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:	Thursday, August 22, 2019

Work Order No.: NRC-0509 Pages 1-149

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

DISCLAIMER

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

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

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

UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

+ + + + +

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

(ACRS)

+ + + + +

METALLURGY AND REACTOR FUELS SUBCOMMITTEE

+ + + + +

THURSDAY

AUGUST 22, 2019

+ + + + +

ROCKVILLE, MARYLAND

+ + + + +

The Subcommittee met at the Nuclear Regulatory Commission, Two White Flint North, Room T2B10, 11545 Rockville Pike, at 8:30 a.m., Ronald G. Ballinger, Chairman, presiding.

COMMITTEE MEMBERS:

RONALD G. BALLINGER, Chair

WALTER L. KIRCHNER, Member

JOSE MARCH-LEUBA, Member

DAVID PETTI, Member*

JOY L. REMPE, Member

PETER RICCARDELLA, Member

DESIGNATED FEDERAL OFFICIAL:

CHRISTOPHER BROWN

ALSO PRESENT:

TAE AHN, NMSS
KRISTINA BANOVAC, NMSS
GORDON BJORKMAN, NMSS
JIMMY CHANG, NMSS
ALADAR CSONTOS, EPRI
ROBERT EINZIGER, NRC Consultant
DONNA GILMORE, Public Participant*
ACE HOFFMAN, Public Participant*
ANDREA JENNETTA, Platts
MARVIN LEWIS, Public Participant*
TIM McCARTIN, NMSS
ROD McCULLUM, NEI

ALSO PRESENT (CONTINUED):

DAVID McINTYRE, OPA
JOHN McKIRGAN, NRC
DANIEL OGG, NWTRB
WENDY REED, NRC
CHRISTOPHER REGAN, NMSS
DON SAFER, Public Participant*
DAVID TANG, NMSS

RICARDO TORRES, NMSS

KEITH WALDROP, EPRI

BERNARD WHITE, NRC

VERONICA WILSON, NMSS

JOHN WISE, NMSS

*Present via telephone

CONTENTS

P R O C E E D I N G S

8:31 a.m.

CHAIR BALLINGER: (presiding) Good morning. The meeting will now come to order.

This is a meeting of the Metallurgy and Reactor Fuel Subcommittee of the Advisory Committee on Reactor Safeguards. I'm Ron Ballinger, Chairman of the Subcommittee.

Members present are Walt Kirchner, Pete Riccardella, Joy Rempe, and Jose March-Leuba. Member Dave Petti is also present, but on the phone.

Chris Brown is the Designated Federal Official for this meeting.

The purpose of today's meeting is for the Subcommittee to receive a briefing on staff's development of NUREG-2224, Dry Storage and Transportation of High Burnup Spent Nuclear Fuel. Today, we have members of the NRC staff and industry to brief the Subcommittee.

The ACRS was established by statute and is governed by the Federal Advisory Committee Act, FACA. That means that the Committee can only speak through its published letter reports. We hold meetings to gather information to support our deliberations.

Interested parties who wish to provide

comments can contact our office requesting time. That said, we've set aside 10 minutes for comments from members of the public attending or listening to our meeting. Written comments are also welcome.

The meeting agenda for today's meeting was published on the NRC's public meeting notice website as well as the ACRS meeting website. On the agenda for this meeting and on the ACRS meeting website are instructions on how the public may participate. No request for making a statement to the Subcommittee has been received from the public.

A transcript of the meeting is being kept and will be made available on our website. Therefore, we request that participants in this meeting use the microphones located throughout the meeting room when addressing the Subcommittee. Also, we remind you to make sure the little green light is on when you're talking; otherwise, nobody will hear you. Participants should first identify themselves and speak with sufficient clarity and volume so they can be readily heard. Also, silence any devices that make noises unexpectedly because we will hear them.

We have a bridgeline established for the public to listen to the meeting. To minimize disturbance, the public line will be kept in listen-in-only mode.

Okay. We'll now proceed with the meeting. I should note that the staff has not requested a letter from the ACRS based on this meeting. However, as you all know, subcommittees can be unpredictable from time to time, and so, that's for the Subcommittee to decide to recommend or not to the full Committee.

We'll now proceed with the meeting and we'll ask Chris Regan, Deputy Director of Spent Fuel, for introductory remarks to make before we begin today's presentations.

Chris?

MR. REGAN: Thank you, Mr. Chairman.

Thank you for the opportunity for the staff to come and talk to you about one of our technical efforts. I'd like to confirm we are not requesting a letter, but if that's the decision of the Board, by all means, that's at your discretion. We would also be more than willing to entertain any feedback or your perspectives, as is always.

I'd like to introduce two members of my staff who will be providing the technical presentation to you today. Dr. Ricardo Torres and Dr. Gordon Bjorkman will each speak about aspects of our work behind development of this particular NUREG.

In a big-picture sense, the purpose of our being here is to provide you a status update of the staff's efforts to address a technical gap with respect to storage and transportation of high burnup spent nuclear fuel.

We have over many of the last several years been requested by cask designers and licensees for regulatory guidance with respect to structural integrity issues on high burnup spent nuclear fuel under both storage and transportation conditions, and this effort is in the interest of filling one of those gaps.

The device or mechanism we're filling that gap is this draft NUREG-2224, and it provides regulatory guidance on how to address a particular aspect of storage and transportation of high burnup spent nuclear fuel, based on test results, analysis, and content of a draft regulatory information summary that we had promulgated in the past.

Next slide, please.

So, speaking of which, back in 2015, the NRC did issue a draft regulatory information summary to provide some guidance to industry on where the Agency was with respect to issues associated with high burnup spent nuclear fuel. We were, in parallel, and at that time, still conducting experiments and tests to continue development and refine our approach, our regulatory approach, on how we address these issues. This eventually got to a point where we pulled that information from the regulatory information summary and the test results and analysis and developed this NUREG-2224.

Late last year in the August timeframe, we were able to issue it for public comment. We did receive some feedback, based on the level of interest from the public for additional time to provide us comments. So, it was issued actually twice for public comment. I believe August was the first instance and, again, in October, if I'm not mistaken. You can see we received about, I would say it's over 450 comments on this particular document, of which the staff has in due diligence addressed them all.

The end state of this document is actually to reference the NUREG in our Standard Review Plan for both storage and transportation. Those are in process, nearing completion, and hopefully, at least I know the Transportation SRP was issued for public comment here and posted in The Federal Register notice quite recently, a week or so ago.

All right. Next slide, please.

I will give you a teaser about what you're going to hear from our two presenters, the two fundamentals, the big question: does high burnup negatively impact the structural behavior -- in this case, hydride reorientation -- of spent nuclear fuel when subjected to normal and accident conditions at loads for storage and transport? That was the crux of what we were attempting to address.

After the testing and the analysis, two key aspects that we were able to conclude from that: we were able to confirm that our current analytical approaches for evaluating high burnup spent nuclear fuel are conservative. And secondly, we were able to improve on our existing technical bases and support the conclusion that radial hydride reorientation will not compromise high burnup spent nuclear fuel cladding integrity during transportation and dry storage for up to 60 years.

And with that, I would like to turn it over to Dr. Bjorkman, who will talk about our testing methodology and the details of how we developed the data.

Thank you.

MEMBER REMPE: So, could I interrupt? Because I think this question may take a while to get an answer to. Are you aware of NUREG/CR-7260 by Alden Research Laboratory and its findings? It's titled, "A CFD Validation of the Vertical Dry Cask Storage System". And I came across it because of some other work ACRS does.

In there, it has here about that, "Even though this validation" -- it's talking about the High Burnup Project -- and it says, "Even though this validation was worth the time and the effort, the experiments can't be classified as a CFD grade experiment due to lack of geometry specifications, which resulted in large validation uncertainty."

And I'm kind of struggling, when I was reading all the information for this meeting, with this other report that was sponsored by the NRC to complete. And if you could have some people try to explain that this conclusion doesn't impact the findings we're going to be hearing today, I would like to hear it.

MR. REGAN: So, I would offer perhaps, during the course of the presentation, there may be identified differences between the two, the intent of the two reports.

MEMBER REMPE: That would be good.

MR. REGAN: As we work through it, maybe

that will become apparent.

MEMBER REMPE: Okay. That would help, because I figured this would be bad to throw at you --

MR. REGAN: Could you repeat the number of the NUREG/CR?

MEMBER REMPE: Sure. Let me get to the top of the report because I don't remember those kind of things very well. NUREG/CR-7260, issued May 2019.

Thanks.

CHAIR BALLINGER: And again, before we get started, I'll put you on the spot. Can you back up one slide? Sixty years, is there any difference between 60 and 80 or 100?

MR. BJORKMAN: The scope of the scenaric was specifically up to 60 years.

CHAIR BALLINGER: I'm not asking that question. I'm asking your opinion. If you store a fuel for 60 years, it's dead cold by the time. So, is anything going to change between 60 and beyond?

MR. BJORKMAN: So, the technical analysis that we performed for licensing under Part 72 have been done to 60 years. Then, after that, the continuous storage rule has been to generate an Environmental Impact Statement that has looked at longer periods of time. But --

CHAIR BALLINGER: Sufficiently evasive.

MR. BJORKMAN: -- I don't like to speculate at this point.

(Laughter.)

MR. REGAN: Yes, I would also offer that. The 60 years is a licensing timeframe.

MR. BJORKMAN: That's correct.

MR. REGAN: That is the extent to which we license for storage, up to 60 years, and that's basically the basis for that number.

CHAIR BALLINGER: Okay.

MR. BJORKMAN: Okay. The primary safety objective for the structural performance of spent fuel under normal conditions of transport and hypothetical accident conditions is to maintain the analyzed configuration of the fuel.

Static bending and fatigue testing, the purpose was to determine the behavior of high burnup fuel in static bending tests and in fatigue tests. The objective was to answer two questions. Will the high burnup fuel rod fracture during the hypothetical accident event, leading to possible fuel reconfiguration?

MEMBER MARCH-LEUBA: That microphone doesn't work. I stand corrected.

(Laughter.)

MR. BJORKMAN: Okay. So, with that puff of wind, the objective again, to answer two questions. Will the high burnup fuel rod fracture during hypothetical accident conditions event, causing possible fuel reconfiguration? And can fuel be transported under normal conditions of transport without failing by fatigue?

Now, to answer these questions required the testing of fully fueled rods to account for the interaction of the fuel pellets with the cladding. To perform the static bending and fatigue testing, the NRC worked with Oak Ridge National Laboratory to develop the CIRFT testing apparatus, which applies a constant bending moment to the fuel rod, the bending moment being equal to P times L.

So, the fuel rod is secured at the bottom of the two vertical legs. The P load is applied. The bending moment is P times L, and it gives a constant curvature to the fuel rod.

As you can see on the following slide, when the P load is inward, you can see that the rod deflects downward. When the P load is outward, the rod is going to curve upward.

So, we subject a fully fueled rod to

constant bending moment.

MEMBER MARCH-LEUBA: Gordon, I'm a little confused. Those are an experimental setup they used in Oak Ridge. It has nothing to do with the cask, right?

MR. BJORKMAN: Correct.

MEMBER MARCH-LEUBA: Okay.

MR. BJORKMAN: Right. This is an experimental setup.

MEMBER MARCH-LEUBA: All right.

MR. BJORKMAN: And you'll see that on the next slide.

Now this produces a circular arc with constant curvature K, where K is 1 over R, where R is the radius of the circular arc. Now the location -- that is, the displacement -- of three points on a circular arc defines the radius R of the circle. The flexural rigidity, the bending stiffness of the rod, EI -- E being the modulus of elasticity, I being the moment of inertia -- is equal to the slope of the moment curvature diagram.

Okay. This is the actual CIRFT instrument. The fully developed instrument is on the slide or the picture to the extreme right. You can see that the load cells apply both inward and outward loads. Those are the green arrows. And you see that, at the location of the fuel rod, the fuel rod -- it says, "test segment," -- the location of the test segment is under there. And you can see that there are three displacement transducers, and these displacement transducers measure the displacement at three points along the circular arc. And from those displacements, we can then calculate the radius of the circular arc, and therefore, the curvature.

Now the photograph on the left is the surrogate fuel rod with its heavy end caps, which are then basically gripped by the machine, and the moment is applied directly to those end pieces. And that produces a constant bending moment in the fuel rod.

MEMBER RICCARDELLA: What's the length of the rod being tested?

MR. BJORKMAN: It's probably on the order of about 2 inches. The overall length is on the order of about 6 inches.

So, the materials that were tested. PWR spent nuclear fuel, Zirc-4 cladding. Burnups ranged from 63.8 to 66.8 gigawatt days per metric ton uranium.

Phase 1 testing, non-reoriented high burnup samples with only circumferential hydrides.

The photograph on the upper right shows cladding with only circumferential hydrides. Four static bend tests were conducted and 16 vibration fatigue tests had a wide range of bending moment amplitudes.

In Phase 2, reoriented high burnup samples had circumferential and radial hydrides. So, you see the mix on the photograph at the bottom right, a mix of circumferential and radial hydrides. Now the reoriented high burnup samples, only one static bend test was done, and it's designated as HR2, and three vibration fatigue tests had a range of bending moment amplitudes.

MEMBER RICCARDELLA: What do you mean by "reoriented"?

MEMBER MARCH-LEUBA: You can use the mouse to point. It will help us a lot. It should be over there on the blue pad.

MR. TORRES: So, actually, I have a slide later on about this. But, just to provide a little perspective, during reactor operations you have water -side corrosion of the cladding. And therefore, you have hydrogen pickup. During reactor operation, you have a high reactor overcoolant pressure that creates compressive stresses on the cladding, and that leads primarily to the precipitation of excess hydrogen,

hydrogen beyond the solubility limit in the circumferential axial direction, which is what you see on the top right image here.

Now you take that fuel out, move it to the spent fuel pool. You subject it to drying operations where you don't have the reactor overcoolant pressure. And now you have a vacuum drying operation. Now you have tensile stresses. The cladding temperature rises and the solubility in the hydrogen increases with temperature. The hydrogen dissolves. As it cools down the fuel, it reprecipitates, but because of the tensile stresses, it precipitates now, it can precipitate in a different orientation than the radial axial orientation. So, that's what we're discussing here, the reorientation from the circumferential on this side to a mixture of circumferential and radial after drying operations for transport and storage.

MEMBER RICCARDELLA: You say "radial," but axial, too, right?

MR. TORRES: Yes.

MEMBER RICCARDELLA: Radial/axial, right?

MR. TORRES: Yes. So, there is a distribution. It fluctuates. I mean, these are platelets and they fluctuate in various directions, but, as you see here, you have more in the radial orientation after drying operations. And here you have circumferential orientation.

MEMBER RICCARDELLA: It's all basically laminar.

MR. TORRES: In Chapter 1 of NUREG-2224, we provide an extensive discussion on what factors lead to that. Fabrication of the cladding is one.

MEMBER RICCARDELLA: Thank you.

MEMBER MARCH-LEUBA: Is it a typical time constant migrating from top to bottom, from circumferential to radial, or it's just random? Does it happen in a week or do you need 25 years?

MR. TORRES: So --

MEMBER MARCH-LEUBA: Or it's related to the temperature change that you --

MR. TORRES: It is related to the temperature change. It's also related to the amount of hydrogen present in the cladding, whether or not you have existing circumferential hydrides that can aid in denuclearization, you know, and growth.

For instance, in 5, you have much less hydrogen. Therefore, you have a higher susceptibility to reorientation because all the hydrogen goes into solution.

MEMBER MARCH-LEUBA: Is it in 5?

MR. TORRES: Yes.

MEMBER RICCARDELLA: Am I misreading the diagram or is it those radial hydrides or cracks are basically on the inside surface of the --

MR. TORRES: Yes. So, I'd like to highlight these are not cracks. I want to make sure that, for the interest of everyone listening, yes, so these are not cracks. So, these are metallographic cross-sections etched. And what you see there is the different refractive indexes of the different materials. So, these are hydrides over here --

MEMBER RICCARDELLA: Yes, yes, yes.

MR. TORRES: -- zirconium hydrides. And the rest are just the zirconium alloy.

MEMBER RICCARDELLA: But the initiate on the inside surface, it looks like? The reorientation looks, just from the curvature on the top there, it looks like that's the inside surface.

MR. TORRES: It can vary. It can vary. It just also depends on where the hydrogen has primarily precipitated at and where it's located.

MEMBER RICCARDELLA: Okay.

MR. TORRES: Yes.

MEMBER RICCARDELLA: Thank you.

MR. TORRES: You're welcome.

MR. BJORKMAN: Great. Next.

Okay. The static test results. The non-reoriented tests, the S1, S2, S3, and S4, these are only the circumferential hydrides. And you can see how those, basically, the moment curvature diagrams looks for those.

You see also that we have the solid red line which is the reoriented HR2, which is the specimen with both radial and circumferential hydrogen hydrides. And we also have a cladding-only. That is, no fuel in the cladding, only the cladding. And you can see that the slope of the moment curvature diagram is significantly less. So, the flexural rigidity is significantly less, and we can see that the fuel has stiffened the fuel rods significantly from the cladding-only response.

MEMBER RICCARDELLA: It almost looks like you have some hysteresis in that curve. What causes that, that non-linear hysteresis?

MR. BJORKMAN: Well, that's because it's unloading.

MEMBER RICCARDELLA: Loading/unloading, yes.

MR. BJORKMAN: Yes. We can only take this to a certain curvature because of the fact that the test apparatus is limited in its displacement capability.

MEMBER RICCARDELLA: Yes, yes.

MR. BJORKMAN: So, we could not take it up -- for example, it looks like these curves want to go up to at least 100 newton meters or more perhaps. But the apparatus itself would not allow that happen. So, we were limited by the displacement of the apparatus.

MEMBER RICCARDELLA: But you did get non-linear behavior?

MR. BJORKMAN: Yes, correct. Correct.

MEMBER RICCARDELLA: Which -- okay.

MR. BJORKMAN: Do you have another question or? Okay.

Now the static test results show that at bending moments less than 35 newton meters, the flexural rigidity of the four as-irradiated rods, which have only circumferential hydrides, and HR2, which has both circumferential and radial hydrides, are essentially the same.

Now this supports the pre-test expectation that, because the bending tensile stresses in the cladding are parallel to the plane of both the radial and circumferential hydrides, the presence of the radial hydrides would not significantly alter the flexural response.

Let me show you exactly what I mean. Let's say these two pieces of wood are cladding. In between the cladding is a hydride. Okay? That's the precipitated hydrogen. There it is. And it is a weak link within the cladding. And if I apply tensile stresses perpendicular to the plane of the hydride, I'm going to get failure cracking. If I apply tensile stresses parallel to the plane of the hydride, the strength doesn't change. And if I reorient it to the radial direction, it's not going to change, either. So, because the tensile stresses are applied parallel to the plane of the hydride, the specimens with radial hydrides and circumferential hydrides perform equally as well as those with only circumferential hydrides.

MEMBER RICCARDELLA: In the non-fuel world, it's what we call laminations.

(Laughter.)

MR. BJORKMAN: Yes.

MEMBER RICCARDELLA: Yes.

MR. BJORKMAN: Exactly.

MEMBER MARCH-LEUBA: How sensitive were your samples? I mean, you only picked four samples, right? And were they treated with a temperature transient to optimize the radial or were, yes, picked out at random, whatever happened to the PNNL?

