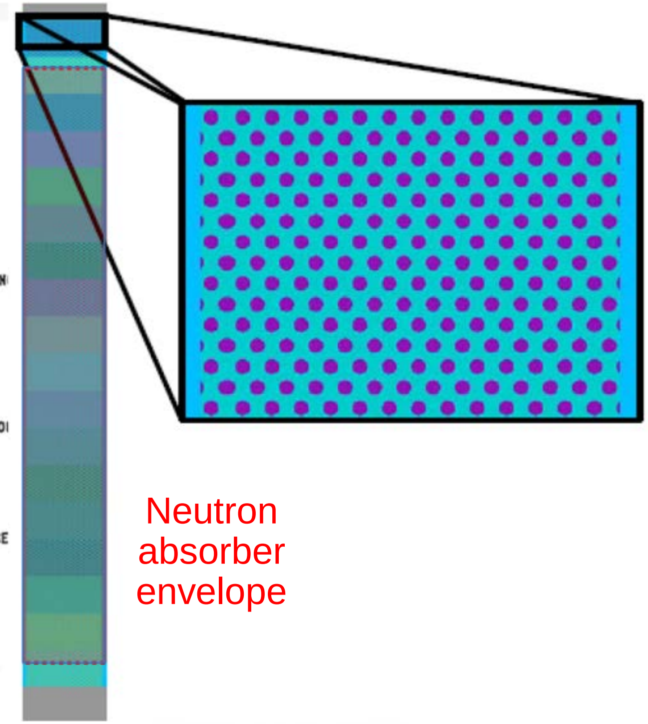
[a] Configuration is bounding but considered non-mechanistic

OAK RIDGE National Laboratory

Assumptions in the bounding criticality case

- Objective was to develop a stylized configuration to maximize k_{eff}
- Hardware omitted
  - Nozzles
  - Fuel spacer
  - Guide tubes
  - Cladding
  - Grids
- Model simplifications
  - Ordered pellet array
  - Burnup profile preserved resulting in lower burned ends being outside absorber envelope

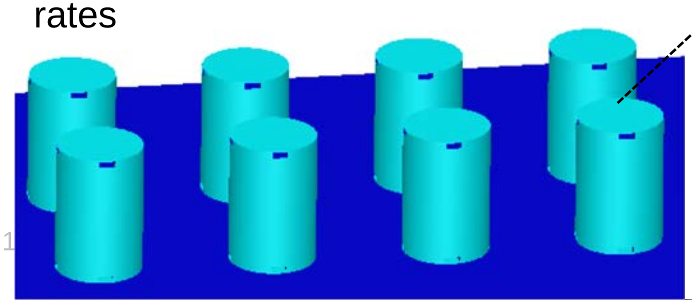


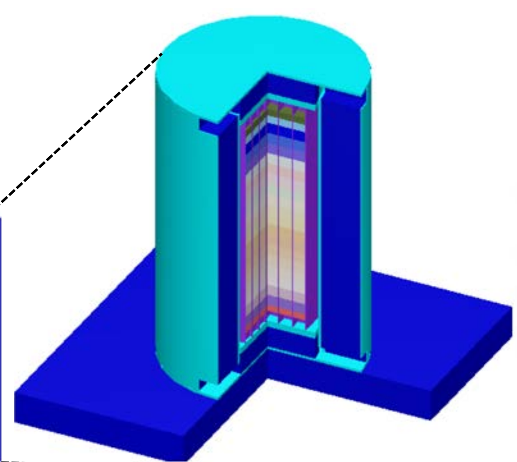


Consequences of geometry change with respect to dose for storage cask

Scenario	Description	Relative change to maximum dose rate (F/I)[a]	
		PWR	BWR
Damaged SNF	One meter from a storage cask; homogeneous fuel mixture distribution settled at bottom	Radial[b]: 4.1 (total)	Radial[b]: 9.2 (total)
Damaged SNF[c]	4×2 storage array evaluation at controlled area boundary	1.8 (total)	2.4 (total)
Change in axial position	One meter from a storage cask; assembly shift allowing fuel assemblies to reach bottom surface of the inner cavity	Radial[b]: 2.7 (total)	Radial[b]: 1.2 (total)

ISFSI model to evaluate impact of fuel failure on site boundary dose rates





[a] F/I is ratio between fuel reconfiguration and nominal intact configuration results

[b] Locations that receive radiation streaming through air vents

[c] Bounding model

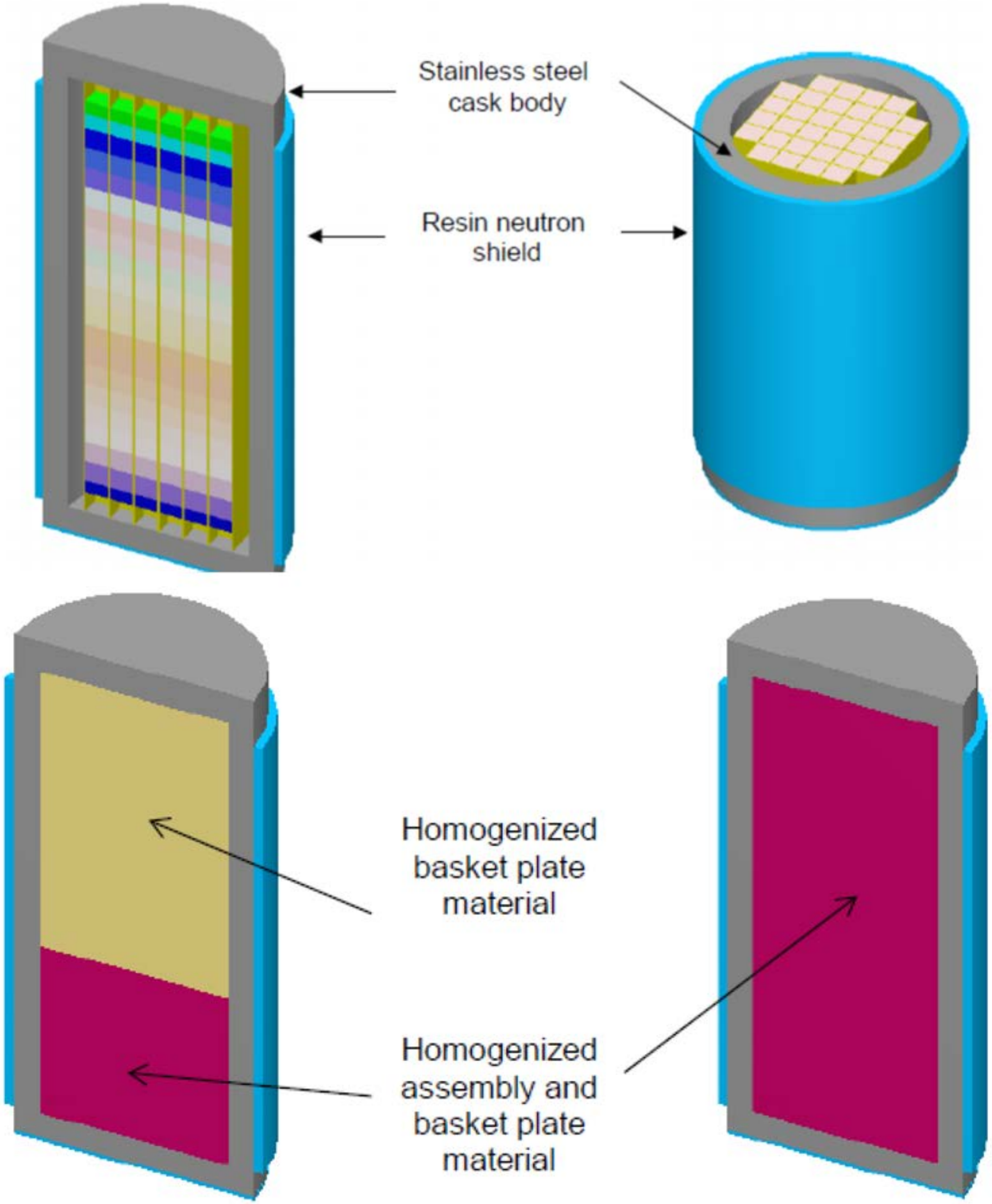
Consequences of geometry change with respect to dose for transportation (total dose rate at 2m and 1m from surface)

Scenario	Description	Relative change in maximum dose rate (F/I)	
		PWR	BWR
Breached spent fuel rods	Varied number of missing rods and distribution of displaced fuel to middle of active fuel region (Failures: PWR 25%, BWR 11%)	Top: 1.11 Radial: 1.02 Bottom: 0.98	Top: 1.11 Radial: 0.97 Bottom: 1.03
	Varied number of missing rods and distribution of displaced fuel to the bottom end-fitting (Failures: PWR-25%, BWR-11%)	Top: 1.05 Radial: 1.02 Bottom: 2.54	Top: 1.09 Radial: 1.04 Bottom: 3.97
Damaged SNF	Homogeneous fuel mixture distribution settled at bottom or uniformly distributed throughout the package cavity (100%)[a]	Top: 5.93 Radial: 0.93 Bottom: 4.01	Top: 12.90 Radial: 0.84 Bottom: 5.45
Rod/assembly deformation	Pin pitch contraction with fuel rods collapsed against fuel basket plates	Top: 1.4 Radial: 1.1 Bottom: 1.2	Top: 1.5 Radial: 1.1 Bottom: 1.3
Change in axial position	Assembly shift allowing fuel assemblies to reach top or bottom surface of the canister cavity	Top: 1.3 Radial: 1.0 Bottom: 1.4	Top: 1.2 Radial: 1.0 Bottom: 1.2

[a] Configuration is bounding but considered non-mechanistic

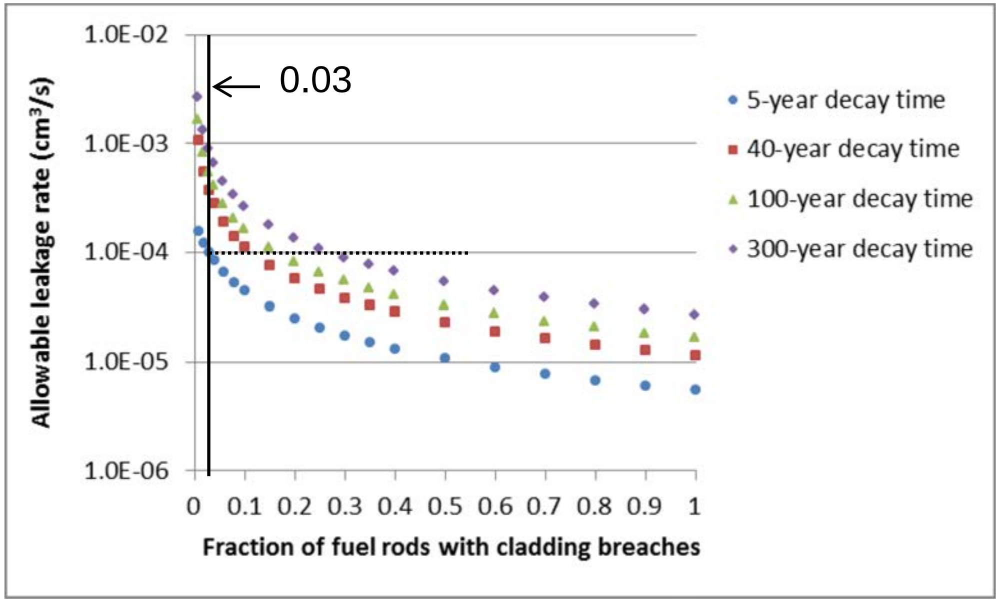
Illustration of bounding shielding analysis model

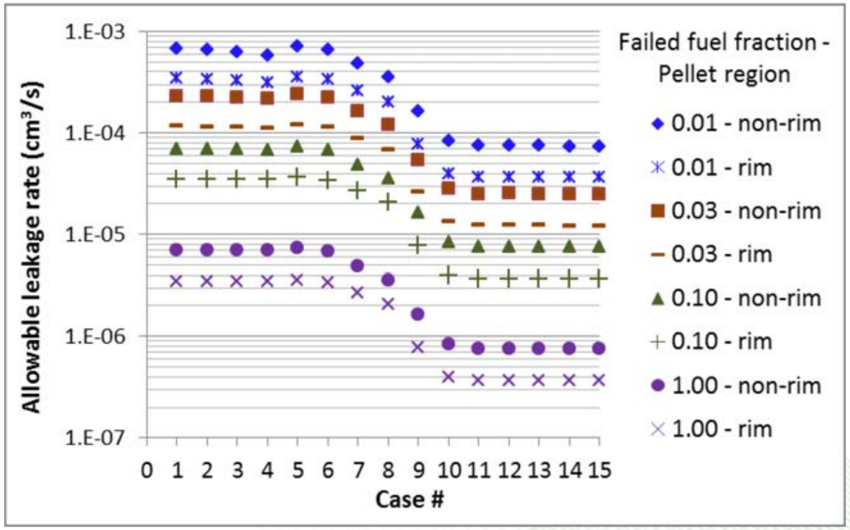
- Objective was to develop a stylized configuration to maximize dose rate
- Model simplifications
  - Source homogenization
  - Source uniformly distributed with canister volume
    - Fuel spacers omitted
    - Basket geometry control omitted



Consequences for containment were evaluated with a series of sensitivity analyses

- Impact of fuel failure may be of secondary importance as compared to the decrease in source term over time
  - Crud is important in calculation of allowable leakage rate for <40-year decay time (^{60}Co $t_{1/2}$ = 5.271 y)
  - Allowable release rate increases with increasing decay time
  - Welded canisters are leak tight
- Allowable leakage rate exhibits the greatest sensitivity to changes in the mass fraction of fuel released as fuel fines due to cladding breach
- Allowable radionuclide release rate and leakage rate for high-burnup fuel vary as a function of the pellet regions from which the radioactive material is released (pellet rim region)





Summary of maximum thermal consequences due to geometry changes

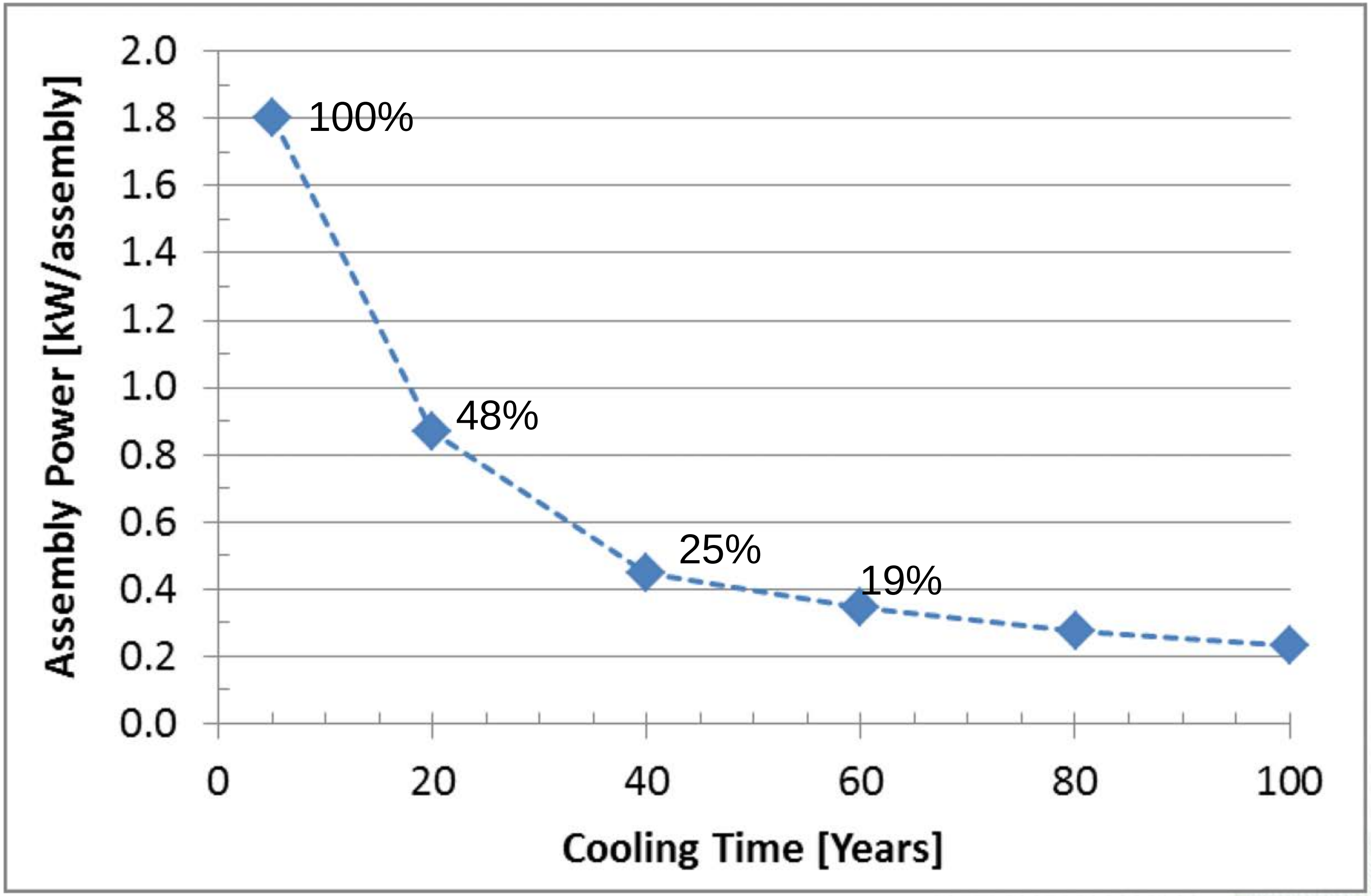
Peak cladding, neutron absorber*, or lid temp. variation [Δ°C]**

Scenario	Description	Vertical Cask Orientation	Horizontal Cask Orientation
-	Decay time (20-60 years)	-221	-226
-	Decay time (40-60 years)	-45	-51
-	Insolation (on vs. off)	-10	-8
Breached spent fuel rods	Failure of one assembly: only gaseous release	-14	+4
	Failure of all assemblies: only gaseous release	-71*	+42*
Damaged SNF	Failure of one assembly: gaseous release and particle bed	-14	+3
	Failure of all assemblies: gaseous release and particle bed	+127* -19**	+31*
Rod/assembly deformation	Bounding rod pitch to diameter ratio	-51	-12
Change in axial position	Axial shifting all assemblies	-11 +3**	+3

** The canister seal temperature is estimated to have similar relative changes as the lid temperature.

OAK RIDGE National Laboratory

Fuel assembly decay heat as a function of time (65 GWd/MTU Burnup)

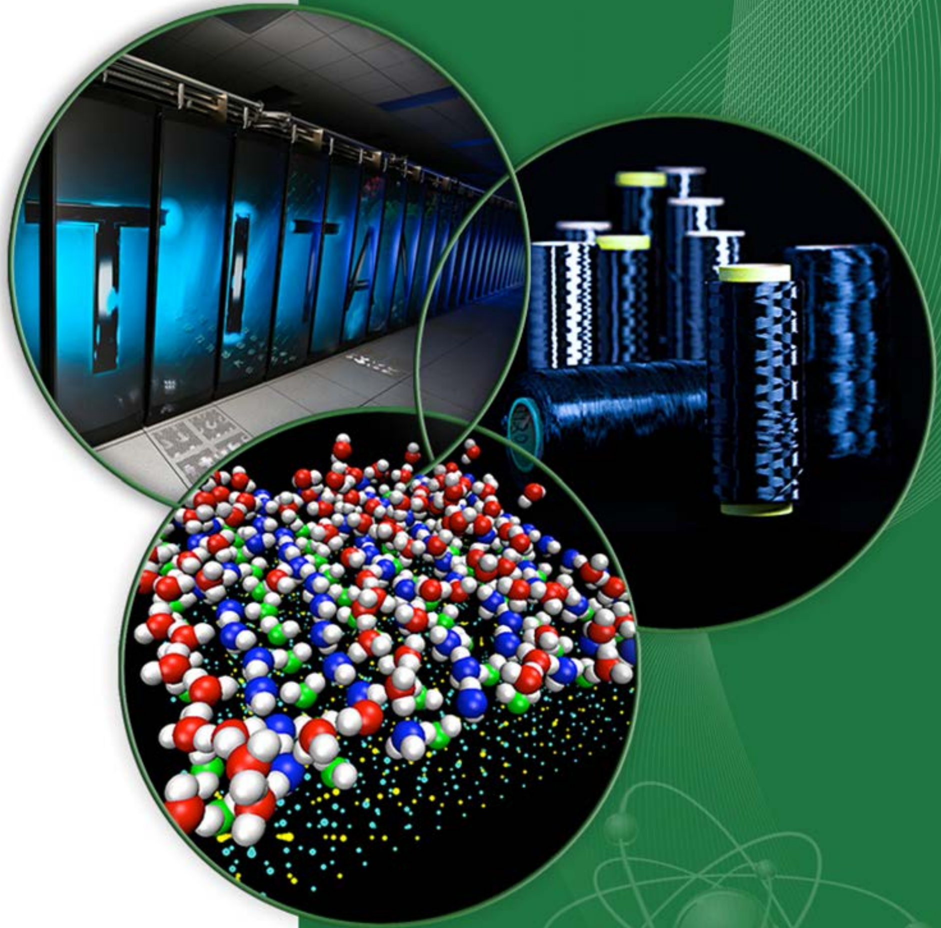


The results of this study provide an understanding of storage and transportation package responses to hypothetical fuel geometry changes

- The reconfiguration scenarios involving cladding failure and fuel axial relocation exhibited the largest impact in the technical disciplines evaluated
  - Criticality: <5% Δk_{eff} increase for plausible scenarios
  - Shielding: <3x difference for 25% redistributed PWR fuel; <4x difference for 11% redistributed BWR fuel
  - Containment and Thermal: allowable leakage rate and decay heat are decay-time dependent so consequences associated with geometry changes are offset by the longer storage times
- The consequences associated with cladding failure for the criticality and shielding technical disciplines are very sensitive to the modeling assumptions, and will be strongly dependent on canister- and assembly-specific characteristics