MR. TORRES: Yes. So, we actually chose a very conservative approach because we had a limited number of samples. So, as you saw, the burnup ranges of the segments, the average rod segments were the burnup range between 63 and 68, which is very high.

MEMBER MARCH-LEUBA: Yes.

MR. TORRES: And the hydrogen concentration was well above 400, close to 500 parts per million per weight. We think that that's very representative and bounding to most cladding alloys. And not just that, but we subjected the segments to a radial hydride treatment which simulated five drying cycles. Generally, you only have one drying cycle. So, we simulated five drying cycles, just to entice, just to try to simulate --

MEMBER MARCH-LEUBA: So, you exaggerated the temperature transients to maximize radial --

MR. TORRES: That's correct. and we also chose a very conservative bounding hoop stress as well, 140 megapascals. And that's also discussed in the report.

MEMBER MARCH-LEUBA: Okay. So, they're not only representative, they're bounding?

MR. TORRES: That's correct.

MEMBER MARCH-LEUBA: Or likely bounding?

MR. TORRES: Yes.

MEMBER RICCARDELLA: I thought of the question I wanted to ask on the previous slide. Could you go back to that for a second?

So, you talked about how there's essentially no difference in behavior up to 30 newton meters.

MR. TORRES: Thirty-five, yes.

MEMBER RICCARDELLA: I presume that, up to that point, if you had unloaded from there, you would go straight back down the same line? You wouldn't have this hysteresis effect, correct, because it's still --

MR. TORRES: Yes, because it didn't go non-linear.

MEMBER RICCARDELLA: It didn't go non-linear, yes.

MR. TORRES: Yes.

MEMBER RICCARDELLA: Okay. Thank you.

CHAIR BALLINGER: And these are all Zircaloy-4 samples?

MR. TORRES: Correct.

CHAIR BALLINGER: So, you would expect M5 to be better?

MR. TORRES: Well, M5 --

CHAIR BALLINGER: Or whatever, non-Zircaloy-4, let's put it that way.

MR. TORRES: Yes. So, Zircaloy, we expect generally has comparable hydrogen content to Zircaloy-4; M5 is going to have lower hydrogen content, and then Zircaloy-2 is also likely to have lower hydrogen content. So, we think it's a good representative bounding case.

MR. BJORKMAN: Okay. What I would like to do is look at a fuel rod safety margin against failure for a hypothetical accident condition side drop event. And you see the side drop event and you see that the fuel assembly and the rods are subjected to significant G loads, and that's going to produce rather high bending moments in the fuel rods.

Now the cask body of the transportation package typically sees about 50 G's on impact in a side drop. Fifty G's is about what the number is. That's the cask body.

Now the flexible fuel assembly and fuel rods experience a lot more than that. They're going to experience about 100 G's. And that's because we multiply the 50 G's by a dynamic load factor. Now what is this dynamic load factor?

If I have a 2x6 spanning 6 feet and I've got two bricks on either side simply supported. I stand in the middle and I measure the displacement, and I get 2 inches. Now I pull myself up on a bar, so that all my weight is hanging and my toes are just touching the plank, and then I let go. Now I'm applying the same load, but dynamically, and we measure 4 inches of displacement. So, that's the dynamic load factor, the difference or the ratio of the dynamically-applied load or the displacement from the dynamically-applied load versus the statically-applied load.

So, the fuel rod itself is going to see about 100 G's. Now, for the fuel rods that we evaluated, the static transverse G load required to produce 1 newton meter of moment varied from about 2.9 to 4.6 G's, depending on the rod cross-section and the assembly geometry.

So, we take the 100 G's, divide that by the smaller number, 2.9, we end up with about 34 newton meters. So, that's the maximum expected bending moment due to this side drop event in a fuel rod.

CHAIR BALLINGER: Now you're expecting that that fuel rod is fixed?

MR. BJORKMAN: No, I'm -- that it is supported as multiple supports over grid spacers.

CHAIR BALLINGER: But those grid spacers have springs.

MR. BJORKMAN: That's correct, but in this analysis we did not incorporate the springs.

CHAIR BALLINGER: Okay. And that would decrease --

MR. BJORKMAN: Correct.

CHAIR BALLINGER: So, this is conservative?

MR. BJORKMAN: Correct.

CHAIR BALLINGER: So, probably considerably conservative?

MR. BJORKMAN: Yes, it is.

MEMBER RICCARDELLA: So, you know, I understand well the dynamic load factor of 2 for a suddenly-applied load. But, on your example, if I had chinned myself up a little bit and picked myself a few inches off the beam, and then let go, you could get a DLF as high as 4, right, if --

MR. BJORKMAN: Yes, but that's because you have --

MEMBER RICCARDELLA: Does that apply --

MR. BJORKMAN: That's because you have a

gap.

MEMBER RICCARDELLA: Yes.

MR. BJORKMAN: And that's not going to apply to these rods necessarily. If you have a gap --

MEMBER RICCARDELLA: Yes.

MR. BJORKMAN: -- and then you apply the load, or you drop it --

MEMBER RICCARDELLA: Yes.

MR. BJORKMAN: -- it's going to fall, so the potential energy is much greater because you have this gap.

MEMBER RICCARDELLA: Right, right, right.

MR. BJORKMAN: It's falling from a --

MEMBER RICCARDELLA: Yes. And why doesn't that happen when you drop a cask?

CHAIR BALLINGER: Because of the springs.

MEMBER RICCARDELLA: Okay.

MR. BJORKMAN: This analysis has assumed that there are no springs at the grid spaces.

MEMBER RICCARDELLA: Gaps.

MR. BJORKMAN: It's just rigidly supported at the grid spaces. But it's a continuous beam supported at multiple locations.

MEMBER RICCARDELLA: Yes. Okay. So, no gaps?

MR. BJORKMAN: It's a very conservative analysis.

MEMBER RICCARDELLA: With no gap?

MR. BJORKMAN: With no gap.

MEMBER RICCARDELLA: But the springs don't make an effective gap?

MR. BJORKMAN: Well, the springs, I mean, you would have to do a rather detailed finite element analysis to actually figure out exactly --

MEMBER RICCARDELLA: I understand.

MR. BJORKMAN: -- what the response is.

MEMBER RICCARDELLA: Yes, I mean, I just wonder, if you could get a dynamic load factor a little bit higher than 2.

MEMBER MARCH-LEUBA: Well, those springs are probably going to act like the famous car crashing against a wall. I mean, at the 100 G's, they're going to collapse.

MEMBER RICCARDELLA: Yes. And they're probably -- yes.

MEMBER MARCH-LEUBA: They absorb much of the energy. But I was thinking, what's the effect of the other rods that fall into the bottom one? And maybe additional elements if they're on top? Would that add load?

MR. BJORKMAN: Well, what's going to happen, then you have the potential for pinch loads. But here what we're doing is we're saying, what is the bending moment that I can expect to get, the largest bending moment?

MEMBER RICCARDELLA: And you're saying it's about 30 --

MR. BJORKMAN: And it's about 34.

MEMBER RICCARDELLA: I presume the cask benders are doing these detailed finite element analyses of cask drop-backs and determining what the actual load factor is, right? Or what the actual loading of the --

MR. BJORKMAN: Correct. Actually, Sandia has done a lot of work on this. Sandia 2406, they have a report where they go through it and they show you exactly what the bending moments are with the leaf springs in there.

MEMBER RICCARDELLA: Uh-um. Okay.

MR. TORRES: And I'll also highlight that the Department of Energy right now is doing additional testing. Actually, they've conducted significant testing to evaluate normal conditions of transport, but they've also been doing additional testing to put accelerometers and strain gauges during drop accidents, the 30-foot drop. They've been doing some testing in Germany.

MEMBER RICCARDELLA: Yes.

MR. TORRES: And those reports are coming out very soon as well.

MEMBER RICCARDELLA: Right.

CHAIR BALLINGER: Well, these tests are for, roughly, round numbers, 70 gigawatt days per metric ton. For 40, which is currently the maximum, 45, or less than 45, you get the same results if you do these tests?

MR. TORRES: Well, so 45 is a licensing threshold, if you want to call it that, that we establish here at the NRC, going from low burnup to high burnup. We specifically wanted to look at the high burnup extreme --

CHAIR BALLINGER: Right, but my question is --

MR. TORRES: I'm sorry.

CHAIR BALLINGER: -- this analysis has already supposedly been done to certify a cask for transportation at 45 or less.

MR. TORRES: So, those analyses are generally done on a case-by-case basis on each design. They do their own modeling to evaluate what are the loads for the specific --

CHAIR BALLINGER: I guess I'm coming back to the fact that, if you did the test on slide, whatever it was that Pete was talking about, for a 45 gigawatt day per metric ton, would you get the same results?

MR. TORRES: I would expect so, particularly when you're looking at the as-irradiated --

CHAIR BALLINGER: Right, yes.

MR. TORRES: -- through the hydride area of the condition.

CHAIR BALLINGER: Yes, yes.

MR. TORRES: I would expect you would get a similar response, yes. Because, clearly, the fuel pellet is imparting significant flexural rigidity.

MR. BJORKMAN: Okay. So, the safety margin is conservatively calculated to be approximately 2.35. That is, they took the maximum load or the maximum bending moment that we actually saw during the test, which was 80, even though, had we been able to go farther than that, it might have gone up to 100. But taking 80 as the maximum load or the load at failure, and then dividing that by 34, we get a safety margin of at least 2.35 against failure of the fuel rod in this drop event.

CHAIR BALLINGER: And again, these are very limited tests. Was this recrystallized Zirc or cold work?

MR. TORRES: This is Zircaloy-4, which is cold work --

CHAIR BALLINGER: Cold work.

MR. TORRES: -- stress relief --

CHAIR BALLINGER: Cold work, stress relief. And that's the dominant Zircaloy-4 cladding pellet?

MR. TORRES: Yes, that's the fabrication for Zircaloy-4, yes.

MR. BJORKMAN: Okay. The pellet-clad structure, you can see this is a longitudinal section through the Zirc-4 rods that were actually tested. You see we have the clad-pellet interface, and we also have the pellet-pellet interface. Now, because each end of the pellet is concave, you can see that we have a large gap at the pellet-pellet interface. But at the top and bottom you see that the pellets are actually in contact.

Now the region of the fuel rod weakest intention is at the pellet-pellet interface. And you can see on the diagram at the right, it's at the pellet-pellet interface that, when the pellet-pellet interface cracks in bending, the tensile stress in the cladding at the cracked face will increase significantly. So, at the cracked face, you see from the cladding stress diagram below that at the cracked face the cladding tensile stress is high, and that the high tensile stress at the cracked face decreases with distance from the crack. Thus, cladding tensile stresses will vary significantly along the length of the rod. Okay.

Now, even though this behavior is known to occur, only the average tensile-bending strain can be calculated from the static test results because the measures curvature is the integrated average curvature over the measured length, which we call the gauge length of the rod. The measured length would be between the first and the third displacement transducers. Okay.

Now the average tensile strain in the cladding, epsilon, along the gauge length is equal to the curvature multiplied by the distance to the neutral axis, which is equal to the outside radius of the rod. Now this is the convention that has been adopted here and in NUREG-7198, even though it is known that the neutral axis will vary along the gauge length. For example, at the crack the neutral axis will be almost equal to the diameter; whereas, between the cracks, the neutral axis will be approximately equal to the outside radius. Okay.

So, the cladding strain is then calculated as the curvature, which, again, is the average -- the integrated curvature over the length times the radius R. And that is the convention that has been established.

Now the calculation of cladding strain using cladding-only properties. Cladding stress and strain and flexural rigidity have always been calculated for hypothetical accident events using only the properties of the cladding, which is very conservative, because no one knew what the properties of the fuel and cladding are together. Okay.

So, applicants and the industry use only the cladding to determine the flexural rigidity and to determine the stresses and strains in the cladding. Now, to remove this conservatism, a factor was developed basic on the static test results to convert the cladding-only stress strain and flexural rigidity to the stress strain and flexural rigidity that would exist in the fully-fueled rod.

So, the equation is the EI minus the

elasticity times moment of inertia of the fully-fueled high burnup rod is equal to the EI of the cladding-only times a factor. The factor that has been conservatively calculated -- and there's a detailed discussion in the NUREG about how this factor was developed, but it was calculated very conservatively. And the factor that we came up with was 1.25.

Now, then, the curvature is M over the flexural rigidity of the high burnup rod, which when substituting is M over 1.25 IE of the cladding. So, the strain is equal to the curvature times the radius of the rod. The stress is equal to the strain times the modulus of elasticity of the cladding. And the stress and strain in the high burnup rod will be less than in the cladding-only rod. So, in the actual rod with fuel in it, the stress and strain that we calculate will be less, okay, because of the presence of the fuel.

MEMBER RICCARDELLA: I hope you don't mind us going into details.

MR. BJORKMAN: Go ahead.

MEMBER RICCARDELLA: This stuff we find real interesting, I find real interesting.

(Laughter.)

MEMBER MARCH-LEUBA: And I wonder why.

(Laughter.)

MEMBER RICCARDELLA: I can appreciate your comment about the flexural rigidity, but in terms of the strains in the clad, wouldn't that strain concentration at the crack that you showed in the previous slide, that could counter this, couldn't it?

MR. BJORKMAN: Oh, we know --

MEMBER RICCARDELLA: Yes.

MR. BJORKMAN: -- we are only calculating the average strain --

MEMBER RICCARDELLA: Yes.

MR. BJORKMAN: -- integrated over the length.

MEMBER RICCARDELLA: Yes.

MR. BJORKMAN: That's all we can calculate. So, perhaps by finite element method you could find out --

MEMBER RICCARDELLA: Yes, or strain gauges.

MR. BJORKMAN: -- what it is, yes.

MEMBER RICCARDELLA: But your tests, whatever that is, that stress-strain concentration due to the cracking, the clad separation effect, that's present in your test, right?

MR. BJORKMAN: Correct.

MEMBER RICCARDELLA: Okay. All right.

MR. BJORKMAN: That's present in the test, correct.

MEMBER RICCARDELLA: Good. Thank you.

MR. BJORKMAN: Okay, let's talk about fatigue, fatigue during normal conditions of transport. Now a transportation cask will experience some level of oscillation due to normal conditions of transport. And here we see a truck carrying a cask going down the road, and we see it's going to be subjected to vibrations. That oscillation will be transmitted in some way to the contents of the cask, that is, the fuel elements. And the oscillation transmitted to the fuel elements will result in local stresses in the fuel rods. And on the right there you see a stress time history.

So, a large number of cycles during transport may result in cladding failures due to fatigue, even if the maximum stresses are far below the yield stress of the material. Therefore, what is needed is called an S-N curve. We needed to develop the S-N curve or stress versus number of cycles to failure or strain versus number of cycles to failure. Okay.

Now the fatigue test results. At the top you see rod failure for the as-irradiated rods. That's the light blue dots, and you see where they fall. And you see the hydride reoriented rods. Three of those were tested, and those are the "X's". And you see that, basically, they're failing at approximately the same levels as the as-irradiated rods. And then, we see the red dots at the far extreme to the right; we see no failure. And these are the as-irradiated rods with no failures.

And what I've sketched in here are three line segments giving a lower bound fatigue curve. Okay. Fatigue damage rule. We're using the fatigue damage rule developed by Miner. It's a linear damage rule. And the way it works is that you sum up, for example, little n over big N, where little n supplies the number of strain cycles at strain level E sub i, so many cycles. And you divide that by the number of strain cycles to produce failure at a strain level Ei, based on the fatigue curve. So, based on the number of cycles at a given frequency and a given stress level, you add up these fractions, and if you get to 1, you have failure. If you're above 1, obviously you have failure. But you want to stay below 1. And, in fact, in the document itself we suggest using a value, rather than 1, of using .7, because based on extensive test results using Miner's Law, that the lower bound value using the linear damage rule. Okay.

MEMBER RICCARDELLA: In fact, in ASME code, we put a factor of 2 and 20 on the mean curve of the data, and then, we calculate these fatigue uses factors on that lower curve with a safety factor of 2 and 20. So, it would be --

MR. BJORKMAN: Well, the lower bound curve here --

MEMBER RICCARDELLA: This is a lower bound curve.

MR. BJORKMAN: In terms of what you want to do from a code perspective when you use these curves, you may want to do exactly what you're talking about --

MEMBER RICCARDELLA: Yes, yes.

MR. BJORKMAN: -- and identify a safety factor there. But this is just putting in some sort of a lower bound curve just to show you where it is.

MEMBER RICCARDELLA: I understand.

That brings to mind another question. Your tests with the bending moments, you said you were applying at load peak, but were the test load controlled or displacement controlled?

MR. BJORKMAN: Yes, load controlled.

MEMBER RICCARDELLA: Load controlled? Okay. But it should make no difference below -- while you're in the elastic range. But when you go non-linear, it can make a huge difference.

MR. BJORKMAN: Yes. Absolutely.

Now the NUREG-2224 provides applicants and the industry with the methodology to develop a lower bound fatigue curve from the fatigue test data and a fatigue damage rule that can be used to evaluate the accumulation of fatigue damage. So, they want to have the applicants and industry using a consistent basis for how they're evaluating fatigue and fatigue damage.

Conclusions regarding the static bending test on Zirc-4. The static test results showed that there was a significant safety margin against fuel rod failure under hypothetical accidents, side drop event. The CIRFT results for high burnup spent fuel rod specimens confirmed that hydride reorientation does not impact the fuel's flexural rigidity for expected bending moments due to drop accidents. Hydride reoriented high burnup spent nuclear fuel rods showed markedly higher bending moment resistance compared to the cladding-only response, and this proposed new approach for crediting flexural rigidity of the pellet in the drop accident safety analysis. So, that's the approach.

CHAIR BALLINGER: Yes, I need to get closure on one thing. And that is hydrides are funny things and they have a tendency to migrate down the temperature gradient. So, did you consider the fact that -- is it possible for hydride concentrations to be much higher in an unfueled portion of the rod, when you would not have fuel cladding? Or you might have dummy pellets or something like that, where you get a very different set of conditions.

MR. TORRES: The short answer to your question is no, but, as I said, DOE is conducting additional testing.

CHAIR BALLINGER: Okay.

MR. TORRES: And they are looking at the ends of the rods. They're looking at segments where there are identified pellet-to-pellet gaps. They're doing additional testing just to confirm conclusions of the NUREG, to help us confirm the conclusions of NUREG-2224.

CHAIR BALLINGER: Thank you.

MR. BJORKMAN: Okay. Conclusions regarding fatigue endurance limits. Hydride reorientation of high burnup spent nuclear fuel rods failed at similar equivalent strains of the non-reoriented high burnup fuel rods specimens. We saw that with, on the fatigue test results, the light blue and with little "x's". They were basically in the same range.

A lower bound fatigue S-N curve developed per NUREG-7198, Rev 1, results, the approach can be replicated with CIRFT test data obtained for other high burnup spent fuel cladding types. So, the same approach can be used. DOE is to acquire additional high burnup spent fuel materials performance data under their ongoing sister rod program.

MEMBER RICCARDELLA: What frequency did you do your fatigue cycle in?

MR. BJORKMAN: Five hertz.

MEMBER RICCARDELLA: Five hertz? Did you look at potential frequency dependence?