OAK RIDGE National Laboratory

Backup slides

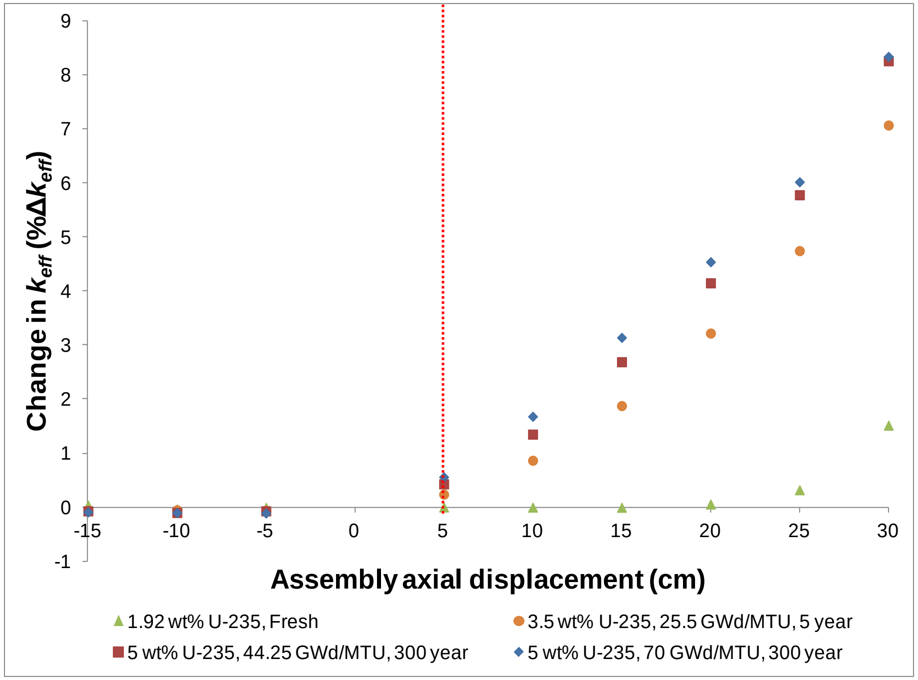


ORNL is managed by UT-Battelle
for the US Department of Energy

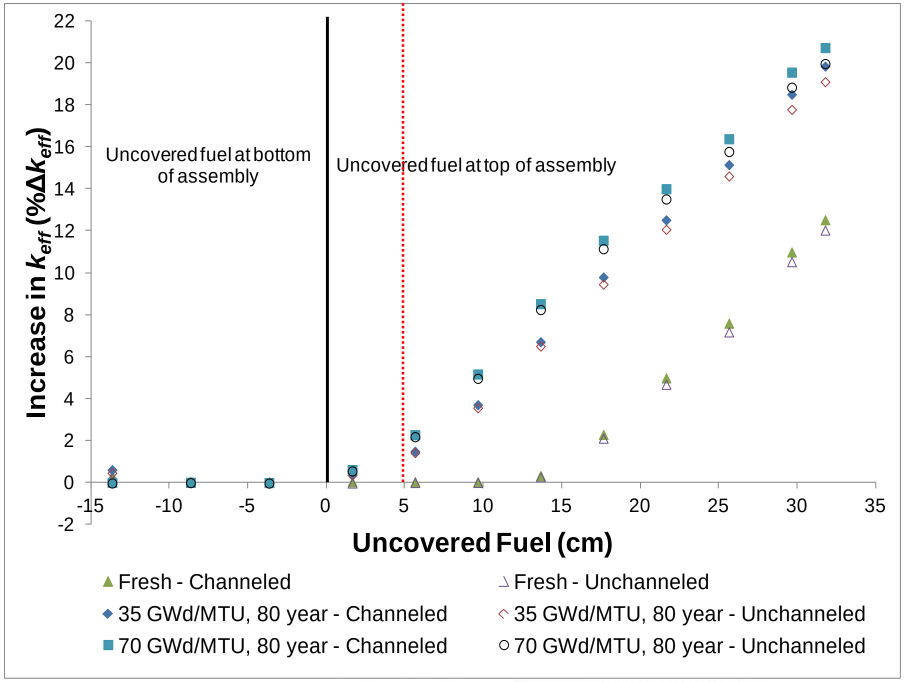
OAK RIDGE
National Laboratory

Plots showing reactivity change as a function of fuel length outside neutron absorber envelope

- Fuel assemblies typically have less than 2 inches (5 cm) of space available to move within



PWR

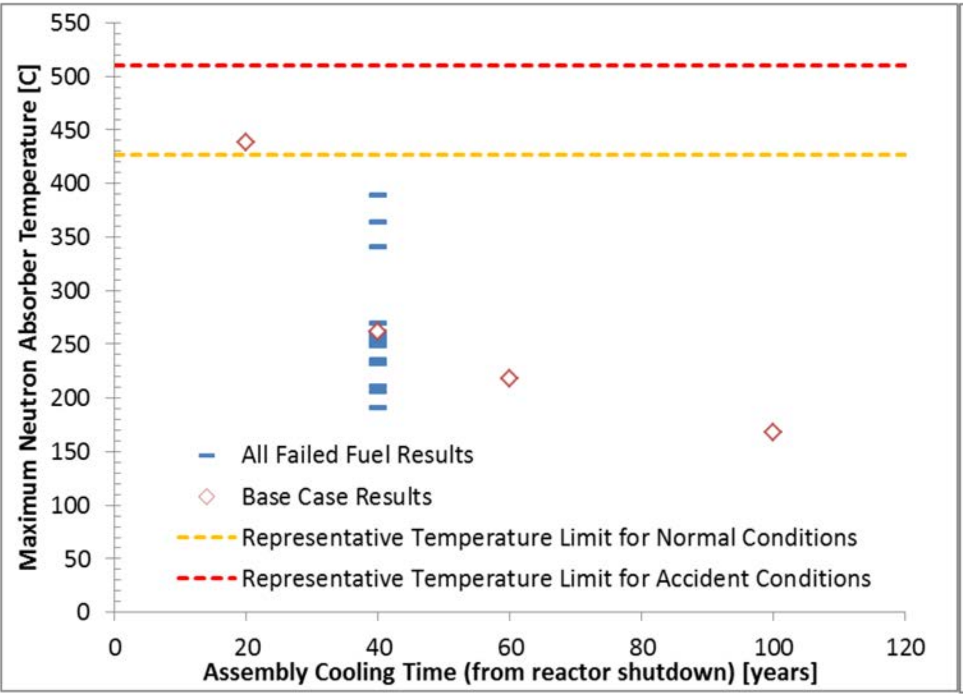


BWR

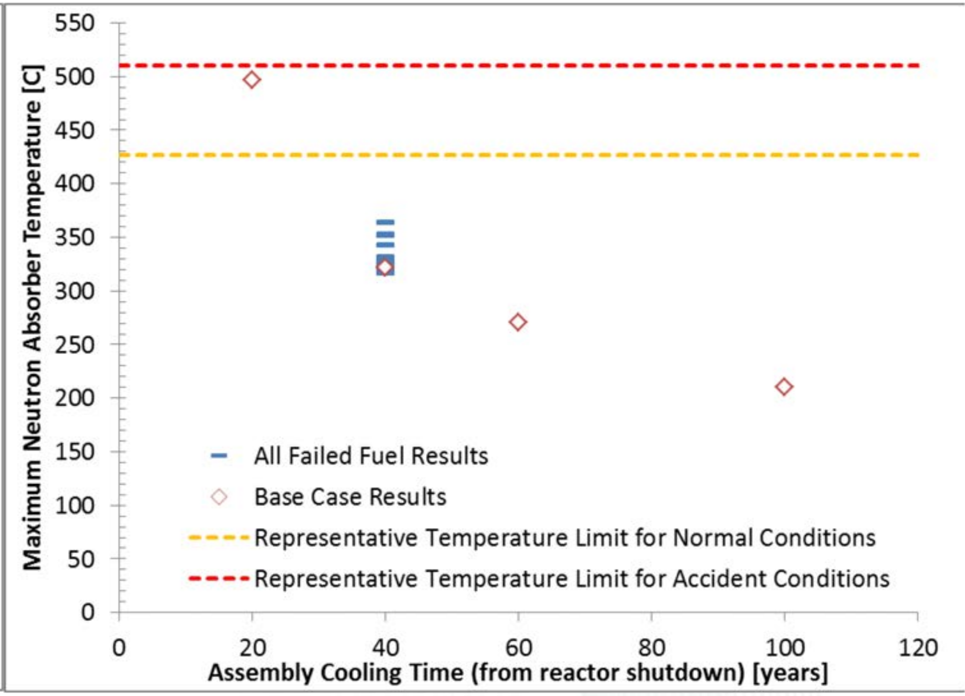
OAK RIDGE National Laboratory

Thermal impacts of fuel failure may only be of secondary importance as compared to the decreased heat load of the fuel

Vertical cask



Horizontal cask

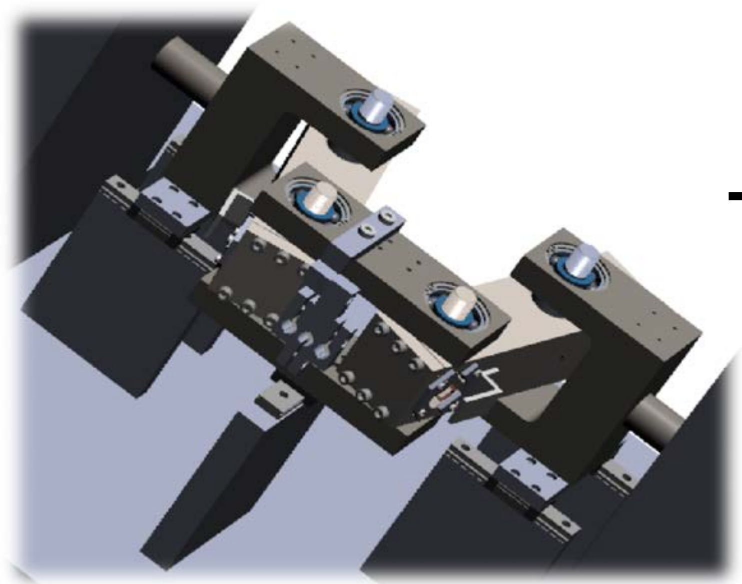


OAK RIDGE National Laboratory

U.S.NRC

UNITED STATES NUCLEAR REGULATORY COMMISSION

Protecting People and the Environment



Mechanical Testing of High Burnup Fuel for Transportation Applications

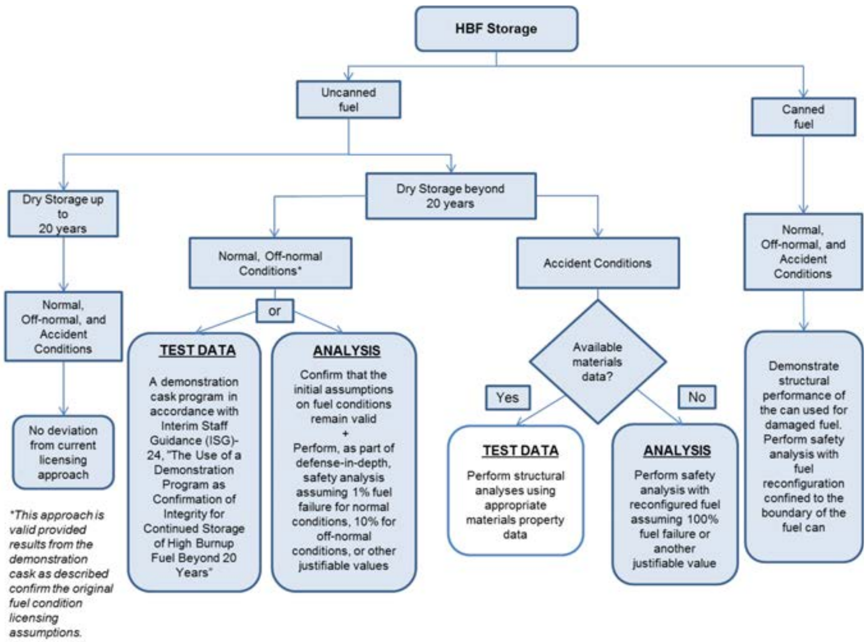
An NRC sponsored research program at Oak Ridge National Laboratory

NRC Project Manager:

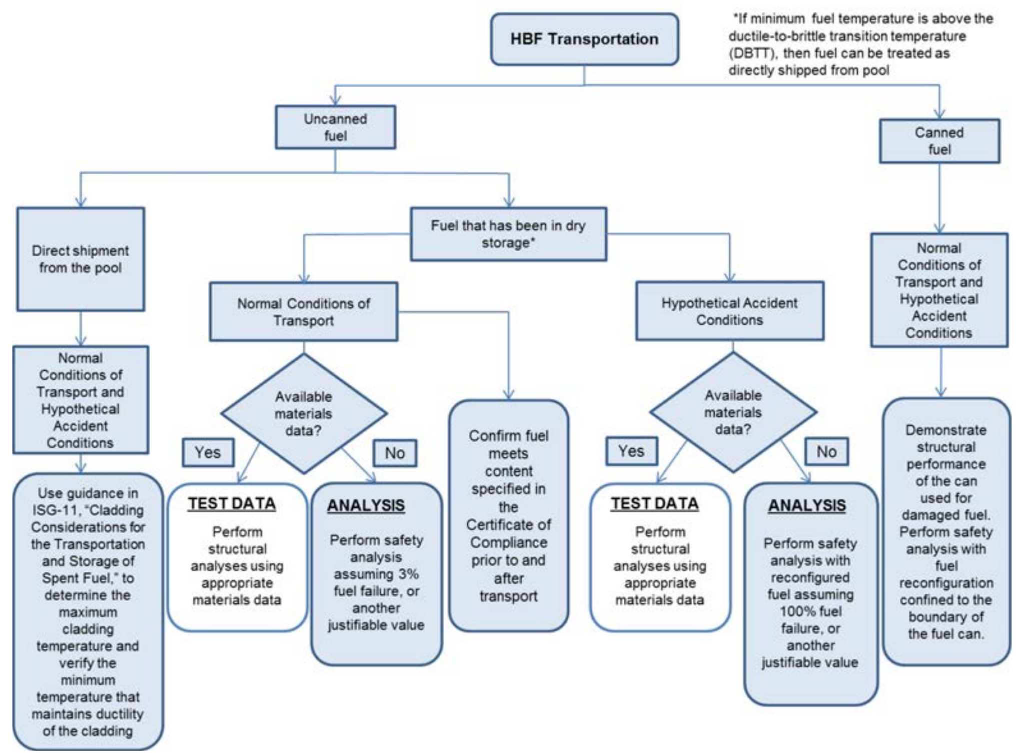
Michelle Bales

Michelle.Bales@nrc.gov

Background



HBF Storage
Uncanned fuel
Canned fuel
Dry Storage up to 20 years
Dry Storage beyond 20 years
Normal, Off-normal Conditions*
Accident Conditions
Normal, Off-normal, and Accident Conditions
Normal, Off-normal, and Accident Conditions
No deviation from current licensing approach
or
TEST DATA
A demonstration cask program in accordance with Interim Staff Guidance (ISG)-24, "The Use of a Demonstration Program as Confirmation of Integrity for Continued Storage of High Burnup Fuel Beyond 20 Years"
ANALYSIS
Confirm that the initial assumptions on fuel conditions remain valid
+
Perform, as part of defense-in-depth, safety analysis assuming 1% fuel failure for normal conditions, 10% for off-normal conditions, or other justifiable values
Available materials data?
Yes
No
TEST DATA
Perform structural analyses using appropriate materials property data
ANALYSIS
Perform safety analysis with reconfigured fuel assuming 100% fuel failure or another justifiable value
Demonstrate structural performance of the can used for damaged fuel. Perform safety analysis with fuel reconfiguration confined to the boundary of the fuel can
*This approach is valid provided results from the demonstration cask as described confirm the original fuel condition licensing assumptions.



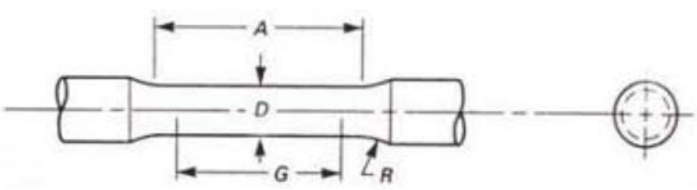
HBF Transportation
*If minimum fuel temperature is above the ductile-to-brittle transition temperature (DBTT), then fuel can be treated as directly shipped from pool
Uncanned fuel
Canned fuel
Direct shipment from the pool
Fuel that has been in dry storage*
Normal Conditions of Transport
Hypothetical Accident Conditions
Normal Conditions of Transport and Hypothetical Accident Conditions
Normal Conditions of Transport and Hypothetical Accident Conditions
Use guidance in ISG-11, "Cladding Considerations for the Transportation and Storage of Spent Fuel," to determine the maximum cladding temperature and verify the minimum temperature that maintains ductility of the cladding
Available materials data?
Yes
No
TEST DATA
Perform structural analyses using appropriate materials data
ANALYSIS
Perform safety analysis assuming 3% fuel failure, or another justifiable value
Confirm fuel meets content specified in the Certificate of Compliance prior to and after transport
Available materials data?
Yes
No
TEST DATA
Perform structural analyses using appropriate materials data
ANALYSIS
Perform safety analysis with reconfigured fuel assuming 100% fuel failure, or another justifiable value
Demonstrate structural performance of the can used for damaged fuel. Perform safety analysis with fuel reconfiguration confined to the boundary of the fuel can.

Research Questions

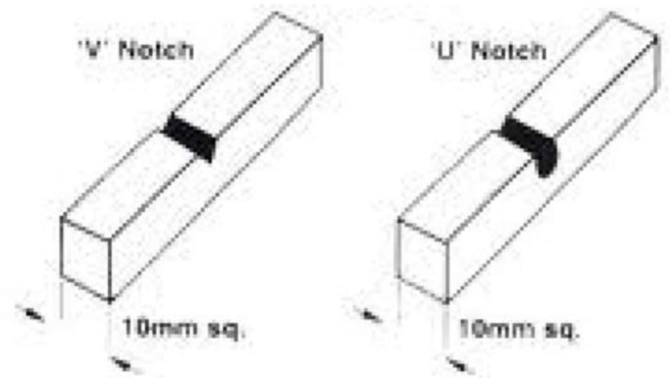
- How does the presence of fuel impact the flexural rigidity (bending stiffness) of the fuel rod?
- How does the presence of fuel impact the failure strain of the cladding?
- How many cycles to failure for high burnup fuel rods at a range of elastic strain levels.
- Will radial hydrides impact the bending stiffness or fatigue life of high burnup fuel rods?

Challenges

- Desire to test **un-modified high burnup rods**; avoid reduced gauge sections or pre-notch methods
- Limited material available
- Hot-cell time is costly
- Many standard measurement devices aren’t compatible with material or test environment



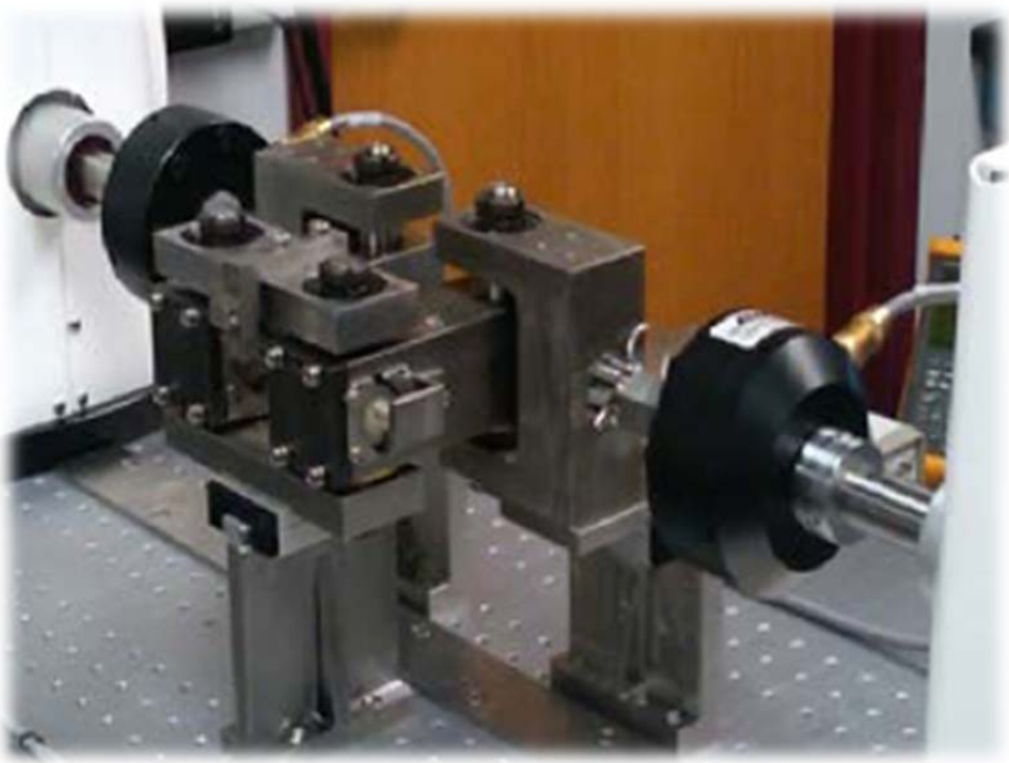
reduced gauge section



pre-notched sample

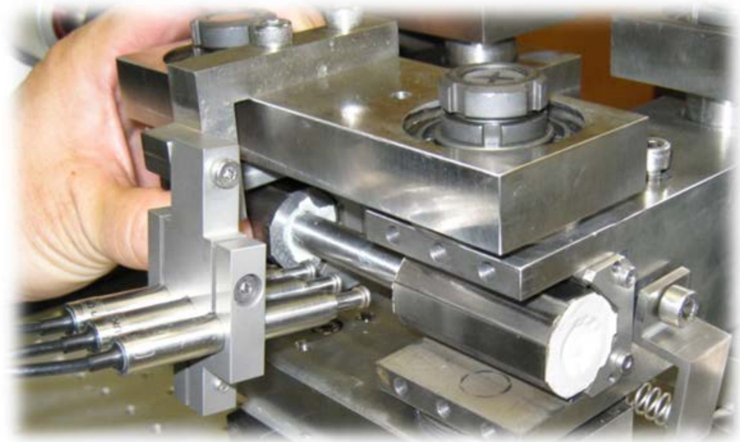
Testing Equipment

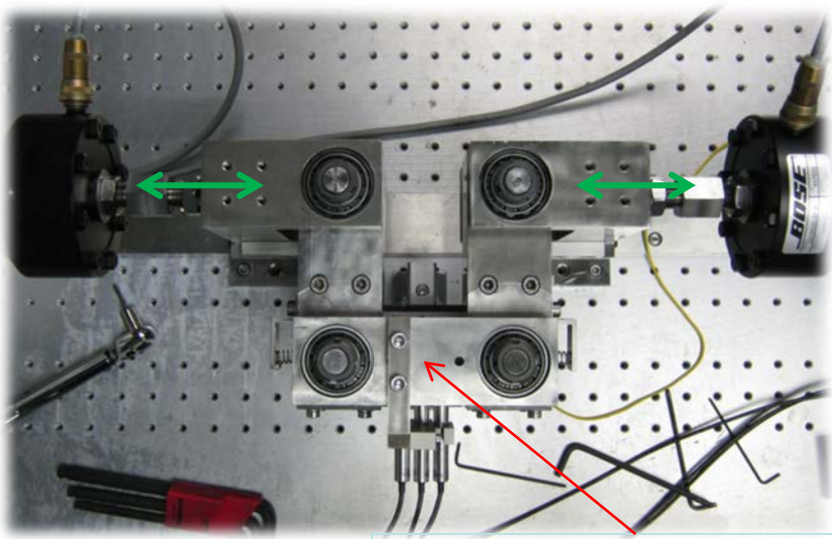
An innovative bending fatigue testing system was developed to measure the static and dynamic response of high burn-up SNF rods. The device is referred to as the Cyclic Integrated Reversible-bending Fatigue Tester (CIRFT)



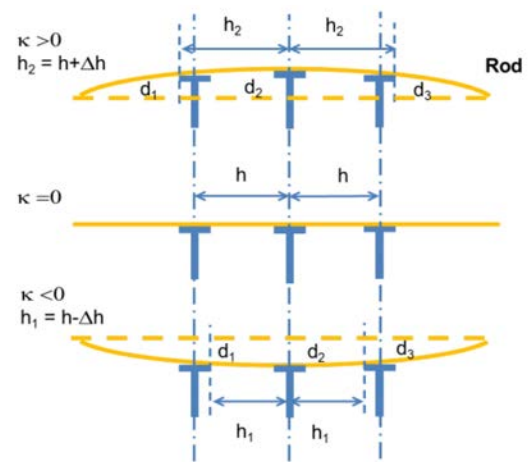
U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

Unique Features





Location of test segment



Irradiated Material Tested

- PWR Spent Nuclear Fuel (SNF) with Zircaloy-4 Cladding
- Burnup ranged from 63.8 to 66.8 GWd/MTU
- Estimated oxide layer thickness 40-110 µm
- Cladding hydrogen content estimated between 360 and 800 wppm
- Cladding diameter ≈ 10.7 mm, Thickness ≈ 0.7 mm
- The pellet height ≈ 6.9 mm (≈ 7 pellets in gage section)
- Phase I testing on rods characterized by circumferential hydrides
- Phase II testing on rods characterized by radial hydrides