MR. BJORKMAN: We wanted to be sure that the load cells were not picking up the inertial load of the actual machine itself. So, we initially started out with a higher frequency, so we can fatigue tests up to, you know, 7 --

MEMBER RICCARDELLA: You've got to get 10 to the 7 cycles.

MR. BJORKMAN: Right, yes, yes.

MEMBER RICCARDELLA: It would take a long time at 5 hertz.

MR. BJORKMAN: Right. Exactly. But at 5 hertz, there was no inertia of the actual machine itself affecting the load cells.

MEMBER RICCARDELLA: You know, in the early days of reactor vessel fatigue testing we got fooled. This is like, you know, 30-40 years ago. We looked at frequency dependence and we found it didn't make any difference. Then, we looked at environmental dependence and we found it didn't make any difference. But you put the two together and you run low frequency in the environment, and we saw huge differences. I don't know if there's any potential effects like that here, but a lesson we learned a long time ago.

MR. BJORKMAN: Everything was run at 5 hertz. I don't know if DOE is doing anything to change that, people looking into that at all.

MEMBER RICCARDELLA: Is there any environmental fatigue aspect of this?

MR. TORRES: So, I would say that, with respect to the environment, the environment is going to be relatively constant across casks while inside, because we have defined some acceptance criteria for drying in our Standard Review Plans, since once you meet that acceptance criteria, it's going to be a backfill helium environment with --

MEMBER RICCARDELLA: Pretty much inert, an inert environment.

MR. TORRES: That's correct. That's correct.

MEMBER RICCARDELLA: Okay, good.

CHAIR BALLINGER: So, essentially, all of the usage is in the elastic range?

MR. BJORKMAN: Yes, the fatigue is in the elastic range, correct. Because, basically, we're oscillating within the elastic range.

MEMBER RICCARDELLA: Well below that 30 --

CHAIR BALLINGER: Yes, well below.

MR. BJORKMAN: Right. That 35 or 34 hertz.

MEMBER RICCARDELLA: That's because that's just doing the transportation, right? Yes, it's not the severe accident. Okay. All right. So, that's basically an endurance limit, the effect is.

CHAIR BALLINGER: I didn't want to use that word.

MEMBER RICCARDELLA: Well, you talk about fatigue usage factor. Once you get out there at 10 to the 7th and above, it's go or no go. You're either above the endurance limit or below it.

MR. BJORKMAN: Right. Now, you know, steel has an endurance limit; whereas, aluminum does not have an endurance limit. So, we don't know if --

MEMBER RICCARDELLA: Zircaloy doesn't have an endurance limit?

MR. BJORKMAN: We don't know if it does. I mean, it looks like it does.

MEMBER RICCARDELLA: Your curve looks like it does.

MR. BJORKMAN: Yes. But it's hard for us to say that without --

MEMBER RICCARDELLA: I understand, yes.

CHAIR BALLINGER: Three data points does not make it.

MR. TORRES: Yes, so I think we're running a little ahead. Shall we just keep going?

CHAIR BALLINGER: Sure.

MR. TORRES: Okay.

CHAIR BALLINGER: Unless there's some other, unless there's another reason why; we're missing a person or something like that.

MEMBER RICCARDELLA: With all these questions and discussions, we're ahead of schedule? Good job, Chairman.

MEMBER MARCH-LEUBA: You're just liking

it. This is your --

MEMBER RICCARDELLA: Pardon me?

MEMBER MARCH-LEUBA: This is your topic. You're not doing your job.

(Laughter.)

CHAIR BALLINGER: Let's do a Petti check. David, are you still there?

MEMBER PETTI: Yes.

CHAIR BALLINGER: Okay, good. Thanks.

MEMBER PETTI: I can hear very well.

CHAIR BALLINGER: Good.

MR. TORRES: Okay. So, again, my name is Ricardo Torres. I'm a Materials Engineer for the Division of Spent Fuel Management.

And now that Gordon has provided a good overview of the test results and where we stand with that, now let's jump into the document itself, which is why we're here.

So, as Chris mentioned, NUREG-2224, the draft report for comment was issued back in August of last year for a 45-day public comment period. We received multiple letters from stakeholder groups requesting additional review time. Therefore, we issued the document once again for a second period of comment. And all the comment submissions you can find via this link, the NRC's electronic reading room, or the Federal eRulemaking Portal.

So, just to provide a little bit of perspective of where I'm going with my presentation, first, I'm going to talk about why the spent fuel assembly is, maintaining the configuration of the spent fuel assembly is important for the safety analysis of transportation packages and dry storage systems; provide some perspective on how we have historically assessed cladding performance during the review process, during the safety review process; why hydride reorientation is important, and how we have addressed it in this document.

So, the structural performance of the spent fuel assembly and the cladding itself is important to make sure that the safety analysis for criticality, confirming containment, radiation shielding are all maintained. And degradation modes in spent fuel cladding are primarily driven by cladding stresses, and there is a direct correlation between the fuel temperature and the cladding stresses. And that is the metric that we have historically used at the NRC to assess the allowable cladding stresses, hoop stresses in the cladding.

So, the way we have provided guidance to applicants has been through ISG-11. That has gone through multiple revisions. We are currently at ISG-11, Revision 3. And that was issued back in 2003. That provides acceptance criteria and peak cladding temperature and thermal cycling that helps applicants just demonstrate to us that the cladding hoop stresses will be acceptable during operations.

That acceptance criteria has fed into, recently into the NUREG-2214, the MAPS report which was just recently finalized, which looks at degradation phenomena all the way to 60 years in dry storage. It feeds into this document. It feeds us an assumption in this document. And it's also moving forward into the consolidated SRPs; NUREG-2215, which will be finalized very soon, and NUREG-2216, which was just issued last week for public comment.

So, ISG-11, it's on cladding consideration. What you see here on the right side is the acceptance criterion document. It provides acceptance criteria on temperature, acceptable peak cladding temperatures for all conditions, normal conditions, short-term loading operations being 400 degrees Celsius, and for off-normal conditions and accident conditions, on your lower right. That would be 570 degrees Celsius.

MEMBER MARCH-LEUBA: That off-normal conditions includes loading when you have the cooling?

MR. TORRES: No.

MEMBER MARCH-LEUBA: That's only accidents?

MR. TORRES: Yes. Off-normal conditions are conditions that are meant to be very short. Like, for instance, you have a blockage in the vents of the dry storage system, which will be picked up and fixed relatively quickly. So, those are considered off-normal conditions.

MEMBER MARCH-LEUBA: That's anticipated occurrences, yes.

MR. TORRES: Yes, anticipated occurrences, yes.

MEMBER MARCH-LEUBA: You guys are the experts, but I only hear rumors here and there from some people in talking. People are saying that we're getting closer and closer to the 400 degrees C loading every time you do analysis. Is that the case? Is that limiting, the 400? Is that heating them?

MR. TORRES: So, historically, the 400 degrees Celsius has served us very well since 2003. But now --

MEMBER MARCH-LEUBA: Yes, but after this, can you really --

MR. TORRES: Yes, so right now we're receiving applications where the applicants are trying to be more efficient doing their heat load, on their loadings, and put in additional feeds. So, yes, we're getting a little closer to the 400 degrees Celsius. We've had some challenges with respect to that, which actually feeds into Dr. Rempe's question on this document, on this CFD validation which actually looked at the vertical dry storage system, validating the peak cladding temperatures for those systems.

MEMBER MARCH-LEUBA: So, what would it take to relax that to 425 or 450?

MR. TORRES: So, that's an upcoming effort. So, there's a couple of initiatives that we have in-house. We have now a work, starting work with Research to look adding some sort of tolerance to that 400 degrees Celsius. And what we're looking at is effectively reevaluated all the degradation phenomena that we looked at in the MAPS report, delayed hydride cracking, all these phenomena, just at slightly higher temperatures.

In addition to that, the Electric Power Research Institute -- I think it will be in October -- they're sponsoring a PIRT, a Phenomena Identification

Ranking Table, which will look beyond the tolerance that we're looking internally. So, there's not really going to be a limit on -- we have to decide that. But we're going to be a participant in that, in that PIRT exercise. So, there are efforts to look at that.

MEMBER MARCH-LEUBA: Would it make sense to have a time and temperature? I mean, it's okay to roll up to 425 as long as it's only 5 minutes because the hydride doesn't have time to move.

MR. TORRES: Yes, and creep. So, that's something that I think we can discuss with the PIRT when we meet together. There will be a report being issued, I'm sure, by EPRI and we'll have our input to say on that.

MEMBER MARCH-LEUBA: It's good to keep an open mind.

MR. TORRES: Absolutely. Absolutely, yes.

MEMBER MARCH-LEUBA: Again, I'm just learning all this in your presentation. Really, the radial hydride doesn't make any difference on the stresses. I mean, you can see on there on the first, the beginning, the first few newton meter, you don't see the difference. So, this limit of 400 is to prevent radial cracks, right?

MR. TORRES: Yes. So, I was just about to talk into that. So, ISG-11 looks at primarily two phenomena, cladding creep and hydride reorientation. Cladding creep has historically been considered as the phenomena that can lead to cladding thinning and potential cladding ruptures. And that's been really the focus.

When ISG-11 was issued back in 2003, there was not a whole lot of work on hydride reorientation back then. So, based on the technical basis of that document, we expected that, at 400 degrees Celsius, there wouldn't be a significant amount of reorientation.

But the research since then has shown that it can be fully prevented. Over the last 16 years, there's been a good amount of research done by DOE and the NRC which ultimately led us to our test program.

So, it's, yes, hydride reorientation is an issue. For ISG-11, that creep will need to be a consideration that we also need to address in the PIRT.

MEMBER MARCH-LEUBA: So, in your mind creep is -- I mean, in my mind now, creep is worse than reorientation because reorientation didn't seem to affect the results.

MR. TORRES: Yes, so that's where our

focus will be.

CHAIR BALLINGER: And is it my understanding that the 400 degrees C is very conservative? There's a consensus, not a consensus, but the 400 degrees C can be considerably higher.

MR. TORRES: I would not quite characterize it like that. I think that the technical basis in ISG-11 looked at accelerated creep testing and, clearly, added a safety factor. So that's ultimately why we came with 400 degrees Celsius. Doing long-term creep tests, it's rather expensive. But I wouldn't exactly characterize it that way. I think that, clearly, over the last 16 years there's also been additional work on creep that we have to reevaluate to see if we can further refine that safety margin that we put in ISG-11, Rev 3.

MEMBER RICCARDELLA: With respect to that 400 degrees C limit, and you say we're approaching it, are these temperatures monitored in any way or are these just analyses that are submitted as part of the licensing?

MR. TORRES: Yes, they're analysis submitting, CFD analysis, and we run our own confirmatory analysis just to verify that those temperatures are acceptable. There are some licensees that measure temperatures on the -- during vacuum operations, I think that they do at the outlets of the vacuum. I mean, they measure at certain locations, inside the cask --

MEMBER RICCARDELLA: Nobody puts thermocouples on the rods.

MR. TORRES: But there's been recent work done under the DOE Research Cask Program, which is being conducted by EPRI in conjunction with Dominion, at the North Anna ISFSI. And they put thermocouples there to measure -- I think they had 63 total thermocouples in there.

MEMBER RICCARDELLA: Sort of an analysis validation effort, apparently?

MR. TORRES: That's correct, and that's part of it.

MEMBER RICCARDELLA: Yes.

CHAIR BALLINGER: But those temperatures turned out to be a lot lower than expected.

MR. TORRES: That's correct.

MEMBER RICCARDELLA: You're talking low?

CHAIR BALLINGER: A lot lower.

MEMBER RICCARDELLA: Yes.

MR. TORRES: But we're learning.

MEMBER RICCARDELLA: I'm with you.

MR. TORRES: Okay. So, as I said, because of the age of ISG-11, there's been significant work, and we wanted to better understand the effects of hydride reorientation on the mechanical performance. DOE has conducted its own set of tests. Our work that we discussed here on NUREG-2224 on the test results and NUREG/CR-7198, Rev 1, are the first results on hydride reoriented high burnup fuel.

So, I'm going to skip this part because I think I've given a good briefing on what hydride reorientation is. So, the purpose of NUREG-2224 is to provide the engineering assessment in 7198, Rev 1, and also provide efficiency in the preparation of review -- I'm sorry, there's a typo here -- it should say, "in all transportation and storage applications, dry storage applications, up to 60 years".

And we do that in Chapter 3 and Chapter 4 of NUREG-2224, which provide example licensing approaches that applicants can follow, replicate, and hopefully, provide sufficiency in the preparation and the review of those applications.

So, the contents of the document itself, you will have an introductory chapter which provides some perspective on cladding performance, the guidance that we've issued in the past, the progression in

ISG-11, the relevance of creep, the relevance of hydride reorientation, the parameters that lead to it.

Chapter 2 is Dr. Bjorkman's lead on the assessment of the 7198, Rev 1, results. Chapter 3 and Chapter 4 are on licensing approaches, a conclusion chapter, and the rest is references, and so on.

So, in Chapter 1, as I said, we discuss creep, hydride reorientation, dissolution, precipitation of hydrogen, the effects of the cladding fabrication, the importance of end-of-life rod internal pressures into cladding hoop stresses, prior results on recompression testing of hydride reoriented samples, our own assessment of those results.

In Chapter 2, you will see an introductory section and a discussion on the setup used by or developed by Oak Ridge National Laboratory under our sponsorship. It has separate discussions on the static bending results, discussions on the performance of the composite behavior of the spent fuel rod, how to calculate cladding strengths, just like Gordon discussed earlier today, and the applicability of those results to the evaluation of design basis drop accidents in dry storage and transportation. It has a separate discussion on fatigue, on the fatigue test data, on the dynamic bending data, how to build that lower bound curve that Dr. Bjorkman discussed, the implementation of a fatigue cumulative damage model, Miner's Rule, and the applicability of that to dry storage and transportation.

So, in Chapter 3 and Chapter 4, we provide example licensing and certification approaches, per the assessment in Chapter 2. We made sure that these approaches are consistent with the consolidated SRPs where dry storage is being finalized, where transportation is just being put out for public comment, as well as the MAPS report and NUREG-2214, which was just recently finalized.

And the approaches vary depending on the condition of the fuel, whether it's undamaged and damaged, and the length of time in dry storage.

MEMBER KIRCHNER: Is there a consensus on the definitions of "damaged" and "undamaged" fuel?

MR. TORRES: That's a good clarification question. So, we are departing from the guidance that we've provided. We have specific guidance on fuel classification, and that's in ISG-1, Revision 2, currently. And we have definitions for "undamaged," intact, which is no hairline cracks, no pinholes, "undamaged," may have hairline cracks, pinholes, and "damaged" which means it just cannot fulfill adequately the functions without additional containment inside the dry storage system or transportation package. So, we've been consistent with our own facts.

MEMBER KIRCHNER: Pragmatically, though, how is that really, that definition actually assessed on loading of the cask? There's not a complete visual inspection of all the fuel pins?

MR. TORRES: There's not. Actually, there's a brief discussion in ISG-1 about fuel qualification prior to loading. Then, licensees use a variety of techniques, sipping methods, visual testing, ultrasonic. There's some old data on a current sometimes that requires more work. So, it varies, the type of data that they use to demonstrate that they comply with the CoC or the tech specs of the CoC or license.

So, we also make it clear in the document that these are example licensing approaches; these are not regulatory requirements. An applicant can come in with other approaches, if they choose to, and we'll review those on a case-by-case basis.

So, the ways Chapter 3 and Chapter 4 are structured is there is a discussion on leak-tight designs, per ANSI N 14.5; non-leak-tight designs. And in this case, we actually expand the technical basis in the current Standard Review Plans to provide release fractions, bounding release fractions that applicants may use for non-leak-tight designs when transporting or storing high burnup spent fuel.

The way it's broken down, there's discussion on dry storage and transportation, fuel up to 20 years of age, and dry storage and transportation beyond 20 years. And those discussions beyond 20 years rely -- there's two approaches.

One is an applicant can choose to rely on an aging management program that evaluates data being obtained under a surveillance and demonstration program such as the one at North Anna. And we have a discussion on that and a reference to NUREG-1927, Revision 1, which provides our expectation for what an aging management program should look like.

And if an applicant chooses not to follow that approach and not rely on the data from a confirmation program, then they can do supplemental safety analysis. But what we're looking here is for confirmatory data. The majority of the work that we've done is separate effects testing, accelerated tests. And like you said, there is sometimes synergistic effects associated with different degradation phenomena occurring over time. So, what we're looking here is confirmatory data that demonstrates that our conclusions continue to be acceptable beyond 20 years.

MEMBER REMPE: This brings up another question. I've not been following the topic as much; it's a little off-topic. But, a few years ago, I remember a big discussion about the definition of "retrievability" and how we might not do it on a fuel rod basis. We might do it on a can basis, which makes a lot of this discussion less important. What was the outcome of that discussion? Did we decide we could just retrieve on a can basis?

MR. TORRES: Yes. So, historically, the regulation says you shall design your system for it to be ready, to allow ready retrieval. The regulations don't really define what "ready retrieval" is.

MEMBER REMPE: Right.

MR. TORRES: So, historically, we have defined "ready retrieval" via guidance, and that has been through ISG-2. And now, the document that you were referring to was in 2016. It was revised through Revision 2, which allows now three options for demonstrating ready retrieval.

You can demonstrate ready retrieval by

removal on a single assembly basis, which is where this document applies to --

MEMBER REMPE: Okay.

MR. TORRES: -- where the cladding is an important consideration. You can demonstrate retrieval by removing a canister from a dry storage system overpack, or you can demonstrate retrieval by removing the entire system, dry storage system, from its location and moving it somewhere else.

So, this document, actually, we received some comments just to make sure that we're being consistent with that revised definition in ISG-2, Rev 2. And now, this document is consistent with those three approaches. But we also make it clear that it's for action one on a single --

MEMBER REMPE: Okay. That's what I wanted to make sure got discussed. Thank you.

MR. TORRES: You're welcome.

MEMBER KIRCHNER: What is a non-leak-tight design?

MR. TORRES: So, the staff has endorsed the use of ANSI N 14.5, which provides criteria for defining what's -- it actually determines what's a leak-tight or non-leak-tight design. There is specific leakage rate for leak-tight systems. So, once you demonstrate that you are leak-tight, if you cannot demonstrate that your system meets that criteria, then there are additional analyses for those consequences that need to be performed, assuming release back, potential releases through the canister.

So, in the past, in our storage Standard Review Plans, we don't have release fractions for high burnup fuel because high burnup fuel is different. It has a different pellet microstructure, and so on. So, in this document, now we have a table that defines those acceptable release, bounding release fractions to us.

Okay. So, conclusions here. We've assessed the mechanical testing conducted in NUREG/CR-7198, Rev 1, and we have confirmed that, for design basis drop accidents, the approach of using the cladding-only mechanical properties continues to be conservative. Applicants can continue to use that.

And in the document, we've also provided a discussion on how to account for the flexural rigidity of the pellet. That's that 1.25 factor that Gordon discussed for Zircaloy-4. Once DOE is obtaining additional data on static bend testing, once that data is obtained for other cladding alloys, we expect that the same approach that we discussed here for Zircaloy-4 can be replicated with the high burnup fuel with other cladding alloys.

So, the purpose of this, as Chris mentioned, Chris Regan mentioned, is that this document, once it's finalized, it will be referenced by our Standard Review Plans, so that applicants can get a comprehensive basis on the history of cladding performance, hydride reorientation, and the acceptable approaches to the staff on the licensing and certification of high burnup fuel.

I was going to skip the slides, but it seems like we're doing pretty good here. I was going to provide an overview of the comments that we have received, if you guys are interested in hearing about this.

So, in The Federal Register notice, we posed six questions to the public, which are listed for them here. Rather than just leaving it open to just receiving comments, we were particularly interested, okay, are these approaches reasonable? And I guess, are they meaningful? Are there any conflicts with the Standard Review Plans? And what do you think about our assessment of the recompression test results, and so on? So, we had some specific questions that we posed to the public.

In reality, we received one response, one comment letter answering these questions succinctly, not a lot of detail. And you'll see that in your copy of the comment response document at the very beginning, those responses, and our responses to those comments.

So, in general, we received a significant number of comments not specific to the technical content of NUREG-2224. And the way we broke them down in your copy of the comment response document, there's clarifications on information supporting the safety of high burnup fuel; on the application of safety standards in Part 71 and Part 72 to high burnup fuel; generic concerns with respect to transportation, railway transport, things along those lines; storage beyond 60 years. And we have extensive answers to the public on these concerns. So, we ended up aggregating many of these comments in the interest of efficiency.

With respect to the specific comments of NUREG-2224, in Chapter 1, as I said, it's a lot of history and discussion about creep and hydride reorientation. We had a number of comments and clarifications on end-of-life rod internal pressures, and we made some revisions just to better reflect accurately the hoop stresses that would be expected during dry storage and transport, per the acceptance criteria in ISG-11, Rev 3. We received some comments to reevaluate the acceptance criteria in ISG-11, Rev 3, to potentially go higher, but that is beyond the scope of this document. There's our parallel efforts that we are taking on to address that. We pointed that out in the document.

We received some clarifications on Chapter 2, on the specifications of the specimens that we tested; on the basis for the radial hydride treatment that we chose; the stresses and the number of cycles that we did for reorientation.

Clarifications on spent fuel rod behavior discussion; our position with respect to the fatigue endurance limit, which Dr. Bjorkman just discussed. We're now making conclusions with respect to an endurance limit and clarifications on how the conclusions of NUREG-2224 are risk-informed.

In Chapter 3 and Chapter 4, we have clarifications on ISG-2 and the ready retrieval, and consistency with the recent revision to the acceptable approaches.

Clarifications on leak-tight versus non-leak-tight designs and the release fractions that we have identified in the document.

And the applicability of the reconfiguration scenarios that are discussed in NUREG/CR-7203, which is the document that we used the basis to evaluate, to provide guidance on how to assess reconfiguration.

MEMBER REMPE: So, I was interested in comment 3.4.17, where they basically said that they needed more guidance to implement some of the -- they basically said, "Further interaction between NRC and the industry is considered crucial for successful implementation," and they needed to understand better the level of justification required and what the acceptance criteria would be.

That seems like a comment that might be worth delving into. I mean, we're trying to give them guidance, and they're saying that they don't have what they need. And the response back didn't seem very responsive to their concern. And did you have any more discussion with them on that?

MR. TORRES: So, that was a comment specific from NEI, I believe, that comment. And I think I'll leave that to -- I think I would point to management on how we effectively managed that. But I think a decision was made that we had held a public meeting on this, this subject, and we requested feedback and we took questions. And it wasn't very clear what clarification is really needed.

You know, the technical comments from EPRI were very specific and easy to address, but it wasn't very clear how the licensing approaches were unclear to follow.

MEMBER REMPE: So, they're going to be giving a presentation later today, and I'll ask them the same question. Because it just seems like, if somebody is asking for more guidance, they ought to be clear enough and the Agency should respond.

MR. TORRES: I'll let them answer that --

MEMBER REMPE: Okay.

MR. TORRES: -- how they interpret that answer.

MEMBER REMPE: Thanks.

MR. TORRES: Okay. So, in Chapter 5, there was just a brief comment on clarifications to the conclusions.

MEMBER KIRCHNER: Ricardo, since you raised it, I'll ask you, for the record, how were your conclusions risk-informed?

MR. TORRES: Yes. So, we had a couple of comments on this. And we believe that, to the extent that engineering judgment can be used to risk inform, we have taken steps to do that. An example is for the static bend testing. We only tested one specimen under static bend testing to demonstrate that up to 35 newton meter there was no change due to hydride reorientation, which corresponds to the 100 G's that Gordon talked about. But, then, we made a comparison with the cladding-only response, and we saw how markedly higher that response is. And we said, well, now you don't even need to provide cladding properties. You can continue to use cladding-only properties, but you don't even need to account for hydride reorientation.

So, there is an extensive database in the literature over the last couple of decades on cladding mechanical properties in the as-irradiated condition, but not enough on the hydride reoriented condition. So, we said, you don't need that data. You can rely on the as-irradiated condition and that's acceptable to us. So, we think that we released some of that burden.

And we concluded that, with respect to the risk-informing, we made that conclusion for all cladding alloys. Because of the hydride reorientation treatment that we chose, we feel that it's conservative on the types of specimens, the burnups, the hydrogen content. We feel that it reasonably balanced the rest of the cladding alloys.

Now, with respect to fatigue, we have a different approach because fatigue, we feel it's more dependent on cladding alloy and it's more difficult to assess and make generic conclusions based on a limited number of tests. But we feel that we have been relatively risk-informed to the best extent by engineering judgment, based on a single test that helps us extrapolate and make conclusions with all the other alloys.

MEMBER REMPE: A couple more questions about your comment document. I was interested in that somebody had pointed out the Japanese even have a lower temperature than 400 C. Do you expect, with all the research that's been done -- I mean, you guys participate in international activities. Do you think they're going to raise their temperature higher? Has there been any discussion with them why that they continue to have such -- I mean, it's 230 or something degrees.

MR. TORRES: Yes, frankly, I'm not sure that the basis for that temperature is directly related to the fuel or other materials that are used in the designs.

MEMBER REMPE: Okay.

MR. TORRES: But we're not sure, to answer your question directly. We're not sure what the Japanese plan on doing. We try to stick to our guidance and the acceptance criteria in ISG-11, Rev 3.

MEMBER REMPE: And I'll go back to my original question about the fact that the high burnup demo instrumentation and the geometry specifications, or whatever, were insufficient to have a validated CFD calculation. And have you had time to come up with any response to that NUREG/CR report that was produced by the Agency?

MR. TORRES: So, there was a blind round robin done on this where the NRC participated. They did their own evaluation of that specific cask that was loaded at North Anna and the comparisons were made with the actual measurements.

And there is a report, I believe, being generated by EPRI. I'll let EPRI discuss what's the status of that. But EPRI's report incorporates the NRC's evaluation of that cask and how it compares the model to the experimental and the results of other entities which also participated in the blind round robin for that specific cask.

MEMBER REMPE: So, the Alden NUREG/CR was just one of several organizations participating in it, and EPRI will respond to that?

MR. TORRES: Yes.

MEMBER REMPE: Okay. Thank you.

MEMBER RICCARDELLA: On the subject of risk-informed, that requires sort of some look at the consequences. I mean, for the reactor we have some general guidances for core damage frequency and large release frequency.

MR. TORRES: Yes.

MEMBER RICCARDELLA: And there's the NRC safety goals for the maximum dose to an individual, and stuff like that. Is there anything along those lines --

MR. TORRES: Yes.

MEMBER RICCARDELLA: -- addressing spent fuel or handling the spent fuel?

MR. TORRES: Yes. So, we have a few efforts underway. We have written a task order for the Center for Nuclear Waste Regulatory Analysis of San Antonio to do a consequence analysis for us. And that will, it's supposed to start next fiscal year, fiscal year '20.

We also have some additional work on trying to identify the right metric to -- because there's some discussion on what's the right metric that should be chosen.

There is also some work on the inspection side. So, under 10 CFR Part 72, there are allowable changes, under 10 CFR 7248, and there's some work being done on the inspection side to provide additional guidance on the risk-significant things that an inspector should focus on during an inspection. So, there's at least those efforts currently.

MEMBER RICCARDELLA: Thank you.

CHAIR BALLINGER: Any other questions before we take a break?

(No response.)

Dave, do you have any questions?

MEMBER PETTI: No, I'm okay.

CHAIR BALLINGER: Thanks.

Okay. We're ahead of schedule, which is good. Let's take a recess until 20 minutes after.

(Whereupon, the foregoing matter went off the record at 10:02 a.m. and went back on the record at 10:20 a.m.)

CHAIR BALLINGER: Okay. We're back on the record.

And I don't know who's going to go first and who's going to go second. Are you going to go?

MR. McCULLUM: I think I'll go first. Once I'm technologically able, I will go first.

CHAIR BALLINGER: Oh, that's better.

MR. McCULLUM: And my name is Rod McCullum for the record, at the Nuclear Energy Institute. It's always a pleasure and an honor to speak to this group.

I was very pleased with the discussion we just heard. I mean, we are learning a lot about, I will say, fuel and dry storage. You know, this has been something -- and I'll reflect here -- we have a lot of experience with. And now, we're understanding more about what that means, and hopefully, that's informing us how we can most smartly regulate it and how licensees can most smartly comply with the regulations.

So, it's really all about how we use this information, and I think Dr. Rempe had the essential question on that a little while ago. And I hope that this presentation is part of the answer. If it's not, I look forward to your questions.

Anyway, we view this NUREG as an important enabling tool to get a regulatory process that has a stronger safety focus. And by that, I mean it's not focused on things that are not important to safety.

In this world of diminishing resources, that is critically important, that we really be strongly safety-focused.

I think Ricardo had a chart earlier where he showed how all the NUREGs fit together. You know, there are a lot of pieces to this puzzle. I think there's more pieces still to come. I'm going to talk about some of the pieces industry is most engaged in. What I'm doing here is really giving context to where we see this and where we see this going. And then, Keith will tell you all the smart stuff you need to know from the industry perspective.

So, you did receive comments. The NRC did receive comments from four industry entities: NEI, EPRI, Holtec International, and NAC International. That's significant. Usually, you just see comments consolidated by NEI. It's one of the things we do. Sometimes when it's really technical or when EPRI needs to exercise an independent scientific opinion, you'll see NEI comments and EPRI comments. But the fact that two of our three suppliers, dry storage supplier companies, endeavored to comment, I think that tells you a little bit about the value of this tool, because they don't normally do that. They want to make it work. They are doing things where they see having the knowledge, better knowledge, of what high burnup fuel is and how behaves in storage is important to their business. And as they are our member companies, we want to represent that.

These were our comments in a nutshell. We support -- and really, that's what this guidance does. It gives us things we can use to demonstrate more tools, more that we can use to demonstrate compliance, particularly pertaining to the hydride reorientation question.

Initially, there was just fuel coming out of reactors. And initially, it was going to pools and, then, dry storage and the world happened. But there wasn't such a thing as high burnup fuel and low burnup fuel.

We had a tradition, because of the way we operated the reactors, of discharging the fuel before it got to 45,000 megawatt days per metric ton. So, when we started to depart from that tradition, we said, well, okay, this is different. So, we coined the term "high burnup fuel," which, you know, we engineers love to coin terms that are out there in the public just to scare people --

(Laughter.)

-- and maybe aren't meaningful.

So, the question got asked, well, is high burnup fuel any different than low burnup fuel? Folks started to think about that, and somebody raised the subject of hydride reorientation. And I thought Dr. Bjorkman's presentation really gave a lot of good insights on that. I am hopeful that we can kind of put that issue in a proper context in terms of safety significance based on what we now know.

So, our most significant comment I've highlighted in yellow here. It is this demonstrates that we have even more safety margin than we thought we did initially when we got into dry storage because we had to, because fuel wasn't going to go from our reactor pools to DOE's repository, like it -- or, initially, it would have been to their reprocessing facility. Neither of those exist.

So, when we got into this, obviously, we took a very cautious approach. I have always in these forums liked to remind that Part 72 follows Part 71 because we thought we were going to transport before we thought we were going to dry store. Obviously, on the road you take a very cautious approach. You're not inside a reactor facility. You're not inside our fences. You're not inside our zones which we control. So, that cautious approach translated over to the dry storage, but I think now we understand things better and maybe it is time for a different approach.

We did not answer the six questions, and I think we weren't alone there. Of all the commenters, only one commenter did answer the six questions. And I don't know if the motivation of the others was the same as ours, but, really, okay, this is great information. The reaction of my industry committees to this was this is a lot of great information; what do we do with it? And I think what I might be hearing from NRC is it's really up to you guys to figure out what to do with it.

So, absent that, we didn't see a lot of value in trying to answer the six questions. We do see this as part of a dialog going forward, and I'll try to frame some of the other pieces of that dialog. How do we intend to -- what can we do with this information?

This is just the landscape. It's important to note we have a lot of experience with dry storage. So, it's a mature industry now and the performance record is strong.

One bullet I'll highlight in here is we calculate we have approximately 1300 casks that have at least one assembly of high burnup fuel. We actually stopped counting a couple of years ago when we were up to 800 because we realized that just about every cask that's loaded now pretty much has high burnup fuel. So, this 1300 is 800 plus the number of casks we've loaded since we stopped counting.

Of course, we still don't know exactly what's going on inside those casks. I mean, we got great insights from the high burnup demo project, and hopefully, we get more.

I have to put in a pitch on the record here to DOE, if they're listening. We must open that cask. We did open one cask of low burnup fuel, again, before we knew there was a difference between high burnup and low burnup, if there is, indeed, one. And that information proved so valuable that the NRC was able to change its regulations to allow 40-year license periods instead of 20-year license periods.

So, what we've already learned from the high burnup about temperatures is gold, and some of that is reflected in here. What we've learned is we didn't cause fuel damage when we dried the thing because we got gas samples out of that.

And, of course, I think the sister rod program was referred earlier. Those rods, high burnup rods, that were captured and found their way into a hot cell are also gold mines of information.

So, while I don't know what's going on inside every one of those 1300 casks, I have the ability to understand it better as a result of these things. So, DOE, if you're listening, please open the high burnup cask. Yes, we're about six or seven years away from them moving to do that, right? I think we wanted at least 10 years there, yes. There's more, seven-plus I think. The time flies.

MEMBER REMPE: So, your comments imply that, I mean, they started this program, but they're not certain they're going to do it? Is that why you're making these comments, Rod?

MR. McCULLUM: I'm making these comments because we haven't seen tangible evidence that they're going to do it. In other words, I would be seeing real -- Keith, off to the side of the record here, is indicating I would be seeing DOE making real decisions to fund real facilities. I would see real construction. I would see things starting, because, remember, we're only less than a decade out, and we're talking about a fairly significant infrastructure capability. They used to have it in the TAN North facility.

And I also say this against the background where DOE has so much uncertainty in the used fuel area because of politics that it's hard for them to commit to anything right now. So, yes, my message is for DOE, but I understand that there's 535 folks up on Capitol Hill that have a lot to say about what DOE can do. And there's some folks in Idaho that have a lot to say about what DOE can do.

So, yes, Dr. Rempe, it is very much an uncertainty as to if and when DOE will be able to open that cask. And that's why I'm raising it.

MEMBER REMPE: Actually, I guess I had not realized that when they started this program. So, I'm glad you're bringing this up. I know there are political concerns about doing it in Idaho.

MR. McCULLUM: Right.

MEMBER REMPE: But they've just not figured out any place else to do it even, huh?

MR. McCULLUM: Yes. So, until I see tangible evidence that they are figuring that out, I have to express my concern. I mean, they are completing -- and Keith is the Project Manager, so he knows this way better than I do -- but they are doing a great job on all the phases of the project that are funded now. But that phase where you open it doesn't exist yet.

MEMBER REMPE: Thank you.

MR. McCULLUM: So, this is Doug True's figure. You brought this to NEI. He calls it a spider chart. I call it a bubble chart. But, since it's his chart, I guess it's a spider chart.

Do you remember, I just mentioned we now -- the dry storage industry and the high burnup dry storage industry has become very mature and we have a strong record of performance. Of the three components on the left, if you have these three things, and the third one being understanding of safety margin, you can do the three things. This is what we mean, we use risk-informed. It's about focusing on what's safety-significant. Because sometimes people hear risk-informed, and then, they think, oh, let's do a bunch of PRAs. It's about being risk-informed. The essence of it is being able to focus your resources on safety-significant. That's the best way to assure safety because you're not diverting your resources to things that aren't safety-significant.

Both the NRC and industry are in a world of diminishing resources. So, this is very important. When you get that, you can do three things. You can disposition low safety-significant issues quickly.

You can implement a graded approach to a reasonable assurance and high standards. And you can implement performance-based inspection.

Now the NRC is doing a lot of work on improving inspection programs in this area. I will highlight one notable success that industry and the NRC are having together on the graded approach. But, in terms of dispositioning low significant safety issues quickly, I think we have a ways to go there. Hopefully, NUREG-2224 can help this spider walk on all sixes, or however many legs a spider has.

So, implementation. I mentioned the graded approach. We have been working with TN on a license amendment for CoC that would reduce licensing burden by 34 percent. Now that's a pretty accurate number. How do I know that? Well, they calculated the percentage of the volume of a CoC that will not be in the one that's a graded approach, and that came out to 34 percent.

Now it might be greater than a 34 percent reduction in burden. When we look at a lot of what's coming out as the fuel qualification papers, it's very specific information on the fuel, which when it has to translate across the licensing boundary, as opposed to being under licensee control, under 7248, we've got an improvement in the works there.

And already we've mentioned the MAPS report and the things that go along with it. Five years ago, I think I was in a meeting, an EPRI meeting, where we really didn't know what the regulatory framework for the extended storage was going to be. I think that's why EPRI created the Extended Storage Collaboration Program. And now we do, and it's in pretty shape.

So, detailed information about the fuel, when it has to cross the licensing boundary, that's a lot of work for NRC. That's a lot of work for the licensees. If we understand more about the real risks, or non-risks of this, if that's a word, less information is safety-significant or has to be focused on any licensing context. And that makes the whole process more efficient and enables us to focus on things that are safety-significant, maybe things that aren't even dry storage, maybe even more focused on some of the reactor things.

So, these are kind of three prongs of this. The pilot is at a point where there's been a lot of back and forth between NRC and the applicant, and the 34 percent is based on what I think will eventually be the compromise that comes out of that.

We have a guidance document on 7248 that NRC has agreed to endorse, but it's still in the endorsement process. At least I should say it more accurately. We've closed on all the substantive issues, and there's correspondence on that.

That's important because the NRC in their inspection program has to have confidence that, if the information doesn't have to all be preapproved by them, that we're managing it properly. So, if we don't have a common understanding -- and we didn't have a common understanding -- of the process of how the licensees control information that's not as important to safety, the greater approach doesn't really work very well.

So, we've got those two pieces. We've got the extended storage piece. Now what we're trying to do is -- we've got one thing that NUREG-2224 is an input to -- we're trying to really understand the safety margin. And industry, by the end of this year, is going to put out a white paper, and then, we have to figure out what we're going to do with that. We've got to still fit this puzzle together.

But we're going to, using the same information and some other things in some areas, we're going to try to quantify that safety margin. And again, that will let us step back and say, what are we focusing on here?

This is why it matters. Remember what I said back here when I was scrolling through. Disposition of low safety-significant issues quickly. And I talked about all the information that has to cross the licensing threshold now. This is not dispositioning low safety-significant issues quickly. What this slide says is that we have -- over the last 25 years, there are 15 CoCs that have been amended 74 times. We have to amend them so frequently because there's a lot of detailed information that's not safety significance that has to cross the boundary for NRC approval.