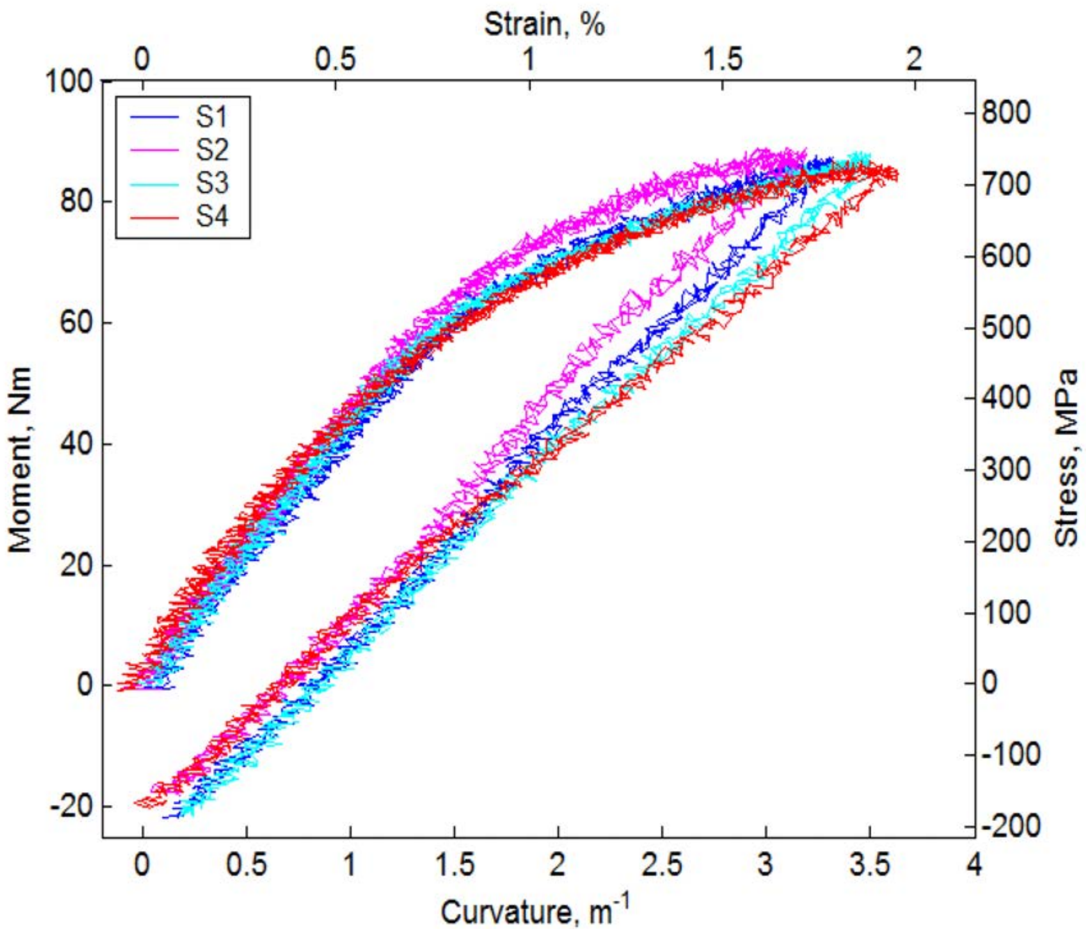
Irradiated Material Tested

- NRC Phase 1 test (non-reoriented HBF samples) program
  - Static bend tests have been completed on 4 samples
  - Vibration fatigue tests have been completed on 16 samples, at a wide range of bending moment amplitudes

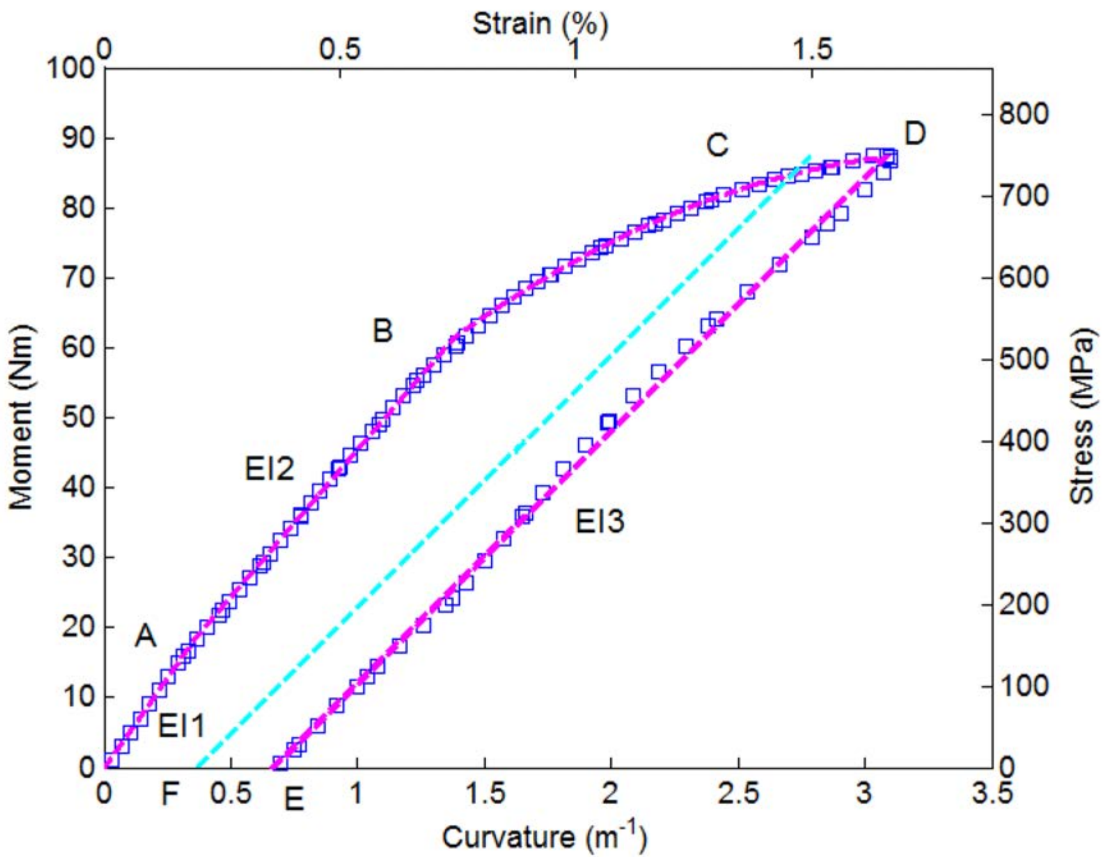
- NRC Phase 2 test (reoriented HBF samples) program
  - Static bend tests will be performed on 1 sample
  - Vibration fatigue tests will be performed on 3 samples*, at a range of bending moment amplitudes

*note, the number of tests is contingent on success of each reorientation procedure.