And these processes take years. They involve multiple rounds of REIs. If we apply what we know today, and some other things we might be about to learn with the demo project, we don't need to be doing this, or we need to be doing a lot less of it. And that frees up resources to focus on more safety-significant issues.

So, really, the question I leave you with is, are the differences between high burnup fuel and low burnup fuel really meaningful? And if they are not, why are we doing a lot of what we're doing? And what could we be doing with the resources that we're doing it with right now? I think we're close to some answers here, and I encourage this Committee to continue to focus a sharp eye on this.

And that leaves me open for questions at this point.

MEMBER MARCH-LEUBA: I have a philosophical comment. As part of the review by the staff of anything that you submit, the idea is to make sure that nothing in there is safety-significant. So, the review is to determine whether or not it's safety-significant, and if it is safety-significant, you don't get approved.

So, if you can disposition the safety-significant before the review happens, you're not doing a review. I mean, you should disposition everything, not --

MR. McCULLUM: Yes. No, I agree.

MEMBER MARCH-LEUBA: The reason, it's not significant or not; it's a gradation of.

MR. McCULLUM: It is a gradation. That's why it's the graded approach and exactly. We've loaded over 3,000 of these things to all of those various licenses I highlighted. And they get approved because, you're right, there's not a safety issue.

MEMBER MARCH-LEUBA: No.

MR. McCULLUM: And, okay, now we know that. And now we're starting to understand a lot more of the underlying why. This is all about, NUREG-2224 is understanding why there's no safety issue there. And now that we understand that, can we be more efficient? In other words, we've approved all these casks. We've loaded all these casks. There's never been a safety issue. And yet, we're spending thousands of manhours of effort continuing to review the same types of things.

MEMBER MARCH-LEUBA: You should concentrate, my opinion, you should concentrate on duplication of effort.

MR. McCULLUM: Yes.

MEMBER MARCH-LEUBA: If that's already been done, refer to that reference; don't ask me again. But the philosophy is there is no safety issue in anything you submit. Otherwise, you don't get it approved.

MR. McCULLUM: I generally agree wholeheartedly, yes.

MEMBER MARCH-LEUBA: But the purpose of the review is to demonstrate it.

MEMBER REMPE: So, I'm doing a lot of

stuff with Fukushima and TMI lately, and they always refer to the Preliminary Environmental Safety, Environmental Impact Safety Assessment, PEIS, or whatever the report was. And they had like a global set of activities, and if it fell within that global set of activities and the risks associated with them, then nothing needed to be done by the regulator when they were trying to clean up TMI.

Have you ever thought of having a different approach that would have a --

MR. McCULLUM: Yes.

MEMBER REMPE: -- global set of activities, the bounding consequences, and not have to deal with a lot of these 70, or whatever the number was --

MR. McCULLUM: Seventy-four. Yes, that's actually in here. The compromise, this 34 percent compromise I'm mentioning here, that is replacing the fuel qualification table, which is all the detailed information about the fuel with an envelope, which is very similar to what you mentioned.

MEMBER REMPE: Yes.

MR. McCULLUM: And this spider or bubble chart, this is not unique to dry storage. This is what Doug True is talking to the NRC, his counterparts at NRC, on the reactor side about. That's exactly, what you just described is exactly what's at the top here. Disposition of low safety-significant issues quickly.

And we don't have enough of a process there right now, but the goal is to get there. And I think dry storage is an area where we can get there, just because of the nature of what dry storage is.

MEMBER REMPE: Yes, but it sounds like, I mean, it seems like there would be enough similarities that one could do something like that.

MR. McCULLUM: Yes, I'll take that back to our folks on the reactor, too. I'll, obviously, take that to heart. There's something we can look at as an example and take that back to them, too. Because I think this is one we're struggling with. We all say, yes, that's great, we should do this. And then, having something that's credible, because you can't just say, aw, I don't care, you know. You've got to have something like what you just described where there's a structure to it.

MEMBER REMPE: Yes, and identify all the hazards and --

MR. McCULLUM: Yes.

MEMBER REMPE: -- bounding conditions.

That shouldn't be a problem. But, anyway, it's just a thought.

MR. McCULLUM: Yes, it's a good thought. I appreciate that.

Well, if there's no further questions, I'll let the real expert here talk, yes.

MR. WALDROP: Do we need to change?

MR. McCULLUM: We do need to change. I'll move the name tents, if you'll move your stuff.

MR. WALDROP: Okay. Moving right along, so I have an opportunity, and appreciate the opportunity, to provide some of the EPRI perspectives on the NUREG-2224 on the high burnup spent fuel.

So, kind of the outline of my talk, first, the NUREG itself does a little bit of looking back at the regulatory guidance, but I want to do a review of that, and it leads this to a motivation of why this NUREG is a good thing at this time.

I'll provide some overall perspectives of the NUREG itself, look at just a sampling of a few of the EPRI comments and how they were addressed. I think that the time that I've had this week to review those, I feel like the staff has done a good job in that effort.

And there's some that leave some future

opportunity of additional work of how we can further move the ball down the field in the future, as well as some ongoing and future work that can further support how we can continue to move the ball. And then, lastly, a summary.

If we look at the review, how we got here, chronologically, as has been talked about earlier, ISG-11, Rev 3, was established in 2003. And Ricardo has talked about what that did for us as far as cladding considerations.

In 2005, EPRI did some finite element analysis looking at the contribution of the fuel pellet. Because ISG-11, Rev 3, really talks about just dealing with the cladding-only properties. So, we did some analysis to look at that, and I'll talk to that on the next slide.

Then, in 2013, just kind of where we were at the time, there was an ISG on moderator exclusion where they said you can go in and do a fuel reconfiguration analysis as allowed in Part 71, except for high burnup fuel, because they said that there's insufficient material property information for high burnup fuel to allow this type of evaluation, that being doing a fuel reconfiguration analysis.

So, the report in 2005, the number here on the screen where some finite element analysis was done looking at what does the fuel pellet contribute. So, they looked at the cladding, inner and outer, at the top and the side. And you see the hoop strain versus load factor curve provided here. You see, initially, how it gets loaded up very quickly in the first part of that, as the cladding is deformed, until there is contact made, and now the gap is closed and you're pressing on the pellet. And now, as you continue to apply the load, there is very little effect on the cladding, to the point that there's no failure.

So, it was shown that the pellets do contribute a major load-resisting component of that system together, such that it prevents cladding failure. And never say "never". So, I've got in here the caveat with the possible exception of extreme cases of a large gap with significant radial hydrides where --

MEMBER MARCH-LEUBA: Sorry. How do you compare this red line with the factor of 1.25 that we saw in the staff presentation? I mean, they were willing to give you a 25 percent credit for the pellet. Do I really hear 500 percent, a factor of 5? Or how do I compare those two numbers?

MR. WALDROP: Their analysis was still,

the testing was cladding-only.

MEMBER MARCH-LEUBA: No, but they say that there's a factor of 1.25 when you account for the pellet that will be -- they're not the same?

MR. WALDROP: No.

MEMBER MARCH-LEUBA: They're not the same number?

MR. WALDROP: The 1.25 was the reoriented, going from, no, 1.96 to 1.4; 1.4 to -- oh, I'm sorry. I'm sorry. I'm thinking of something else.

MEMBER MARCH-LEUBA: You don't know the question?

MEMBER RICCARDELLA: The 1.25 is the difference between the strain and rigidity of a tube, of a cladding-only tube versus a tube with fuel pellets in it, right?

MR. BJORKMAN: That's correct.

MEMBER MARCH-LEUBA: No, you need the microphone, and very loudly because this is a big help.

MR. BJORKMAN: Okay. The gentleman is correct. If you look at the irradiated cladding only, and you take a mean minus 2 standard deviation, you're going to get a factor of about 1.96 as the factor that you multiply the cladding-only flexural rigidity by to get the effect of the fuel pellet.

We, then, said, oh, but we also have the reoriented sample. And when you look at the reoriented sample, you have to multiply that 1.96 by a factor of about .7. That brings you down to a factor of 1.4. And then, we said, well, we have so few samples, that we're going to reduce it even further to 1.25. So, that's how we got there.

MEMBER MARCH-LEUBA: Yes, but how does that compare with the X-axis in this figure? I mean, I see a "5" there for a load factor. Is that the same number as your 1.97? I mean, what I'm asking, are we in violent disagreement on the calculations?

MR. BJORKMAN: I don't think we're talking about the same thing.

MEMBER RICCARDELLA: Would you just explain what the graph is? I don't quite understand it.

MR. WALDROP: It is the hoop strain versus the load factor that's applied. So, as you continue to apply the load, again, the point that it's showing is this first part of the graph the cladding deflects. And so, the cladding is taking all of that load and increasing the strain, until this part of the curve -- where did my thing go? --

MEMBER MARCH-LEUBA: You can use the "real mouse". It would be easier.

MR. WALDROP: Until you get to this point. Now the gap is closed. Now you're pressing on the cladding and the pellet. So, it provides significant resistance to --

MEMBER MARCH-LEUBA: If I extrapolate the slopes of before the inflection point and after, it's a factor of 10 in this load. I mean, once you touch the pellet, you are 10 times stronger. That's what that tells me.

MR. WALDROP: Okay, yes.

MEMBER MARCH-LEUBA: But they tell me it's only 1.97.

MR. McCULLUM: Bu the load is increasing. So, you're getting the 1.97 which is helping you against that load. But I think that's a parameter inside the equation that makes this curve, and not the result of the curve. Does that make sense?

MEMBER RICCARDELLA: I guess I have a basic question. Why are you talking hoop strain? I thought the load drop, the loading created axial bending, not hoop strain. What does hoop strain have to do with it?

MR. WALDROP: That was what was evaluated in the report in 2005, what we are looking at. Again, the point, just showing how much the pellet provides resistance.

MEMBER MARCH-LEUBA: Okay. So, the degree to which you agree is that the pellet is beneficial?

MR. WALDROP: Yes.

MEMBER MARCH-LEUBA: And at the end you're going to agree that they're not going to give you credit for it and you want to get some?

MEMBER RICCARDELLA: It becomes a composite. It becomes a composite structure, basically. But, to me, it's --

MR. BJORKMAN: But the loads are being applied differently. You're using almost like a pinch load.

MR. WALDROP: This is a pinch load.

MR. BJORKMAN: Whereas, we're doing bending of the entire rod. So, they're totally different.

MEMBER RICCARDELLA: What do you mean by a "pinch load"?

MR. WALDROP: Like bring compression pressing from the top and bottom.

MEMBER RICCARDELLA: Oh.

MEMBER MARCH-LEUBA: Of course you're

going --

MEMBER RICCARDELLA: But if you drop a cask, doesn't it create bending load? It's not pinch load?

MR. BJORKMAN: Well, it creates bending, and it's true you get very large deformations and, then, you'll get a pinch load.

MEMBER RICCARDELLA: Okay. All right.

MEMBER MARCH-LEUBA: I don't need to run this test. If I pinch, I will collapse the gap. And then, when it hits the oxide, it won't pinch anymore.

MR. BJORKMAN: That's correct.

MEMBER MARCH-LEUBA: All right, but --

MR. WALDROP: And that's what this is showing.

MEMBER RICCARDELLA: Yes. Okay.

MEMBER MARCH-LEUBA: All right.

MR. WALDROP: So, following that chronology of the regulatory guidance, it shows that there's a motivation here to try to advance that guidance. The current basis ignores the credit for the structure of the pellet, and it's indicated that it provides a significant contribution to the resistance of the load.

We have lack of material property data on high burnup fuel. And there's a limited understanding of the effect of what hydride reorientation does under realistic conditions. So, with those questions out there, the NRC initiated the test program that they've described in the NUREG and really looking at what those results did.

So now, moving on to EPRI's overall perspectives of the NUREG, in the abstract it talks about the purpose of the report to expand the technical basis, providing guidance on adequate conditions as it pertains to hydride reorientation and high burnup spent fuel. And we agree that we feel that the purpose of this NUREG was absolutely met.

Ricardo has walked through a little bit, and you've got the document. So, you see some of this. But in Chapter 1, they go through a detailed review looking at past NRC research, providing the current regulatory basis.

Then, in Chapter 2, heavily focused on the results in the NUREG/CR-7198, as is appropriate because that's the exact question they were seeking to answer.

And I did note a few references to some other recent research in that. So, it's good; they've done a very thorough review of what research is out there to support this.

I think they did a very good job providing the explanation of what they were thinking and the logical progression on the steps. And that's going to be very important, as it says in the NUREG. Here, we went through with the data we have; follow those same steps later on as we get more data, without having to go back and revise the NUREG. They've kind of set up the roadmap for that. So, I think that was some very good forethought.

One other note to me personally is, the high burnup NUREG now considers transportation of high burnup fuel. ISG-11, Rev 3, while it says it addresses transportation, it does not address high burnup, transportation of high burnup fuel. It says we'll address it on a case-by-case basis. So, that is now brought back into the mix.

The EPRI comments, again, we appreciate having the draft NUREG out there, the ability to review it and provide some comments. We feel that the comments have largely been addressed, and some were not addressed at this time. I'll talk to a couple. But I think that that's appropriate. I think we can still move forward with the NUREG as it is, and we have an opportunity to maybe further update the guidance in the future. But this NUREG as it is provides guidance that is needed right now.

So now, I'm going to go through and just look at a sampling of a few comments that we provided and how they have been addressed. One, we had a comment related to a figure that looks at the rod internal pressure for integral fuel burnable absorber rods. Where that is, you've got a zirc diboride coating on the outside of the pellet. So, as that burns, it creates helium and adds to the pressure inside the rod. So, we're traditionally separated what we call non-IFBA rods and IFBA rods as far as internal pressures.

But the data that was used, and it was even commented in the draft there was some inconsistency. Staff has gone back and looked at that, identified the discrepancy, and appropriately resolved it.

In the end, there's no result to the NUREG or its conclusions. What happened was that higher rod internal pressure for IFBA rods drove the NRC to pick a much higher rod internal pressure for their hydride reorientation treatment. So, it's bounding, it's really bounding. But, in the end, the conclusion, that hydride reorientation doesn't need to be accounted for when using cladding-only properties, that conclusion remains valid. So, there was no impact to the overall conclusions.

Another comment we had was related to the fission gas contributing to the end-of-life rod internal pressure. Actually, it's primarily your pre-load when the rod is built and there's not that much contribution to the end-of-life rod internal pressure from the fission gas being released. Couldn't get outside the pellet that much. And that was addressed and clarified in the revision.

Ricardo talked about this already. We had some comments on retrievability and that that wasn't including the new definition of canister-based retrievability. It doesn't really impact this NUREG, but now the NUREG properly addresses the current guidance that's out there.

Another comment we had was on the ring compression test cooling rate. The cooling rate chose, the testing done at Argonne is 5 degrees C per hour. That's too rapid to allow any kind of annealing to occur. And so, that has now been addressed in the revised NUREG. They've basically clarified that.

And that's appropriate for what they wanted to do. The ring compression test, they wanted to isolate the effect of hydride reorientation only and not include other competing effects. So, it's just been clarified in the text.

Another comment was they had a discussion of cold work stress relief, anneal versus recrystallized anneal cladding types, but they didn't talk about the liner that's typically used in BWR fuel, where there's a solid zirconium liner provided which has a high affinity for hydrogen. So, when the hydrides are in solution, when they start to come out of solution, they'll tend to migrate towards that liner. The effect that that has is BWR fuel is essentially immune from hydride reorientation because the hydrides migrate to the liner area.

So, the staff has added some discussion of the BWR liner and the impact it has. They didn't further go on to talk about the effects of hydride reorientation, but that's okay. There were some notations made in the text to address the liner.

The previous work that I talked about where the finite element analysis showing the contribution of the fuel pellet was not discussed, in the revised document they have added a reference to it, but I would note that in the reference list it didn't appear.

Another comment in the discussion, looking at the composite behavior of the fuel rod, and Gordon walked through some of these examples earlier looking at how the composite system behaves. It ignored looking at the fact that previous analyses have always only considered the cladding. So, as you go through that discussion, you want to keep that in the back of your mind as you're walking through what's the effect on your moment of inertia of different systems aligned with the center of gravity. So, they've added some discussion at the beginning of the section as a good reminder, as you go through that nice discussion, to keep that in the back of your mind.

Another comment was the NUREG actually stated at one point, the draft, that seismic events are not expected to compromise the fuel. But, yet, in the final conclusion, looking at the composite model of the cumulative damage, they didn't talk about excluding the effect of seismic. And they've since included some text that says you can ignore that. Basically, it's such a small component, it's not expected to compromise the fuel. So, it was a good clarification that in your cumulative damage evaluation you don't need to consider that.

Now I'm moving on to some comments that we did have that I would say there's future opportunity for improvement to kind of further, as we continue to learn more. One comment we had was that the structural analysis considered lateral inertial load only. But, yet, in a transportation side drop accident that would include the pinch load from both the top and the bottom, as we've talked about.

As I understand the response to the comment, basically, I believe what was done was that the testing, they were only looking at understanding the impact of the rigidity. So, they were only interested in the lateral inertial loads at that point and what impact it would have.

But we need to remember that, as the cask vendors do their hypothetical accident condition side drop analysis, they will continue to monitor, look at what that pinch load is. And I think that's an important factor.

And I would also add that, well, part of, again, the testing done at Oak Ridge and the CIRFT testing, looking at just the vibratory response, the flexing response, that that load might be proper for that. We're lacking data on, well, what really does that fuel pellet contribute in a true pinch load. And there is some international experimental work that is just beginning that will provide some data for that in the future.

I know Studsvik has a program that the NRC is going to participate in that is looking at doing some analysis. EPRI is involved in some other work that's going to begin in France. And then, even the sister rods that are available for testing at Oak Ridge, they're going to be further doing some additional testing in the pinch load mode with the pellet. So, we get more data. We'll be able to apply that and further advance and improve the guidance.

MEMBER RICCARDELLA: So, the pinch load is what occurs what, right at the grids, as you drop the cask and you get a loading at the support points? Is that what you're referring to? Is that what causes the pinch load?

MR. WALDROP: Yes, well, the pinch load really comes from the rod above it. As you drop it and they all come down together, one rod will land on the other rod, and that load is transferred through the --

MEMBER RICCARDELLA: But enough to touch during the drop?

MR. WALDROP: Through the grid.

MEMBER RICCARDELLA: Oh, through the grid?

MEMBER MARCH-LEUBA: At 100 G's you would collapse it in.

MEMBER RICCARDELLA: Through the grid, though, not -- they don't collect mid-span such that they touch, but it's just, yes, the loading at the grids. Yes, I got it. Thank you.

MEMBER MARCH-LEUBA: And when you say "side drop," do you mean it falls off the table at such a speed or do you mean a truck going at 60 miles an hour hitting something?

MR. WALDROP: The hypothetical accident condition in Part 71 has a 9-meter drop accident that needs to be --

MEMBER MARCH-LEUBA: Starting from zero velocity?

MR. WALDROP: From zero velocity --

MEMBER MARCH-LEUBA: Right? I mean not moving --

MR. WALDROP: A 9-meter side drop.

MEMBER MARCH-LEUBA: And that's how you get the 100 G, right? That's a lot of G's.