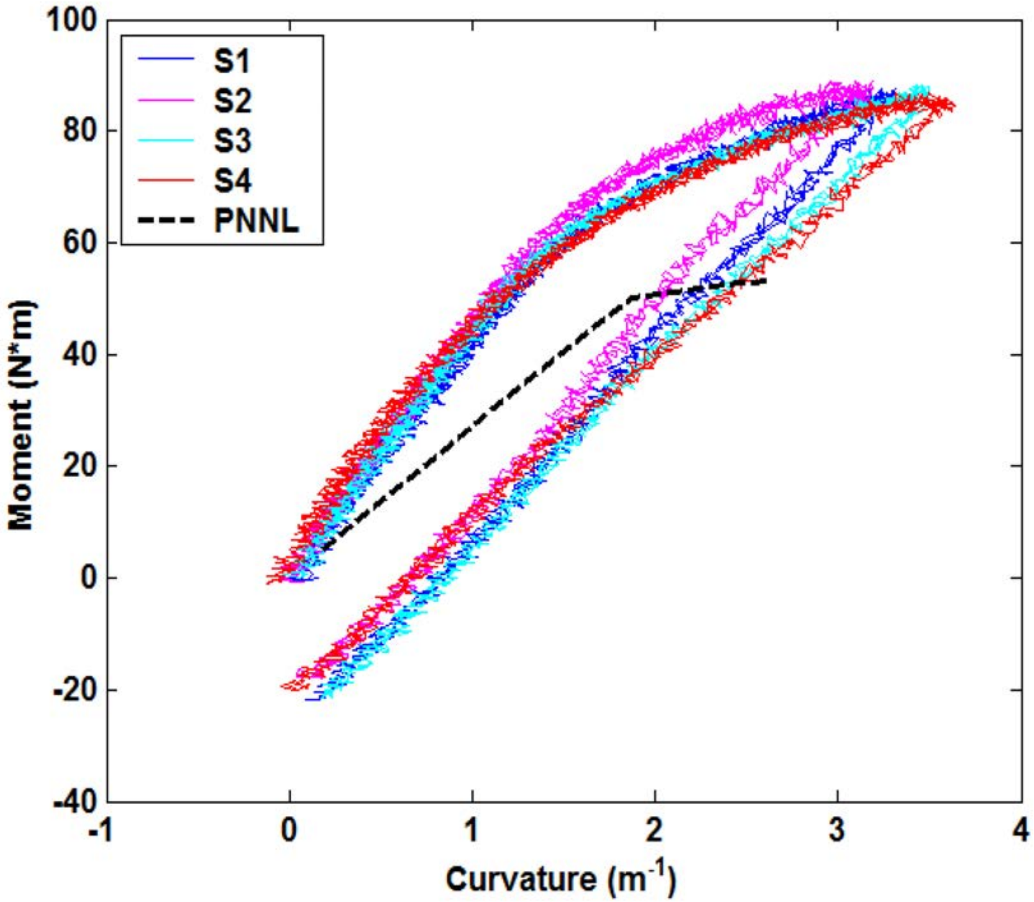
Phase I Results - Static



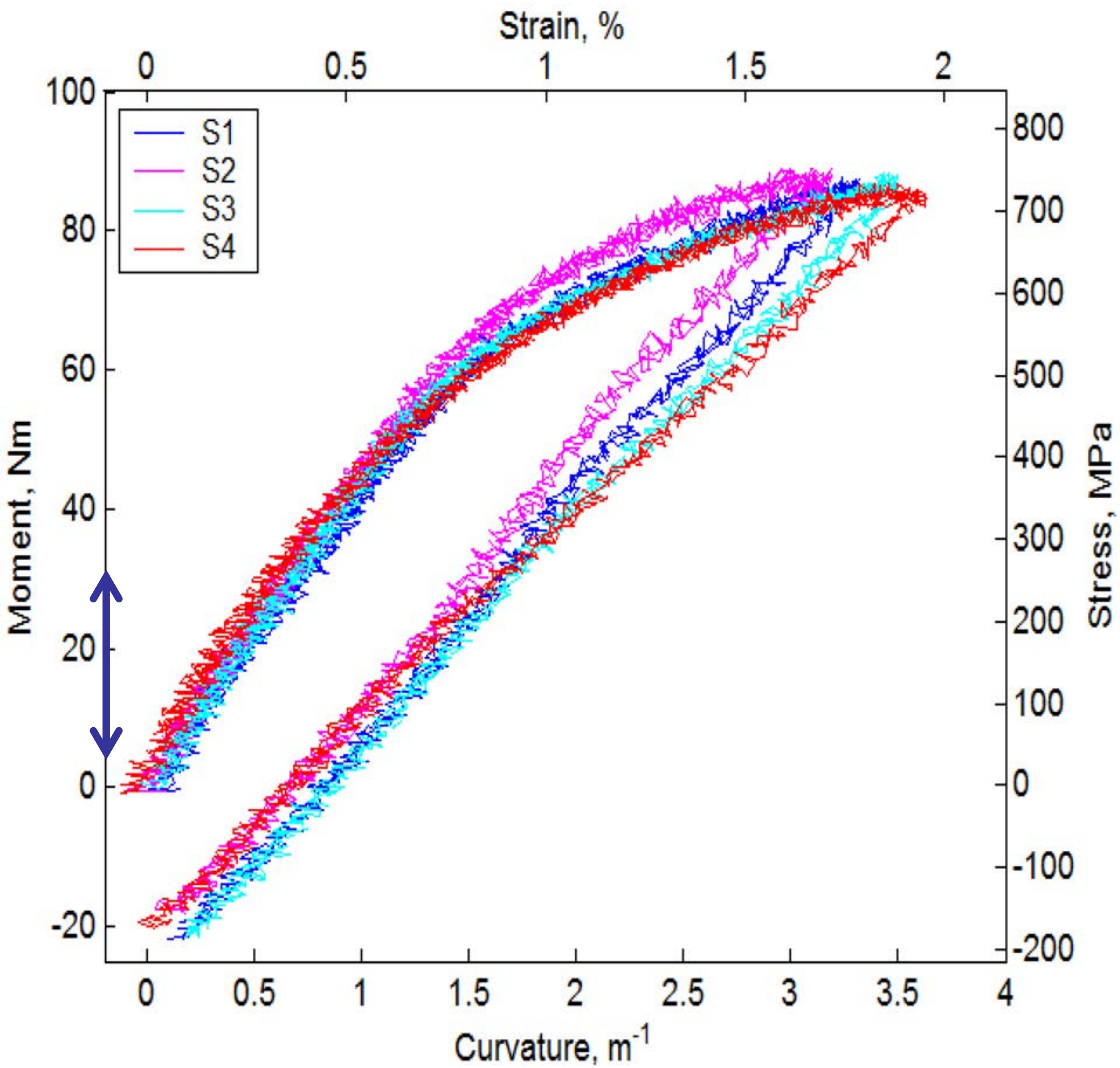
Phase I Results - Static



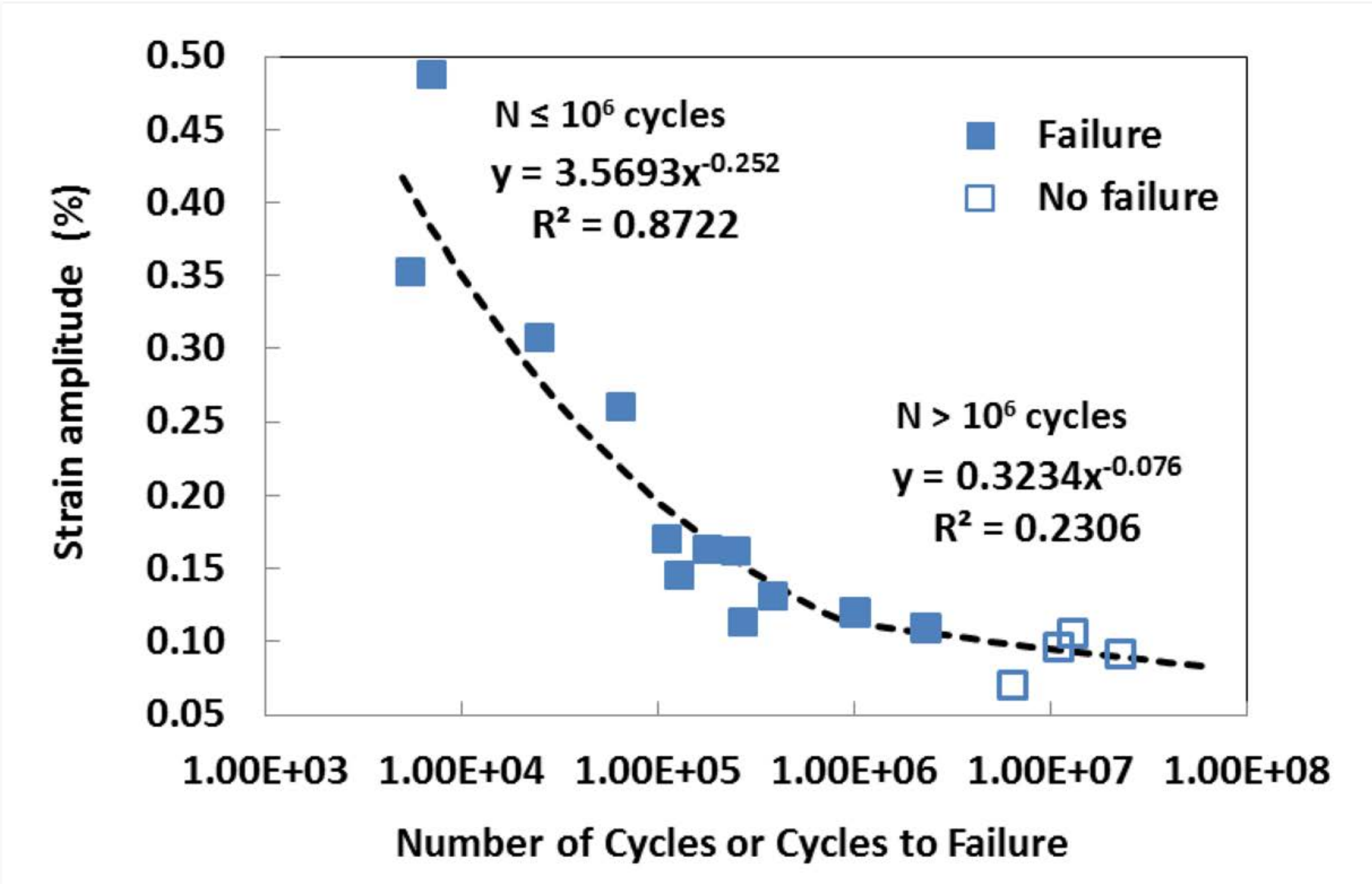
Phase I Results - Static



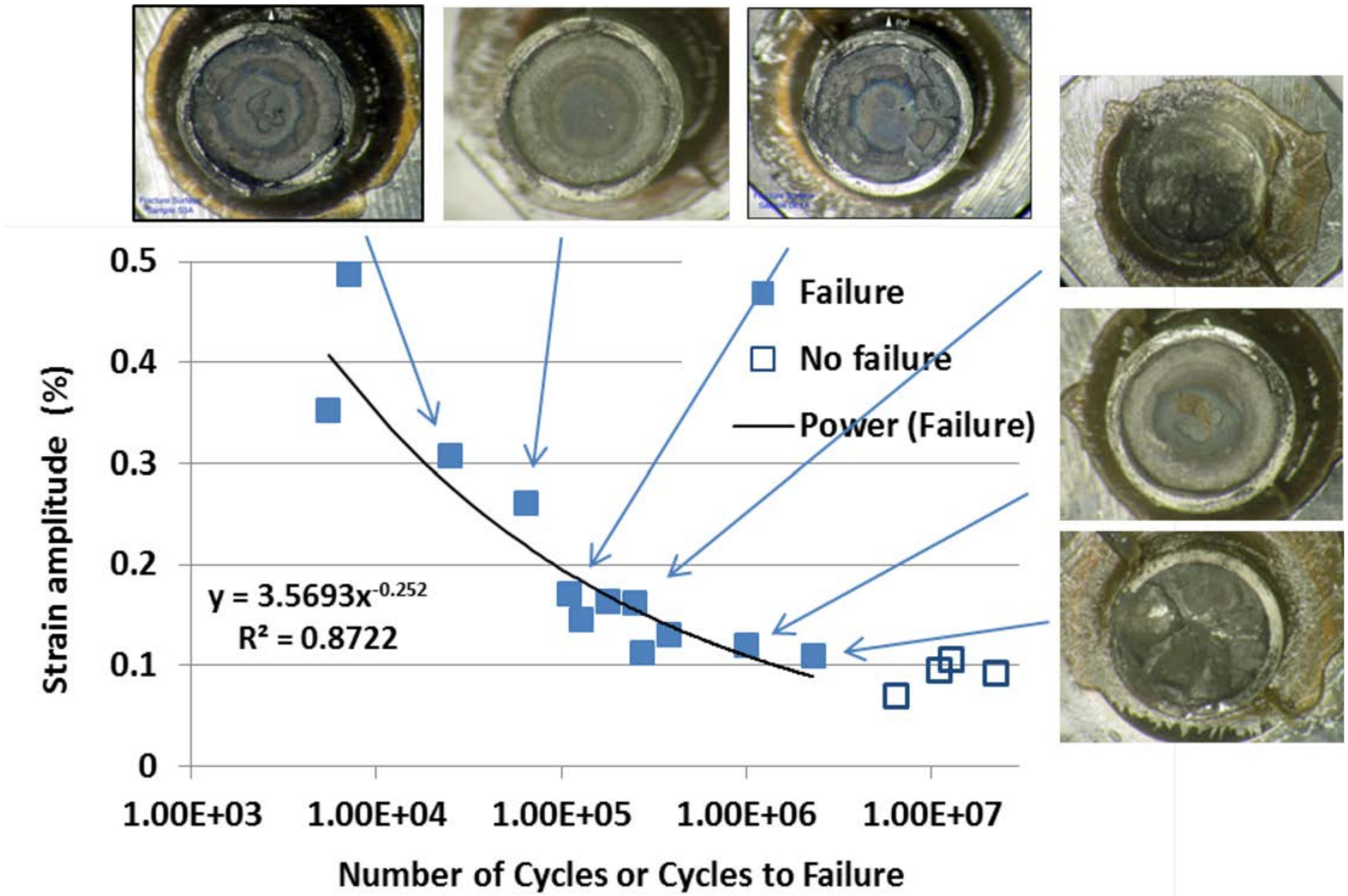
Dynamic Testing



Phase I Results - Dynamic

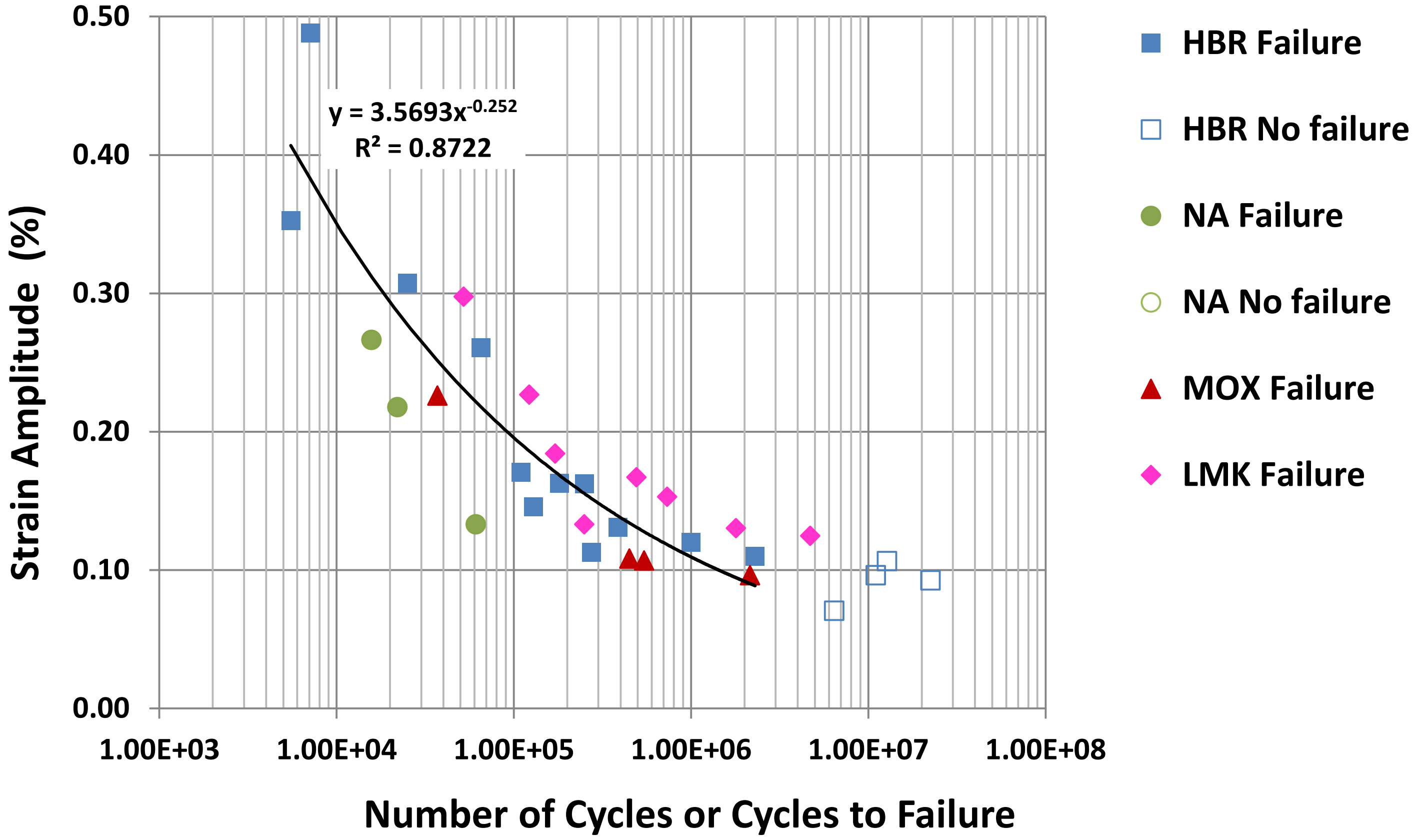


Phase I Results - Dynamic



PPI close-up

Ongoing Testing on CIRFT



Ongoing Testing on CIRFT

- Fatigue tests will be conducted on HBU fuel segments that have been subjected to radial hydride reorientation.
- Test segments will be from the same father rod as previous NRC tests.
- Impact of radial hydrides on the fatigue life of high burnup fuel rods will be evaluated based on comparison of the fatigue life of rods with circumferential hydrides to rods with radial hydrides.
- Equipment build up and procedure development for hydride reorientation for high burnup fuel are nearly complete.
- Phase II testing is expected to be completed this summer.