MR. WALDROP: We've talked a little bit about this, but another comment that we made was, overall, there's excessive reduction. So, the testing was done. The pellet provides some rigidity, but the section that goes through that, basically, continues to take piece after piece away.

So, initially, like we talked about, cladding-only versus fuel with the pellet, they did that testing and found about a factor of 2 more rigid. And that factor of 2 did use what few data points they had to do a 98 percentile 2 sigma to reduce that to 1.96.

Then, the factor was reduced to 1.4 to account for hydride reorientation. That's appropriate. That was part of what the testing was. But it also commented that the factor came up by doing cladding-only tests of what that was, not including the rigidity of the pellet, as we've talked about. So, going from 1.96 down to 1.4, it's probably too much of a reduction if you consider the pellet. Further reduced to account for uncertainty. Agreed, there's three data points of as-irradiated, one data point reoriented. There's not a lot of data. So, they did take a further reduction due to uncertainty.

But, then, in the end, it was a factor of one. So, the end conclusion was use cladding-only properties and take no credit for the rigidity. And that last step was taken because the testing was only done on Zirc-4 fuel, but, yet, they're saying we think the reorientation treatment was applicable, was bounding of all types. But, again, the end result is there's no credit given for the rigidity whatsoever. But you can use cladding-only properties and you don't have to account for hydride reorientation.

We would like to continue to gather more data, and let's try to further that down the road and get better guidance where we can take credit for these things in the future.

And how we get there is ongoing in future-related work that we're looking at doing that, including realistic approaches. One area where we've learned a lot is the DOE-EPRI high burnup demo. We're finding there that the cladding temperatures as measured are low, such that we are not getting significant hydride reorientation in any high burnup fuel cask loaded. Agreed, the temperatures in the high burnup demo were even lower, but Oak Ridge went back and did some more best-estimate analysis on all the casks out there and found that it's in around the 320-325 C range, such that there would be no significant hydride reorientation whatsoever.

MEMBER REMPE: Is this a good place to interrupt and ask you to talk about this analysis effort and what I mentioned earlier to the staff? I mean the staff had this effort that they sponsored with all the laboratories, and they said there wasn't enough instrumentation to have a high fidelity CFD type of validation done. Is that what others are finding that did this effort?

MR. WALDROP: So yeah, as we talked about, the NUREG you are referring to is the staff's own report of their analysis versus the measurement.

MEMBER REMPE: Right.

MR. WALDROP: The EPRI report, it's in the publication process. It will be coming out soon, I don't know, by the end of the year. I can't remember the date. But it's going -- it's not just only NRC. It has a cask vendor and the national lab modeling done as well, again that blind benchmark of four different model submittals and how they did versus the measured data.

The measured data is very good. We're using the thermocouples based on reactor operation, uncertainty of I think less than 2 degrees C in those measurements. So those are good. What we don't have as good a handle on for the modelers it to understand the gaps, and going through this effort, when the modelers were trying to determine what the answer was compared to the measurements.

We found that this is a conductive-based system. It's a cask with basket transferring heat through conduction. There is uncertainty in the actual condition of what the gaps are, and we feel that that's the largest uncertainty as input to the models. So as we go forward, I'll talk about it as well as Ricardo's talked about it.

We're looking at doing some expert elicitation through the PIRT process. One key area we're looking at, not just cladding performance but also thermal modeling, and that will be looked at very much in that area, including uncertainty quantification of things like well, where's your biggest uncertainty and how do we address that and what impact does it have so --

MEMBER KIRCHNER: It seems to me that you can bound this problem, and I'm not sure what degree of accuracy you're chasing. It's sitting there pretty much as a stable pot little container. So you can deal with these kind of variations with uncertainty and sensitivity analyses that will give you plenty of confidence and margin at the same time for the application at hand. I'm wondering if you're over-working the problem.

MEMBER REMPE: Well I'm just wondering

again, the report's not out yet, but this was one set of calculations done by one organization. Did the other organizations have the same type of conclusion, that it was going to present problems for characterizing what they get out of the high burnup demo?

MR. WALDROP: I wouldn't characterize it that way. I would say it led us to, for this particular task, the gaps were a big factor and we feel that it's not knowing what those gaps are in reality that is contributing to the difference between what the models say and what we measure.

MEMBER KIRCHNER: But the point is trying to make is you're not going to know that for every cask going forward. So you're going to bound this problem with some uncertainty and sensitivity analyses.

MEMBER REMPE: But the problem I'm trying or question I'm trying to understand is right now there's been an issue where I brought about the VA is trying -- it's not clear they're going to open up this cask. They spent a lot of money getting the cask together. If they did open it up and they did try and evaluate the rods in a hot cell, would there be so much uncertainty that it's not worthwhile, or is that question addressed by this EPRI report?

MR. WALDROP: No, no. Again, I think it's a step in the direction. I think where we're trying to go with the PIRT is to better understand where are the things that make the difference, and let's get our -- let's understand what those are. Again, this is conduction-based system, a bolted cask system --

MEMBER REMPE: Thermal couples --

(Simultaneous speaking.)

MR. WALDROP: --those, but most systems are canister-based that include convection. So as we further do the work in this PIRT to look at the thermal modeling puts that matter the most, we need to concentrate on what are the factors that affect those convective-based systems.

MEMBER REMPE: So with respect to the high burnup demo, is it overstating the case to say you've got the thermal couples? We're good for understanding what the temperatures are where we don't have thermal couples.

MR. WALDROP: Yes, I think absolutely.

MEMBER MARCH-LEUBA: Is any of this analysis involve any kind of Monte Carlo simulations to determine where the uncertainties actually are and what are the important ones? This PIRT thing is just a sort of elicitation, right?

MR. WALDROP: Yes.

MEMBER MARCH-LEUBA: But is somebody doing an actual propagation of errors if you want to call it?

MR. WALDROP: Sensitivity, individual sensitivity analyses are --

MEMBER MARCH-LEUBA: It's a multivariate.

MR. WALDROP: --run in a Monte Carlo simulation to my knowledge.

(Simultaneous speaking.)

MEMBER MARCH-LEUBA: Yeah. When you have a multivariate problem, at some point the number of variables that you're doing sensitivity on just get out of hand. And so you do a Monte Carlo simulation, where you put distributions on all of the parameters, and then you look and see what's going on. Is anybody doing that?

MR. WALDROP: I'm not aware. I don't know if Oak Ridge might be, you know.

MR. CSONTOS: Hi. This is Csontos from EPRI. So I just want to make a couple of points. One was the purpose of the high burnup demo, you know, benchmarking study, it wasn't there to do a CFD model validation. This is a real canister or a real cask, okay, that we outfitted with real thermal couples to get real data, okay.

I understand that, you know, there's been work done between DOE, NRC and others to look at doing CFD benchmarking, full-blown CFD ISFSI type code benchmarking, okay. That's not what the purpose of this work was. The purpose of this was hey, we've got an opportunity to have a real cask to get that data set, okay.

What it showed us was that a very small percentage of the cladding surface ever got to the highest temperatures, which was between roughly, you know, between 20, almost 30 to 90 degrees off on the lower side, okay.

When you take a look at best -- so you have bounding calculations from the, from the licensing counts, okay, to what Member Kirchner was saying is that, you know, this is the way that it's been done. It's done right now with bounding calculations with everything worrying about this 400 degrees C limit on the high side. So we have to be worried about all those things.

But when what he was mentioning is that Oak Ridge went back and did a recalculation of all the available data, of all the canisters that have been loaded to date, okay, did a best estimate calculation, and what we found is that only about less than one percent of the claddings that were at the highest temperature, okay. The vast majority of it is even 30 to 40 degrees lower than that when you look at the histogram.

When you take a look at all the canisters loaded all across the country with high burnup fuel in it, okay, where they were -- design-based calculations were shown to be 400 degrees or near 400 degrees C at the max, we're at most 325 for maybe a few packages, and the rest of them are less than 300. And that's for the peak temperature of like maybe one to two percent of the cladding. The vast majority of it is even 30 to 40 degrees lower than that.

So this is where we're looking at this, taking a look at hey, what is the reasonable best estimate that we can look at, because it's now a combination of both just -- not just the fuel that we can think about. We're also thinking about the canister. So getting a canister temperature wrong at a high end may be non-conservative for corrosion calculations.

So in this way we're trying to get a best estimate, to make the best decisions possible. I think that's kind of where -- and Ron, to your question about Monte Carlo simulations, no one has done that yet, okay. We're not planning to do that right now. What we're doing is we're trying to identify all the different -- because there's a nexus between fuel, temperature, decay heat, fuel and performance and also temperature modeling, we're doing a PIRT to look at all three of those simultaneously.

Taking all those uncertainties together at one time we'll be able to then go into that next step of really starting to maybe do some more work on those, on the certainty quantifications. But at this point, there is a group of experts that we've -- international group of experts that we're bringing together, and including NRC and external, you know, DOE external folks, to try to get to this understanding of quantifying the uncertainties in a expert elicitation qualitative manner, then go into more quantitative after that.

CHAIR BALLINGER: But when you're doing, when you have these multiple variables and you're doing an -- well, you're doing a sensitivity analysis, you're ignoring the fact that in a lot of cases it's likely that some of these variables are correlated?

MR. CSONTOS: Yes.

CHAIR BALLINGER: So that's what the Monte Carlo simulation lets you deal with, and you know super computers are cheap nowadays.

MR. CSONTOS: I don't disagree with you.

CHAIR BALLINGER: I think.

(Simultaneous speaking.)

MEMBER REMPE: And the PIRT, will it evaluate both the drying, the uncertainties in the drying process as well as in the long-term story?

MR. WALDROP: We were -- so that's a question in terms of the scope of the PIRT. We were looking at storage and transportation. So the short term operations, you know, it has to play. That's a dynamic, you know, type of effort. The drying part, yeah we'll have to be thinking about that, because that's where the peak temperatures are.

MEMBER REMPE: Okay, thank you.

MEMBER MARCH-LEUBA: I'm easily confused. Can you explain to me what we're trying to do, what you're trying to do, because we have a whole bunch of canisters out there. We've put a lot of fuel in dry storage and it's working fine. Nobody has a problem with it. If you got everything you wanted, what would you be doing differently?

MR. WALDROP: We could be more efficient in our process for trying to license these systems. We could be more safety-focused on okay, in thermal, what are the things that really matter and what are the things that don't?

(Simultaneous speaking.)

MEMBER MARCH-LEUBA: You want to reduce the licensing burden, or would you be loading more fuel in the same canister or what -- I'm trying to --

MR. WALDROP: That's going to be the next. But first we want to better understand what are the margins that are there. Then the next step would be implementing where do we want to go with that, and that is an open question of where, what it is that we want to do with that. First we need to identify it.

MR. McCULLUM: I'll give you a tangible example. Keith is right. We do want to reduce the licensing burden. That means I don't have to go through a two-year process, you know, to get a license for something or to get an amendment for a distinction without a difference for parameters that changes that doesn't matter to safety.

I do that, and then I'm a decommissioning plant. Right now the business models for decommissioning are advancing very rapidly, and a key component of those business models is get the fuel out of the pools more quickly. Get into dry storage and then get down to tearing the plant down faster. That really uses the decommissioning trust funds a lot more effectively. But if I've got to submit an amendment to load hotter fuel, because that means loading hotter fuel.

You know, the last core is done, I don't want to wait three years before I load it. I want maybe a year and a half, two years, whatever they're going for, whatever they're trying to do to get these plants down. I was just up at Connecticut Yankee talking to Wayne Norton, who decommissioned all three of the Yankee plants, and he brags, you know, we did it in seven and a half years and nobody's beat us yet.

Well they want to beat that, and when you see the Connecticut Yankee site and it's down to green field except for the ISFSI, it's a true testament to why nuclear is clean energy. Yeah, zero carbon, but it's also because of the stewardship of the land. Being able to do that, being able to load hotter fuel faster, another tangible -- will support these decommissioning programs happening on tighter schedules and improved budgets.

Another thing we're looking at is, you

know, extending burnups even further with HALO fuel, so that we can shorten or lengthen periods between refueling outages. Right now, we've got a population of PWRs in this country that are on 18 month outages. We want to take those to 24 months. That's going to mean eventually loading hotter fuel in the dry cask on down the line.

If we are constantly applying for amendments that take years to get, that's getting in the way of being able to do those things that keep our industry competitive.

MEMBER MARCH-LEUBA: But let me see if I understand what you're saying. You want to extend the operability of loading casks to conditions, call in (phonetic) temperature, call in burnups for which we don't have any data, have not been analyzed.

MR. McCULLUM: Well, I think we have the data. I think that's the point. If we have the data and we have the knowledge, we should be able to do these things. I think it's --

MEMBER MARCH-LEUBA: That's what the license amendment process is. If you have the data, send it to them. They'll look at it and figure out if it is the correct data and it demonstrates what you're doing. But --

MR. McCULLUM: The question is in the level of detail of the data that I have to submit.

MEMBER MARCH-LEUBA: But I see inconsistent approaches, okay. You want to reduce the licensing burden. You accomplish that by doing what Walt is saying, bound the problem, envelope the problem and I don't have to do the analysis over and over and over again because they're bounded.

MR. McCULLUM: Exactly. If I have --

MEMBER MARCH-LEUBA: But you're telling me now what you really want to do is expand the problem.

MR. McCULLUM: No, I want to draw, I want to draw --

MEMBER MARCH-LEUBA: That complicates your licensing.

MR. McCULLUM: I want to draw a boundary that encompasses more stuff. That's what I want to do. I still want a boundary that these guys already agreed to, but I want that boundary to give me more degrees freedom inside it.

MEMBER MARCH-LEUBA: Well then you need data.

MR. McCULLUM: And I think what the argument here is we have that.

MEMBER MARCH-LEUBA: Oh, so what you want is NUREG-2224, with what?

MR. McCULLUM: We want NUREG-2224.

MEMBER MARCH-LEUBA: And Rev 1. You want Rev 1.

MR. McCULLUM: We want that. We want the demo. But it can't be a never-ending series of we always need to know more, if we already know if that knowledge won't matter to safety.

MEMBER MARCH-LEUBA: What we know in regulatory affairs is NUREG-2224, which gives you 400 degrees, and they might have gone hotter but --

MR. McCULLUM: 400 degrees is an arbitrary limit.

MEMBER MARCH-LEUBA: It is -- it's one-dimensional. I mean at least one significant digit.

MR. McCULLUM: Right, yes. So if I know --

MEMBER MARCH-LEUBA: I complained about that before, but right now that's what it is. If you want to expand it, don't tell me you want to reduce the regulatory burden. You're going to increase the regulatory burden on yourself if you want to expand something.

MR. WALDROP: Again, what we want to do is understand the margin and then determine what might be the best application of once we understand what it is. Increasing the temperature limit, that is, you know, from maybe we load hotter, maybe we go above 400 and we -- but we -- going above 400 C for a peak clad temperature limit is going to open up a bit of Pandora's box.

We certainly will need more data, because most of the testing has been done with that limit in mind. Do we want to go to a hotter system and still demonstrate that we're at 400, that we're below 400 degrees.

MEMBER MARCH-LEUBA: I'm a computer guy and analysis guy. Whenever you start to do your calculations, you know, that you can see the calculations are conservative. I have a joke about conservative calculations. They're in error on one direction. But do better calculations, stay within 400 and then you don't have to change the regulatory basis.

MR. McCULLUM: But what we're saying is that's not good enough to get us to where we want to be in terms of decommissioning and offloading pools, in terms of going to higher burnup so we can lengthen fuel cycles, you know. That --

MEMBER MARCH-LEUBA: So what you're saying is 22224 with a NUREG is not sufficient for you. You need NUREG-22224 revision --

(Simultaneous speaking.)

MR. McCULLUM: Oh, I'm saying --

MEMBER MARCH-LEUBA: --that increases some of the parameters.

MR. McCULLUM: Well, we'll see. That's where this white paper and this PIRT are going to take us next, is I think you can take the information in 2224 and combine it with some other things in getting there. I'm not saying we have to revise 2224.

MR. WALDROP: The 400 degrees is in ISG-11 and now the SRP. So it wouldn't necessarily impact 2224, but again that's a -- it's not a foregone conclusion that we want to go above 400.

MEMBER MARCH-LEUBA: Let me -- I mean I kind of have a reputation for being frank. Make up your mind and see what you want. Let us know.

MR. WALDROP: I think the point I'm trying to make here is 2224 does a good job. It gets some guidance out there today that to use for high burnup fuel particularly in transportation. But my point on these slides is we can continue to go even further beyond where we are now, and so I'm trying to be forward-looking here.

MR. CSONTOS: So yeah, I've been hearing -- one, to answer your question, thermal hits everything on the back end. It's the line or the thread that goes through the entire back end, storage transportation disposal. DOE's interested as a disposal. Can you store more fuel? I mean you can't in terms of total tonnage. You have to go to other repositories.

But if you have a better understanding, you may be able to do better, you know, management at that end. For us, every year you can reduce the time for decommission, it's 25 million plus, okay, for that judgment, for the decommissioning fund, okay.

MEMBER MARCH-LEUBA: Per plant?

MR. CSONTOS: Per plant, per plant.

(Simultaneous speaking.)

MR. CSONTOS: So the other thing is is that -- to think about is that we're moving to higher burnup fuel. What's coming out is higher burnup. So you're not having the ability, you're losing some flexibilities going to the future, especially if we go to ATF, possibly go to higher burnups and higher enrichments.

You're going to go to higher burnup fuel, which is going to be hotter. And so we're, you know, we're trying to expand the operational flexibilities. But I completely agree with what you're saying, which is you're asking for possibly more -- it looks like we're looking for more regulatory burden, and that's not -- that's not what we're --

So we're trying to do with the PIRT and a lot of these other things here is to figure out what kind of an approach that we could do to take some of those uncertainties that right now we have a bounding assumption for. So for example, we're doing the ambient temperature assumption, okay. For North Anna, for the high burnup demo was I believe 105 for the first, for your initial licensing basis counts, okay.

That was reduced to 90 degrees, okay, and the day that it was loaded was 70-something degrees, okay. Could you figure out a methodology where you could use real data, okay, instead of bounding assumptions and show that you're still within the safety window, okay?

There you then can have both. You can get more flexibility, more windows, more margin, using the margins that's already in the canisters, but also not increase your burden, okay. So that's kind of where we're seeing that this is where we'd like to go. But

I completely agree, that we're not trying to increase burden here at all with this effort.

It's trying to better utilize the margin, but make sure that we still keep the fuel interval, all right. There's nobody wants to cause any problems, but as long as there's a very low probability for the spent fuel, you know, for any kind of problems with the spent fuel integrity, to keep that extremely low but have the margins to be able to, you know, load from either hotter fuel assemblies or if you give this opportunity to the vendors, maybe those vendors can design better canisters to load more as well.

So would reduce -- so in some cases, you could reduce the number of transportation events, okay, if you could load more fuel more efficiently into canisters, okay. The other thing is that for our utility members, we're being limited in some cases for dose considerations to the workers by putting on thermal blankets, okay, because we're really close to the 400 degree C limit with respect to the bounding calculation approach, okay.

MEMBER MARCH-LEUBA: So that's because of dose rates to the workers?

MR. CSONTOS: They want to put -- so some of the utilities want to put more, you know, blankets on there. But they're limited because of the thermal counts to be able to put more --

MEMBER MARCH-LEUBA: To put blankets for --

MR. CSONTOS: Shielding blankets.