Documentation

- A number of publications have been written to document the development of the testing device, surrogate materials testing and testing protocol.
- The results of Phase I testing have been published in NUREG/CR-7198, "Mechanical Fatigue Testing of High-Burnup Fuel for Transportation Applications."
- The latest results of the DOE CIRFT testing program are available through DOE task leaders.
- Phase II testing will be reported in a future publication

Conclusions

- A unique testing device was developed to measure bending stiffness and fatigue behavior of high burnup spent fuel rods as a fuel/cladding system.

- **5 static tests:** 4 completed on as-irradiated HBU fuel, 1 to be completed on a HBU fuel rod subjected to hydride reorientation
  - Static results to date demonstrate that the presence of fuel increases the bending stiffness relative to calculations using cladding properties alone.

- **19 dynamic tests:** 16 completed on as-irradiated HBU fuel, 3 to be completed on a HBU fuel rod subjected to hydride reorientation
  - Dynamic results to date demonstrate that high burnup fuel can experience a large number of cyclic loads without failure. An effective fatigue limit can be interpreted from the available data.

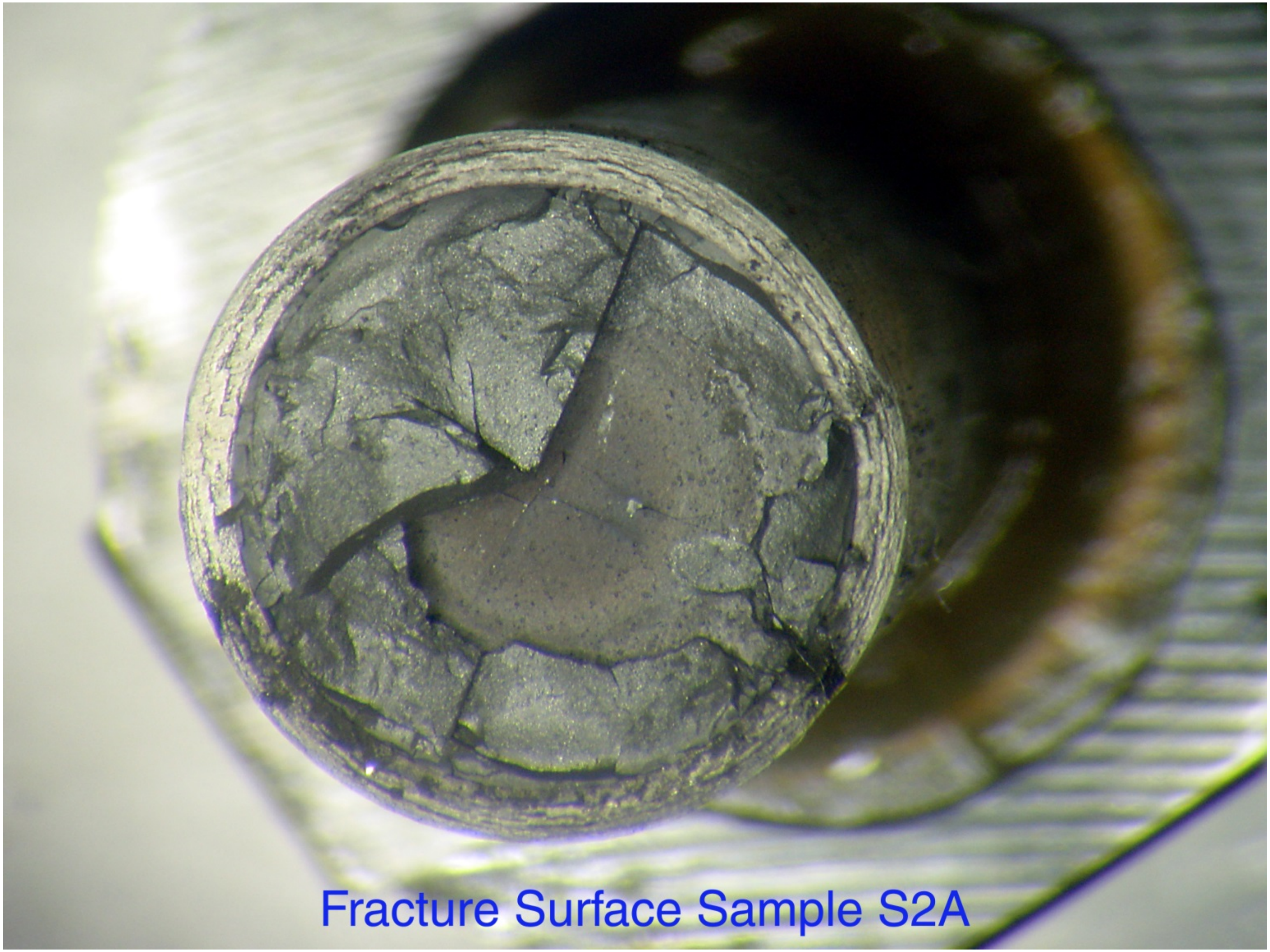
- Comparison of as-irradiated and reoriented results will address whether radial hydrides impact the bending stiffness or fatigue life of high burnup fuel rods.

Backup

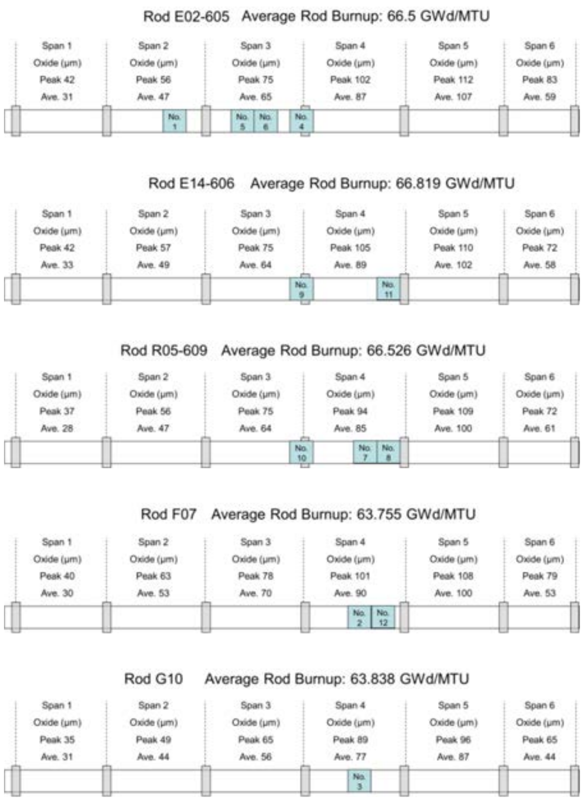
Publications

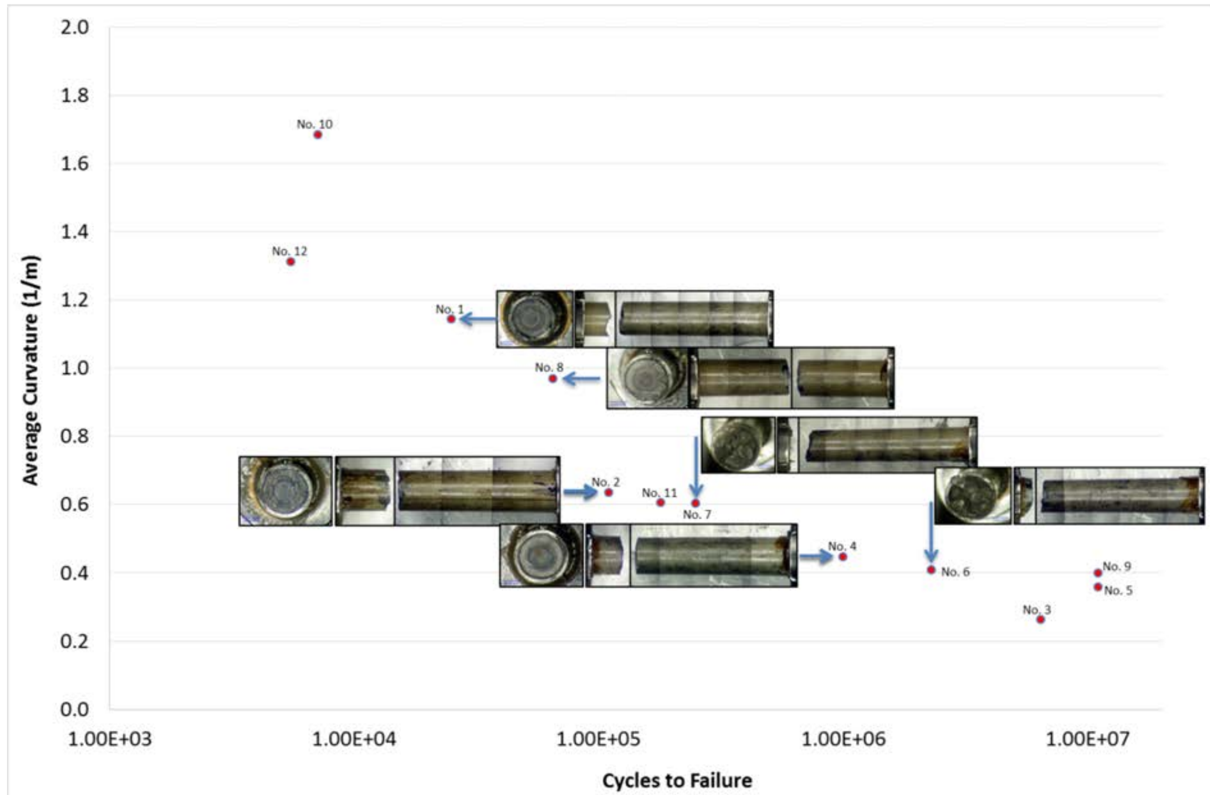
- J.-A. J. Wang, H. Wang, Y. Yan, R. Howard, and B. Bevard, “High Burn-up Spent Fuel Vibration Integrity Study Progress Letter Report (Out-of-Cell Fatigue Testing Development–Task 2.1),” ORNL/TM-2010/288, Oak Ridge National Laboratory, Oak Ridge, TN, January 2011.
- J.-A. J. Wang, H. Wang, T. Tan, H. Jiang, T. Cox, and Y. Yan, “Progress Letter Report on U Frame Test Setup and Bending Fatigue Test for Vibration Integrity Study (Out-of-Cell Fatigue Testing Development–Task 2.2),” ORNL/TM-2011/531, Oak Ridge National Laboratory, Oak Ridge, TN, January 2012.
- J.-A. J. Wang, H. Wang, T. Cox, and Y. Yan, “Progress Letter Report on U-Frame Test Setup and Bending Fatigue Test for Vibration Integrity Study (Out-of-Cell Fatigue Testing Development–Task 2.3),” ORNL/TM-2012/417, Oak Ridge National Laboratory, Oak Ridge, TN, August 2012.
- J.-A. J. Wang, H. Wang, and Ting Tan, “An Innovative Dynamic Reversal Bending Fatigue Testing System for Evaluating Spent Nuclear Fuel Rod Vibration Integrity or Other Materials Fatigue Aging Performance,” ORNL Invention Disclosure 201102593, DOE S 124,149, April 8, 2011, Patent in review, 13/396,413, February 14, 2012.
- H. Wang, J.-A. J. Wang, T. Tan, H. Jiang, T. S. Cox, R. L. Howard, B. B. Bevard, and M. E. Flanagan, “Development of U-frame Bending System for Studying the Vibration Integrity of Spent Nuclear Fuel,” *Journal of Nuclear Materials* 440, 201–213 (2013).
- J.-A. J. Wang, H. Wang, B. B. Bevard, R. L. Howard, and M. E. Flanagan, “SNF Test System for Bending Stiffness and Vibration Integrity,” *International High-Level Radioactive Waste Management Conference*, Albuquerque, NM, April 28–May 2, 2013.
- J.-A. J. Wang, H. Wang, T. Cox, and C. Baldwin, “Progress Letter Report on Bending Fatigue Test System Development for Spent Nuclear Fuel Vibration Integrity Study (Out-of-Cell Fatigue Testing Development–Task 2.4),” ORNL/TM-2013/225, Oak Ridge National Laboratory, Oak Ridge, TN, July 2013.
- J.-A. J. Wang, H. Wang, B. B. Bevard, R. L. Howard, and M. E. Flanagan, “Reversible Bending Fatigue Test System for Investigating Vibration Integrity of Spent Nuclear Fuel During Transportation,” *Proceedings of the 17th International Symposium on the Packaging and Transportation of Radioactive Materials* PATRAM 2013, San Francisco, CA, August 18–23, 2013.
- J.-A. J. Wang and H. Wang, “Progress Letter Report on Reversal Bending Fatigue Testing of Zry-4 Surrogate Rod (Out-of-Cell Fatigue Testing Development–Task 2.4),” ORNL/TM-2013/297, Oak Ridge National Laboratory, Oak Ridge, TN, August 2013.
- J.-A. J. Wang and H. Wang, 2014 Semi-Annual Progress Letter Report on Used Nuclear Fuel Integrity Study in Transportation Environments, ORNL/TM-2014/63, April 2014
- J-A Wang, H. Jiang, and H. Wang, “Using Surrogate Rods to Investigate the Impact of Interface Bonding Efficiency on Spent Nuclear Fuel Vibration Integrity,” ORNL/TM-2014/257, July 2014.
- J-A Wang, H. Jiang, and H. Wang, “The Impact of Interface Bonding Efficiency on High Burn-up Spent Nuclear Fuel Vibration Integrity,” ORNL/TM-2014/288, August 2014.

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



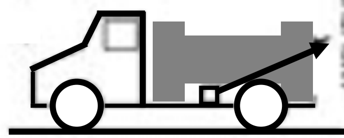
Fracture Surface Sample S2A

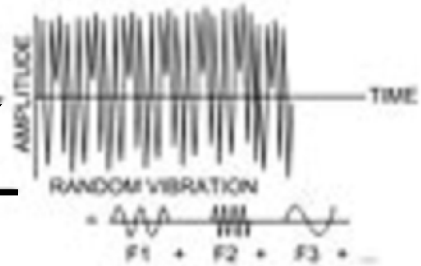

Rod E02-605 Average Rod Burnup: 66.5 GWd/MTU
Span 1 Oxide (µm) Peak 42 Ave. 31
Span 2 Oxide (µm) Peak 56 Ave. 47
Span 3 Oxide (µm) Peak 75 Ave. 65
Span 4 Oxide (µm) Peak 102 Ave. 87
Span 5 Oxide (µm) Peak 112 Ave. 107
Span 6 Oxide (µm) Peak 83 Ave. 59
No. 1
No. 5
No. 6
No. 4
Rod E14-606 Average Rod Burnup: 66.819 GWd/MTU
Span 1 Oxide (µm) Peak 42 Ave. 33
Span 2 Oxide (µm) Peak 57 Ave. 49
Span 3 Oxide (µm) Peak 75 Ave. 64
Span 4 Oxide (µm) Peak 105 Ave. 89
Span 5 Oxide (µm) Peak 110 Ave. 102
Span 6 Oxide (µm) Peak 72 Ave. 58
No. 9
No. 11
Rod R05-609 Average Rod Burnup: 66.526 GWd/MTU
Span 1 Oxide (µm) Peak 37 Ave. 28
Span 2 Oxide (µm) Peak 56 Ave. 47
Span 3 Oxide (µm) Peak 75 Ave. 64
Span 4 Oxide (µm) Peak 94 Ave. 85
Span 5 Oxide (µm) Peak 109 Ave. 100
Span 6 Oxide (µm) Peak 72 Ave. 61
No. 10
No. 7
No. 8
Rod F07 Average Rod Burnup: 63.755 GWd/MTU
Span 1 Oxide (µm) Peak 40 Ave. 30
Span 2 Oxide (µm) Peak 63 Ave. 53
Span 3 Oxide (µm) Peak 78 Ave. 70
Span 4 Oxide (µm) Peak 101 Ave. 90
Span 5 Oxide (µm) Peak 108 Ave. 100
Span 6 Oxide (µm) Peak 79 Ave. 53
No. 2
No. 12
Rod G10 Average Rod Burnup: 63.838 GWd/MTU
Span 1 Oxide (µm) Peak 35 Ave. 31
Span 2 Oxide (µm) Peak 49 Ave. 44
Span 3 Oxide (µm) Peak 65 Ave. 56
Span 4 Oxide (µm) Peak 89 Ave. 77
Span 5 Oxide (µm) Peak 96 Ave. 87
Span 6 Oxide (µm) Peak 65 Ave. 44
No. 3


Average Curvature (1/m)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1.00E+03
1.00E+04
1.00E+05
1.00E+06
1.00E+07
Cycles to Failure
No. 10
No. 12
No. 1
No. 8
No. 2
No. 11
No. 7
No. 4
No. 6
No. 9
No. 5
No. 3

Background

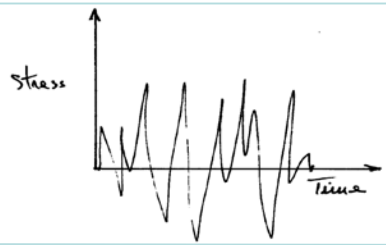
A transportation cask will experience some level of oscillation due to normal conditions of transport.



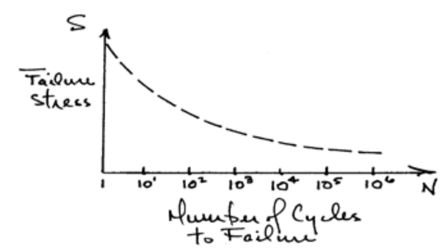


That oscillation will be transmitted in some way to the contents of the cask, the fuel elements.

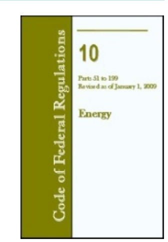
The oscillation transmitted to the fuel elements will result in local stresses



The fuel cladding has the potential for fatigue failure if a large number of cycles are seen during transport, even if the maximum stresses seen by the cladding are far below the yield stress of the material. High burnup material in particular may be highly brittle. In addition, it is not clear how the ceramic fuel will effect the potential for cladding failure.



Current regulation state: “Evaluation of each package design under normal conditions of transport must include a determination of the effect on that design of the conditions and tests specified in this section” 10 CFR 71.71(c)(5) specifies the condition: “*Vibration.* Vibration normally incident to transport.”



High Burnup Licensing for Storage and Transportation

Kristopher Cummings
Sr. Project Manager, Used Fuel Programs
kwc@nei.org

June 8th, 2015 • ACRS Subcommittee

Industry Comments Overview

- New requirements are being stipulated in the RIS
- Approach is based on laboratory experiments that are not representative of spent fuel assemblies
  - Ring compression testing of defueled cladding does not account for benefit of fuel-clad bond or presence of the fuel pellet.
  - Insufficient stresses in storage and transportation to cause significant fuel reconfiguration.
- Clarification needed that this is only applicable for license renewal (not initial license period) and accident conditions of transport
- The RIS is premature and licensing approach needs to be risk-informed
- The RIS needs to rely on ISG-24 as the principle basis for storage and transportation of high burnup fuel.

Regulatory Requirements

- Storage - 10CFR72.122(h):
  - "The spent fuel cladding must be protected during storage against degradation that leads to *gross* ruptures or the fuel must be otherwise confined such that degradation of the fuel during storage will not pose *operational safety problems* with respect to it's removal from storage"

How are Regulatory Requirements Met?

- Storage:
  - Inert environment (i.e., helium)
  - Limited/no residual water via established drying process
  - Basket/canister design prevent significant fuel movement
  - Limitation of the peak clad temp below 400°C (realistically much lower)
  - Natural events fail to cause significant stresses on the fuel
  - Confinement boundary prevents water ingress

Regulatory Requirements

- Transportation - 10CFR71.55(d)(2):
  - "The geometric form of the package contents would not be *substantially* altered under normal conditions of transport described in 10CFR71.71"

How are Regulatory Requirements Met?

- Transportation:
  - Inert environment (i.e., helium)
  - Limited/no residual water via established drying process
  - Containment boundary and canister independently prevent water ingress (moderator exclusion)
  - Limitation of the peak clad temp below 400°C (realistically much lower)
  - Impact limiters reduce stresses on package and contents during hypothetical accident conditions to prevent substantial alteration

Ongoing Research

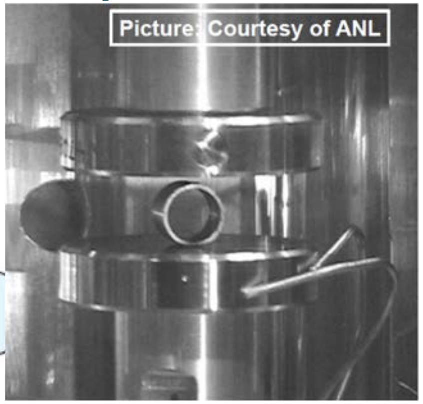
- Sandia studies on loads during normal conditions of transport, fuel assembly shaker table experiments.
- DOE/EPRI demonstration program to provide additional verification for high burnup fuel.
- ORNL fatigue testing of high-burnup fuel (including fueled cladding segments).

RIS is Premature

- First high-burnup fuel loaded into dry cask storage in 2004 (period of extended operation not until 2024).
- No current location to transport fuel.
- DOE/EPRI High Burnup Research and Development Project will garner gas sampling data in 2017, additional hot cell data in the future.

Risk-Informed Perspective

- Risk-informed perspectives and risk analysis continually show low risks
  - EPRI and NRC Dry Storage PRAs conducted in 2007
  - Annual cancer risk between 1.8E-12 and 3.2E-14 *



High Burnup Fuel is Likely NOT Brittle

- EPRI Results
  - Best estimate: No or little re-orientation should be expected during dry storage
    - Consequence: no unexpected behavior during storage and transportation

- Fuel and cask/canister internals issue: "significant" fuel geometric rearrangement?
  UNLIKELY EVEN FOR ACCIDENT CONDITIONS

Radionuclide release (if any) due to loss of confinement is a slow, low health consequence process

* Compares to 2E-6 LCF/yr. public & 1E-5 LCF/yr . worker thresholds of negligible risk from NRC's framework for "Risk-Informed Decision-making for Nuclear Material and Waste Applications", Revision 1, February 2008

Link to Retrievability

- Retrievability
  - Framework for retrievability should focus on the dry storage system to perform the safety function, with cladding as defense in depth
  - Technologies exist today to handle fuel with gross ruptures or structural defects without impact on worker or public safety.
  - A revised performance-based and risk-informed definition for "canister-based" retrievability needs to be established; NRC efforts currently underway to allow canister based retrievability

Summary

- Draft RIS is premature (additional data to become available in near future)
  - Previous experimental tests were not representative of actual spent fuel
  - Newer studies are showing that high burnup fuel is not significantly different (high burnup fuel may actually be better – as seen in operation through lower fuel leaker rate)
  - DOE/EPRI HBRDP will provide confirmatory data
- Returning to a canister based retrievability definition is consistent with a risk-informed framework.
- Need to adhere to the actual words contained in the Code of Federal Regulations – no extra-regulatory requirements or interpretations
- Current cask designs and loading operations already provide reasonable assurance that fuel assemblies will be protected against significant degradation.