MEMBER MARCH-LEUBA: Shielding.

MR. CSONTOS: Shielding blankets, right.

MEMBER MARCH-LEUBA: Lead blankets?

MR. CSONTOS: Yes, yes. And so in this way, we could be helping by increasing that margin or increasing the operational flexibilities there. We can also help the worker doses.

MEMBER MARCH-LEUBA: Have you considered refrigerator chamber? I mean work at 37 degrees man.

MR. CSONTOS: Exactly.

MEMBER MARCH-LEUBA: If it doesn't work, you stop loading.

(Off mic comments.)

MEMBER MARCH-LEUBA: Microphone, microphone.

MEMBER RICCARDELLA: I think, you know, I'd refer back to Ron's comment about I think the way to get to where you want to go is through quantifying what the distributions are on all these, and maybe this will come out of your PIRT and then do a Monte Carlo analysis that shows hey, I only have ten to the minus 3rd probability that any point in the fuel is going to exceed 400 degrees.

That's risk-informing it as opposed to planning margin on top of margin on top of margin. Because what happens is, you know, you have all these distributions and when you do a deterministic analysis, you assign a safety factor to each one. But the probability of all of those, of ending up on the bad end of all those distributions is very, very slim.

MR. CSONTOS: Correct, and that's exactly why we have an uncertainty expert from Sandia National Labs who's worked on a lot of reactor projects, SFPR (phonetic) and other things to come in with that understanding of hey, let's take a look at all these uncertainties, okay, of these individual parameters. But also let's look at the cumulative effects of coupled conservatisms, and see how that's being promulgated down the line.

Because then that way that uncertainty expert can then give us on the deterministic side a little bit better understanding of how it is. And then like you said, then going through some sort of analysis might be the approach to go.

CHAIR BALLINGER: I rest my case. Your best uncertainty expert is a computer.

MEMBER KIRCHNER: Well, may I make an observation?

CHAIR BALLINGER: Of course.

MEMBER KIRCHNER: I asked a leading question earlier about whether this whole thing is risk-informed. My own assessment is that, and it's just one member's opinion, is this is a problem that is amenable to the risk-informed approach, and it's a problem that's amenable to working from the outside in instead of the inside out, by which I mean by and large you're really relying on the cask for the protection of the health and safety of the public.

Certainly you want to contain fission products and keep structural integrity for a number of reasons shown in the very nice chart that was provided earlier. But I would submit that almost everything inside the cask is really an economic issue of retrievability, and keeping it intact so it's manageable when the time comes to actually dispose of the fuel.

And so I feel it's a problem that's amenable to bounding through that kind of uncertainty analysis, and then you could go I think to a more generic approach to the cask licensing or certificates, so that's you're not constantly forced to have an amendment for every change of fuel loading in that cask.

This is a boundable problem and there is methodologies out there and there's enough data to support bounding it in a manner that would reduce the burden that you would see for the cask in the licensing arena. Just one person's opinion, and you set those limits and that would set the amount of fuel you could put in the cask, and the question of high burnup versus lower burnup is more --

First, it's a thermal issue initially, and loadings on the cask. You want to maintain the performance that's in the diagram, of course. You want to ensure that you can maintain some criticality. You have the radiation. But in the end, if you're really doing this from a risk-informed approach, then you would be looking at consequences and you could bound this problem I think very nicely with that approach. So just one member's opinion.

CHAIR BALLINGER: Another member's opinion. I've been personally pushing on the fact that we've got the cart before the horse from the beginning, that we've not done the consequence analysis which should have been done first. One person's opinion.

MR. McCULLUM: Doesn't EPRI have some work going on in that area?

MR. WALDROP: Not currently. I mean we've -- back in the mid-2000's, there were a couple of PRAs on casks.

CHAIR BALLINGER: But that was all on cask drops --

MR. WALDROP: Right.

CHAIR BALLINGER: --and things like that, not --

MR. WALDROP: I'm talking about Shannon's work with the, you know --

(Simultaneous speaking.)

MR. WALDROP: Looking at it from outside. Yeah, looking at it from the outside in. You know, what Dr. Kirchner said is it really is an economic issue. The question is what am I going to have to have in place at whatever facility opens these things up.

CHAIR BALLINGER: Yes.

MR. WALDROP: Yeah.

MEMBER KIRCHNER: The building becomes an economic question for either the government or for the industry.

MR. McCULLUM: Or it goes away entirely. We already have retrievability by canister and I will remind again on the record that NEI has a contention in the Yucca Mountain licensing process where we maintain, based on scientific analysis, that the existing dual purpose canisters can be direct disposed of in Yucca Mountain, and in that case it's not even that issue. So I would say in consequence from the outside in --

CHAIR BALLINGER: Yes, yes, you're right.

MR. McCULLUM: Right.

CHAIR BALLINGER: You're right. Some work going on looking at the consequences of a canister breach, looking at the contents of the fuel inside, you know, what gets released and what would the true consequences of the offsite dose limits, and that work is going on.

MEMBER KIRCHNER: But if I were in your shoes and industry's shoes, I would approach the problem so that I could get a more generic capability or certificate or license for these canisters, rather than amending it every time you put a different fuel in.

MR. McCULLUM: That's exactly where we're trying to be.

MEMBER KIRCHNER: And that -- and by the way, this is not to in any way dismiss all the good work we've heard about this morning. I mean that also is necessary. You need that kind of data to make this kind of case. But I do submit this is one that you could really bound.

MR. McCULLUM: That's the ultimate goal, and I couldn't have put that better. Thank you for your opinion.

MR. WALDROP: Very good perspective. I agree with it. Not to make excuses, but that's one way to approach the problem. If you go back and look at the regulations, here we are talking about cladding integrity. It is assumed that cladding integrity is maintained. The regulations do not require cladding integrity to be maintained.

They require you to do things if it's not, that you know looking at to prevent storage, to prevent gross rupture. In transportation, you need to be -- analyze the most reactive configuration, I mean those kinds of things. But it does not require that the cladding integrity be maintained.

CHAIR BALLINGER: You end up having to change Part 72 and 71, because that basically says --

that defines confinement, right.

MR. WALDROP: It's -- the cask provides that.

CHAIR BALLINGER: Right. But the definition of confinement --

MR. WALDROP: It doesn't have to be the fuel.

CHAIR BALLINGER: Yeah, that's true.

MR. WALDROP: Having it be the fuel makes it easy to get through the safety analysis, to say okay, what is our most reactive condition? If the cladding integrity's maintained, I know what I get to analyze. So it allows the ability to get through the regulatory process and approve a system. So there is benefit in that but yet, you know, as the regulations are set up for a general license system, you try to bound a number of things so that you can have one license that a bunch of people can then go use.

In doing so, you've included uncertainties of a bounding, what's the most reactive assembly, what's the heaviest assembly. Those two aren't the same, but we assume that they are. So you've got a lot of those assumptions built in to make it more useable to the industry to begin with.

We've got -- we're a mature industry now.

We've learned a lot. So is it time to go back and can we get to a point where we can do a cask-specific analysis and demonstrate safety? That's a big, that's a heavy lift and a different structure in being able to approve methodologies like you do on the reactor side with the core operating limits report kind of thing.

Do you do that for cask? I don't know, but it's the time with our mature industry to start thinking about where can we go to improve efficiency.

MR. McCULLUM: It is the time. I do see paths where yeah, you could change 71 and 72 and get there too. We're trying to get there without changing those, to get to a more bounding approach that can generically be applied. The reason for that is quite simply illustrated by the ongoing decommissioning rulemaking.

You know, making a rule that codifies exemptions that are already being issued is a fairly simple thing. That rulemaking started in 2014. It's 2019 and it's still not done yet. When I look at the decommissioning projects that may want to load hotter fuel, when I look at our country is about to get its first four-unit PWR, we don't want four units all on 18 month cycles at the same site, you know. These problems are more urgent than rulemaking will support.

CHAIR BALLINGER: I mean I -- this is a great discussion, but my handler tells me that there are four people on the phone that are waiting to make comments.

MR. McCULLUM: Keith, we get it back on schedule.

CHAIR BALLINGER: Yeah.

(Laughter.)

MR. WALDROP: Good discussion. So let me wrap this up. I've just got a few more slides and comments. So again, the work that we learn on the high burnup demo is an opportunity to further advance guidance. This was alluded to.

Sandia and ENSA (phonetic) conducted a transportation test, where they had a cask, a real spent fuel cask with simulated assembly -- well, mock assemblies, highly instrumented, and they found that the actual transportation loads for normal conditions of transport are orders of magnitude below the fatigue limit.

So does that open the door that maybe we don't need to do a fatigue limit analysis for normal conditions of transport from what we learned there? And also there's ongoing -- there's recently-initiated work looking at the mechanisms of hydride reorientation to better understand that. Like I said, pinch load testing.

Another area is what about high burnup fuel. The fuel clad has a bonding and what impact does that have on hydride reorientation? We've done a little work there and seen a tremendous benefit, and the expert elicitation I've mentioned. So in summary, our perspective is the NUREG accomplished its objectives. It provides needed guidance at a time when we need it.

We went back and looked at the history of the regulatory guidance. A lot of information over the last 16 years since that was put in place, and the NUREG went and created more and looked back at what was available to update this guidance, so I think that was well done. The comments were generally addressed, and overall I think it's a step in the right direction and these are good discussions.

But I think we've got future opportunity to consider what, how can we evaluate more realistic conditions, take credit, real credit for the structure of the pallet? Hydride reorientation, maybe it's not a concern after all given the temperatures and hoop stresses we're seeing. What about the loads of normal conditions at transport being very low? How can we implement that?

And again, continuing research that I mentioned, to the point of eventually trying to gather this information, do what this NUREG did and further ball with updating guidance with this new information. I'm done.

CHAIR BALLINGER: Well thank you very much. I thank everybody for their presentations. Now we need to go to public comment from people in the room. We'll do that last, yeah. So while we're getting the phone line open, it's open? Are there any members of the public in the room that would like to make a comment? We have a five second rule here for food and public comments.

So hearing none, are there -- is there -- I understand that there are about four people on the phone line that would like to make a comment. If anybody's out on the phone line, would you state your name and make your comment?

MS. GILMORE: This is Donna Gilmore. I'm at San Onofre, Sacramento. I submitted extensive comments on this NUREG. The one thing that really troubles me is (audio fading) has gained on over 4,400 data points from real operating data on the level of offsite buildup at various burnups, and I don't understand, since you have so little operating data which is really not even the typical operating data, why you aren't using that? That's one point.

I have a whole list of things. I can send you the link as to my comments online, and various like the explosion risk and there's other data and experiments that point to opposite conclusions. And then where is the defense-in-depth of the system, because that, you know, is what you're supposed to allow for in anything. There doesn't seem to be anything.

We have damaged fuel that's not been packaged. We have high burnup fuel, we don't know what's going on. We have thin-walled canisters mostly a half inch thick that we know can crack due to the pressure vessels, that they have no pressure monitoring of pressure release valves. And then the Nuclear Reg Technical Review Board is saying we need to know how much water is left over in these canisters, so we know how fast the hydrogen is going to build up from the radiation.

All these and a whole slew of other issues, it seems like they should be considered, you know. We're dealing with millions of people in our national economy and security, and so this is more than just about hopefully industry profit as being a priority there. So I'd like to see this. I have a lot more that I want to say, you know, cut it short because I know other people may have comments.

CHAIR BALLINGER: Thank you. I'm told that there are about four, so that means there's three more that may be there. If you're out there, could you state your name and make your comment?

MR. SAFER: Yes. This is Don Safer. Do you hear me?

CHAIR BALLINGER: Yes.

MR. SAFER: I'm in Nashville, Tennessee and I have listened intently to this conversation, and as a citizen who follows this issue, it is of great concern that all of the uncertainties that you in the industry, the NRC, the DOE are seeming to make assumptions. At a time when we've only been generating high burnup fuel for a couple of decades at the most, and we're expecting this fuel to last indefinitely in whatever canisters it's going to be stored in, either on surface in a CIS type site or in some deep geological storage.

And it just seems like the cart before the horse in terms of maximizing industry profit, when we do not really know how this stuff is going to behave over periods of time. It doesn't give me a lot of confidence that we're talking about computer simulations and that the sister rods study (phonetic), there's questions even coming from within the industry that DOE's isn't even going to be able to complete that study, of actually seeing what that fuel does in a short period of ten years, let alone 100 years, 1,000 years, 10,000 years.

When at this point the industry is talking about burying this stuff at Yucca Mountain altogether and at Nuclear Waste Technical Review Board hearings there have been questions about how you keep criticality from reoccurring in this material. Once the cladding does disintegrate, once the fuel pellets do start turning to dust and you start getting reconfigurations in a major way with all of that heat.

So I am happy that the considerations are being given, but I don't have a high level of confidence that the big picture is properly being looked at, and that public safety is of the highest priority in this process. Thank you.

CHAIR BALLINGER: Thank you. So now we're down to two potential. Is there anybody else out there that would like to make a comment?

MR. HOFFMAN: I would also like to make a comment. Is that okay?

CHAIR BALLINGER: Who? Can you repeat your name?

MR. HOFFMAN: My name is Ace Hoffman, and I'm a citizen in Carlsbad, California, and just a couple of comments. First of all, I think it was Rod McCullum who was saying when I first came on the line, I missed the beginning, that we really need DOE to open up one canister that they've been -- that they have presumably for studying.

And he was -- I believe it was him that was stressing that we need to open that canister. I think you can count on your thumbs in the 40 years or so I've been attending nuclear meetings and concerned myself with this issue, the number of times Rod McCullum and I are in complete agreement.

But we are there, except I'd like to add that 40 years ago when I was doing federal supplies, we had to go to a random box out of the hundreds and thousands we were shipping and then to a random product inside the box and then to a random item inside the product. That's what we had to test with and make sure we were delivering a good product.

I'm surprised that some 10,000 casks are coming and 3,000 or so built, that you don't need to open a dozen casks or two dozen casks. The expense would be great, but you might get enough information that can drive this whole conversation in the direction you need it to go. So those are basically all I'd like to say. I suppose there's a lot more about pinched loads and so forth that I'd like to comment on, but I'll leave it at that. Thank you very much.

CHAIR BALLINGER: Thank you. Is anybody else out there that would like to make a comment?

MR. LEWIS: My name is Marvin Lewis. May I make a comment?

CHAIR BALLINGER: You sure can.

MR. LEWIS: All right. Well, I've been a material engineer undergraduate work, metallurgical engineering, graduate work chemistry for almost 60 years or since 1960. You figure out the numbers. Anyway, I listened to this and one thing that is missing and keeps on missing, whether you talked about (audio fades) number one's drop or the drop in moving a cask or whatever, the one thing you guys seem to forget is there's people there, and people have been making mistakes a long time, a long time before they couldn't see a little bit late at Three Mile Island

No. 2, because there was a hanging maintenance tag.

People make mistakes, and we'll have people who make these casks and make mistakes. I don't see the human factor in any of your studies. I don't know where it went. Are these being loaded by computers? Are these being loaded by angels? I don't know, and you fellows think you know either. Thank you.

CHAIR BALLINGER: Thank you. Is there anybody else out there that would like to make a comment? Five second rule applies there too. Can we get the line closed? Okay. So can we go around the table now for members who would like to make any comments? By the way, at the onset we said that the staff did not desire a letter, but that given the fact that subcommittees are erratic, you might make a comment on whether you think we should write a letter or not.

MEMBER MARCH-LEUBA: I have enjoyed this presentation, and I think they've done a good job on trying to simplify the problem and provide us some guidance. I like the NUREG, but if they don't like a letter, I don't think we should make one.

MEMBER REMPE: I also appreciate the presentations and the discussions. I'm not sure a letter's needed on this, but the concern about not opening up the high burnup demo cask if -- that's something that if we want -- we might want to explore further and bring it up as part of our biennial research review if it's important to staff efforts. So we might want to keep that in mind.

MEMBER RICCARDELLA: I think I do enjoy the presentations. I think that the NUREG-2224 is a very nice piece of work. I congratulate the staff and but I guess I see it as very, very useful data, but not guidance. I wonder are there any plans to issue another rev to the ISG that would, you know, introduce some new guidance based on the research that was done in the NUREG?

MR. TORRES: Is that on?

CHAIR BALLINGER: Yes sir.

MR. TORRES: Okay. So yes, there are plans to update the guidance in ISG-11, Rev 4 to account for all the work that's been conducted over the last 16 years, to account for the conclusions in this document. So yes, that's the next step and that will be incorporated into 2215 and 2216. Thank you.

MEMBER RICCARDELLA: Thank you.

CHAIR BALLINGER: Walt?

MEMBER KIRCHNER: Good presentations and

discussion. I think I made my thoughts. I hope they were clear. I think there's opportunity to go much further in this particular area, and I'll stop with that.

CHAIR BALLINGER: Dave, if you're still out there?

DP Yeah. I want to thank the staff for all of their good work, and I don't think we need a lot of (audio fades).

CHAIR BALLINGER: Thank you. (Off mic) appreciation as well for everybody else, and we have succeeded in finishing three minutes, three minutes early, so we are adjourned.

(Whereupon, the above-entitled matter went off the record at 11:56 a.m.)

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

NUREG-2224
Dry Storage and Transportation of High Burnup Spent Nuclear Fuel

Christopher Regan, Gordon S. Bjorkman, Jr.,
Ricardo Torres
Division of Spent Fuel Management
Office of Nuclear Material Safety and Safeguards

Meeting with Advisory Committee on Reactor Safeguards:
Metallurgy and Reactor Fuels Subcommittee
Rockville, MD
August 22, 2019

NUREG-2224, Dry Storage and Transportation of High Burnup (HBU) Spent Nuclear Fuel (SNF)

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

- Purpose is to provide a status update of the staffs efforts to address a technical gap with respect to storage and transportation of HBU SNF
- Cask designers have been requesting regulatory guidance with respect to structural integrity of HBU SNF under storage and transportation conditions
- Draft NUREG-2224 provides regulatory guidance for storage and transport of HBU SNF based on the test results and previous draft RIS

NUREG-2224 (cont.)

- NRC issued a draft Regulatory Issue Summary (RIS) in 2015 while conducting tests on HBU SNF samples

- Draft NUREG-2224 was issued for public comment in August 2018

- About 450 comments were received and addressed by staff

- NUREG-2224 is planned to be referenced in storage and transportation Standard Review Plans as an method for analyzing HBU SNF in storage and transportation

NUREG-2224 (question and findings/results)

- Does high burnup (i.e., >45 GWd/MTU) impact negatively the structural behavior (i.e., hydride reorientation) of spent nuclear fuel when subjected to normal and accident condition loads for storage and transport?

- NRC has confirmed that current analytical approaches for evaluating HBU SNF are conservative and that the existing technical basis is improved that supports the staff's conclusion that radial hydride reorientation will not compromise HBU SNF cladding integrity during transportation and dry storage for up to 60 years

Safety Review Objective for Structural Performance

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

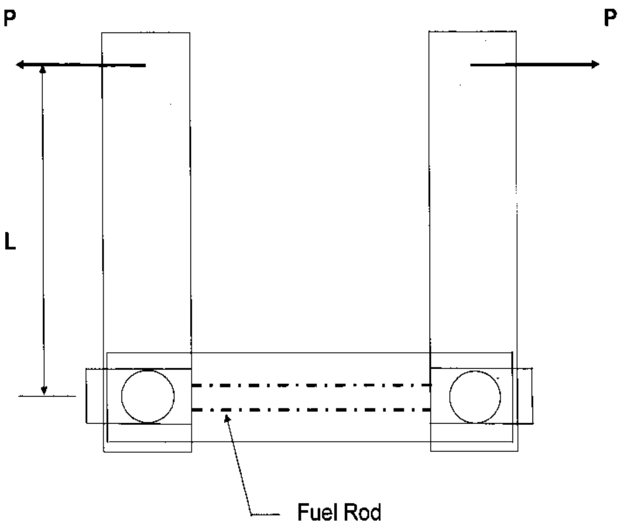
- The primary safety objective for the structural performance of spent fuel under Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC) is to maintain the analyzed configuration of the fuel

Static Bending and Fatigue Testing

- Purpose: To determine the behavior of High Burnup (HBU) Spent Fuel Rods in Static Bending and Fatigue
- Objective: To answer two questions
  - Will the HBU fuel rod fracture during a HAC event leading to possible fuel reconfiguration?
  - Can HBU fuel be transported under NCT without failing by fatigue?
- To answer these questions required the testing of fully fueled rods to account for the interaction of fuel pellets and cladding

CIRFT Testing Apparatus

To perform the static bending and fatigue testing the NRC worked with ORNL to develop the CIRFT* testing apparatus which applies a constant bending moment, M, to the fuel rod. Where M = PL



* Cyclic integrated reversible-bending fatigue tester

Experimental Methodology

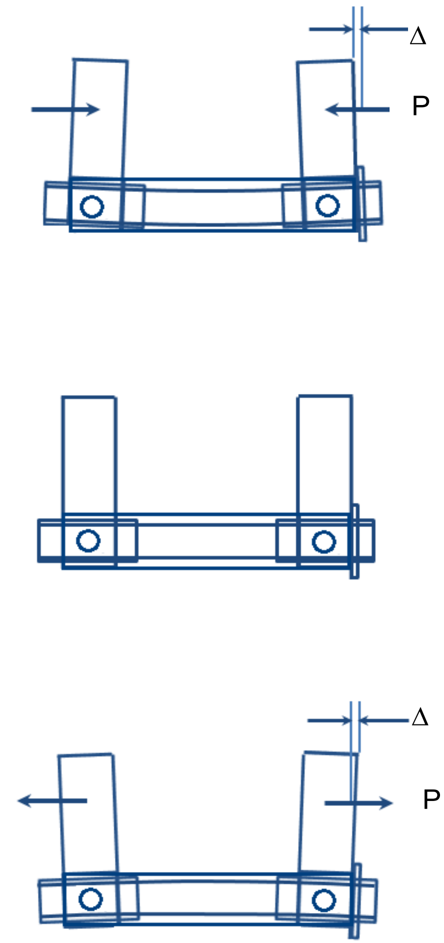
Subject a fully fueled rod to a constant bending moment

This produces a circular arc with constant curvature, κ, where

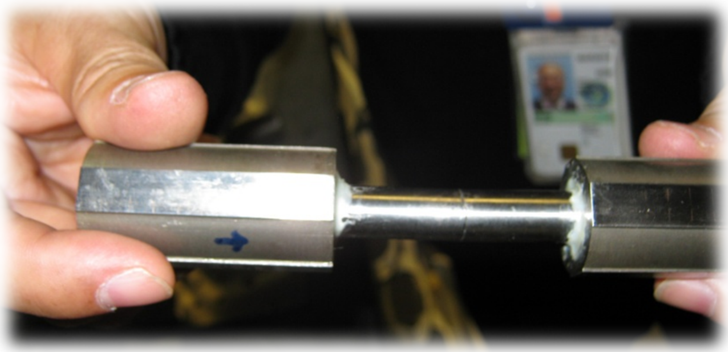
$\kappa = 1/R$ and R is the radius of the circular arc

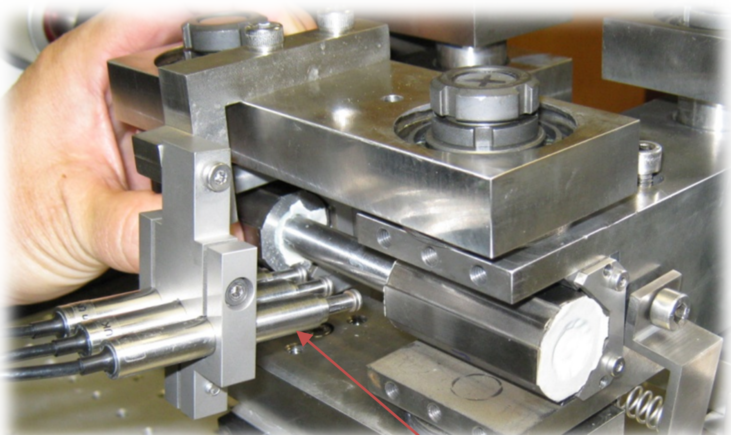
The location (i.e., displacement) of three points on a circular arc defines the radius, R, of the circle

Flexural rigidity (bending stiffness) of the rod, $EI = M/\kappa$

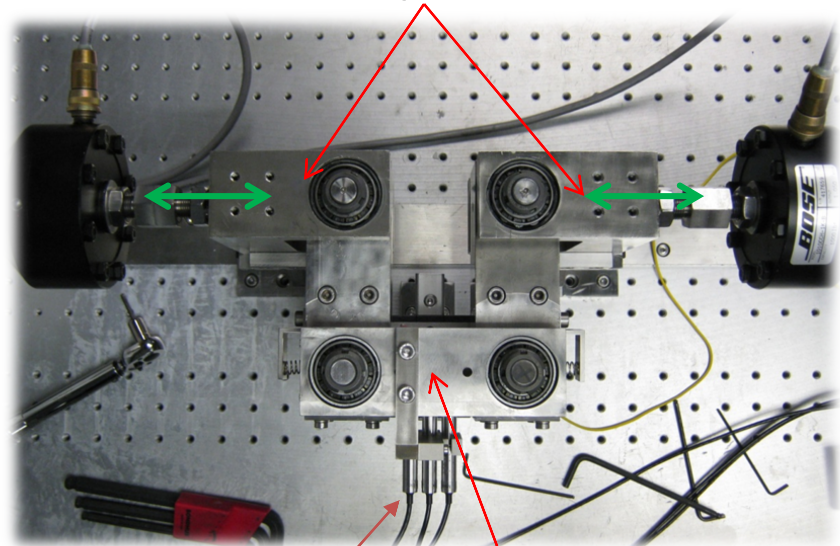


Instrumentation (CIRFT)





Push-pull force applied to U-Frame by the load cells results in a constant bending moment on the test segment

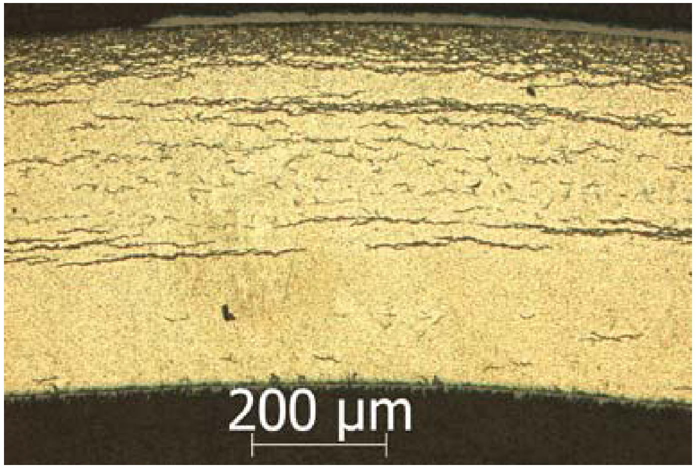


Location of test segment

Three displacement transducers

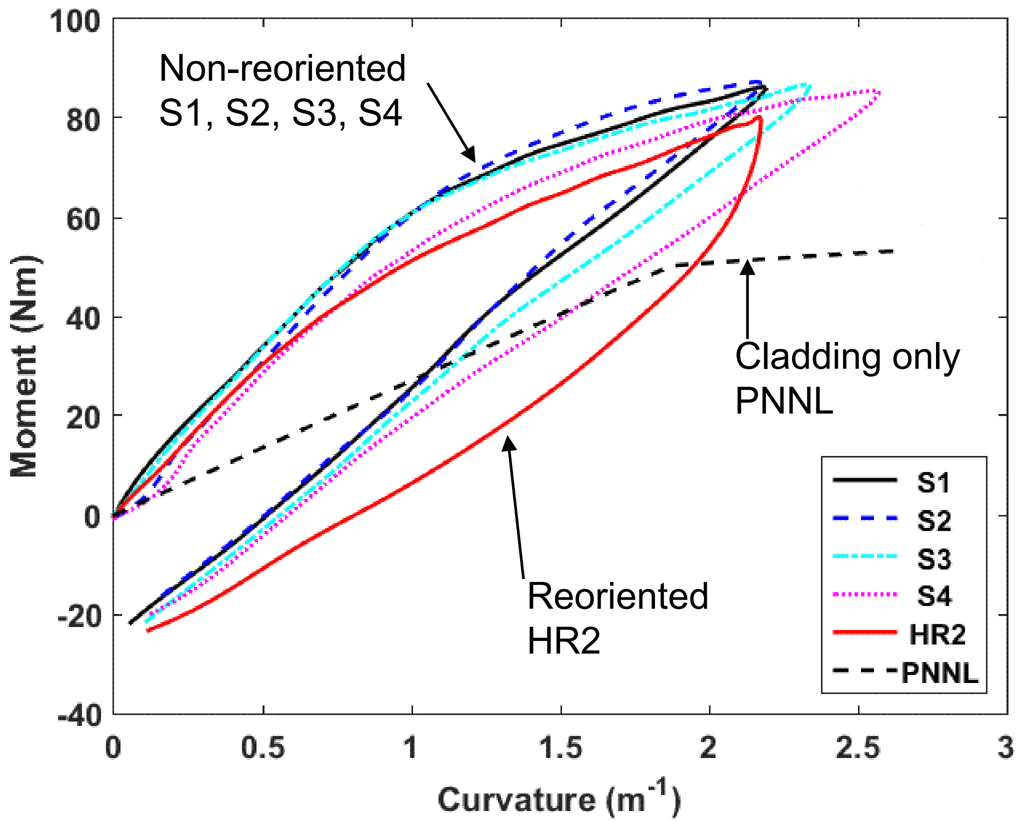
Materials Tested

- PWR SNF with Zircaloy-4 cladding (NRC-sponsored)
  – Burnup range: 63.8 to 66.8 GWd/MTU
- NRC Phase 1 test (non-reoriented HBU samples circumferential hydrides only)
  – 4 static bend tests + 16 vibration fatigue tests at a wide range of bending moment amplitudes
- NRC Phase 2 test (reoriented HBU samples circumferential and radial hydrides)
  – 1 static bend test (HR2) + 3 vibration fatigue tests at a range of bending moment amplitudes



Static Test Results

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

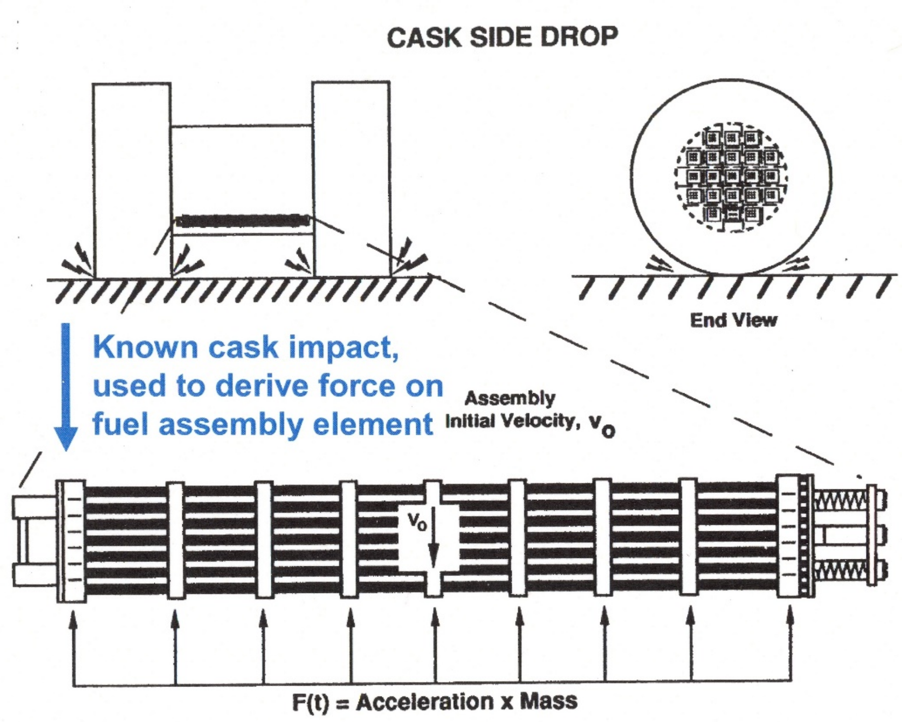


Static Test Results

- The static test results show that at bending moments less than 35 N-m the flexural rigidity of the four as-irradiated rods, which have only circumferential hydrides, and HR2, which has both circumferential and radial hydrides, are essentially the same

- This supports the pretest expectation that, because the bending tensile stress in the cladding is parallel to the plane of both the radial and circumferential hydrides, the presents of radial hydrides would not significantly alter the flexural response

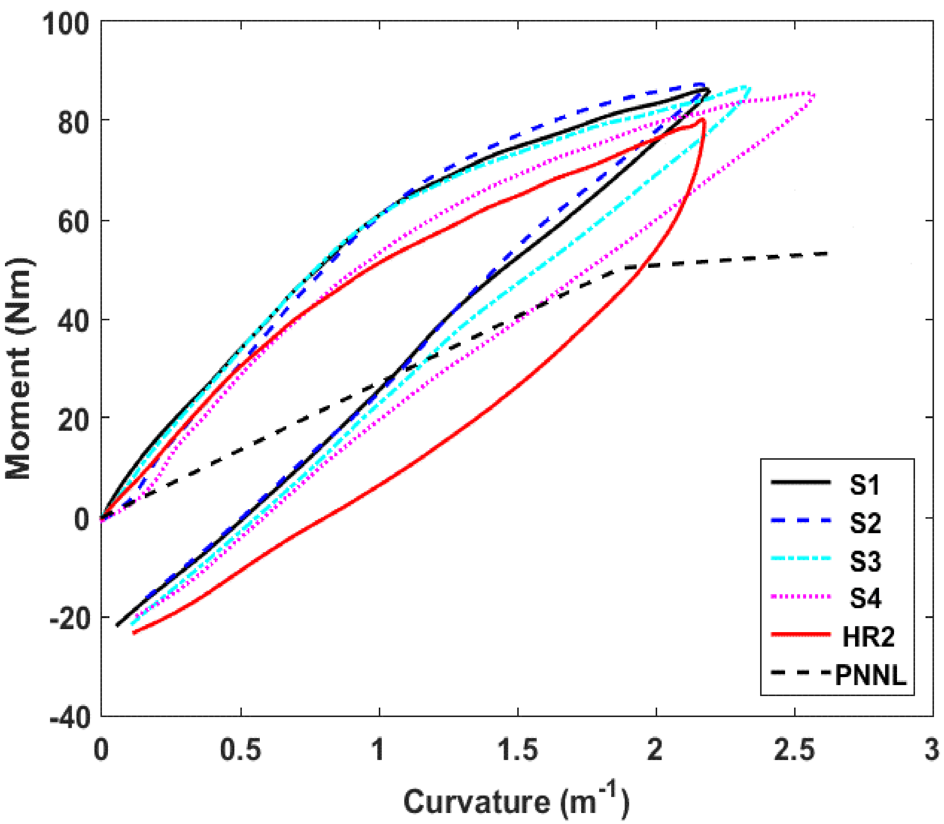
Fuel Rod Safety Margin against failure for HAC Side Drop Event



Fuel Rod Safety Margin against failure for HAC Side Drop Event

- Cask body of the transportation package typically experiences 50g on impact
- The flexible fuel assembly and fuel rods experience: Dynamic Load Factor x 50g = 2.0 x 50g = 100g
- For the fuel rods evaluated the static transverse g-load required to produce 1 N-m varied from 2.94 to 4.63g depending on the rod cross-section and assembly geometry
- So 100g / (2.94g/N-m) = 34 N-m

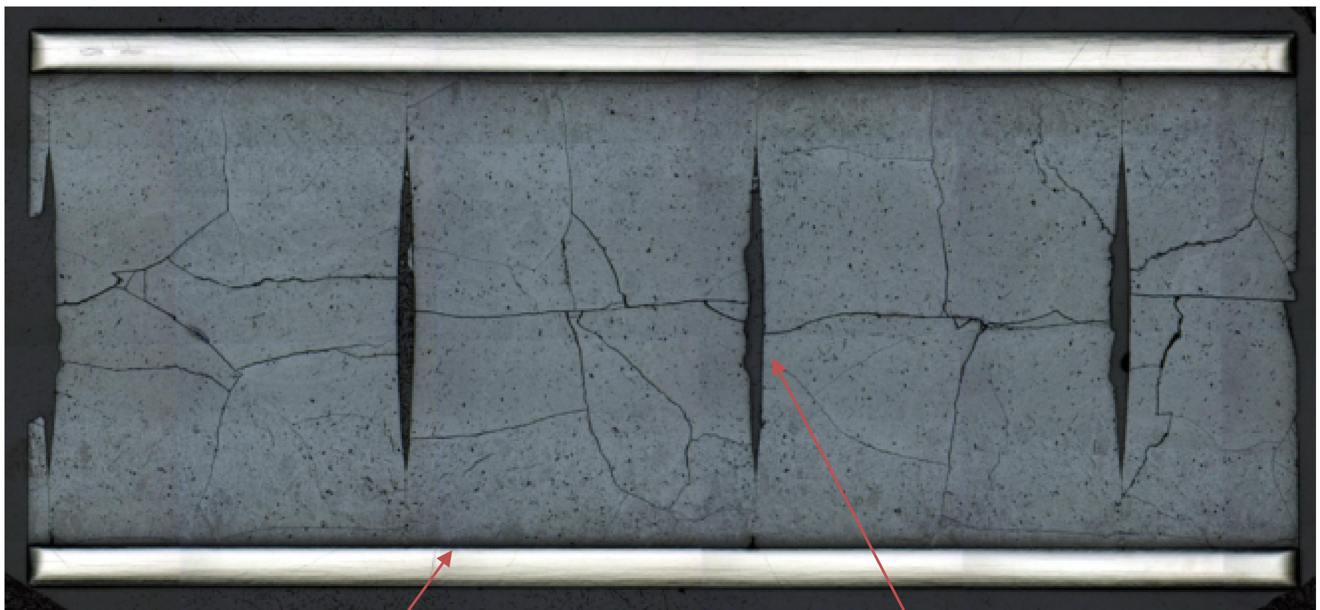
Fuel Rod Safety Margin against failure for HAC Side Drop Event



Safety Margin is conservatively calculated to be

80 N-m/34 N-m = **2.35**

Cladding-Pellet Structure in a HBU SNF Rod

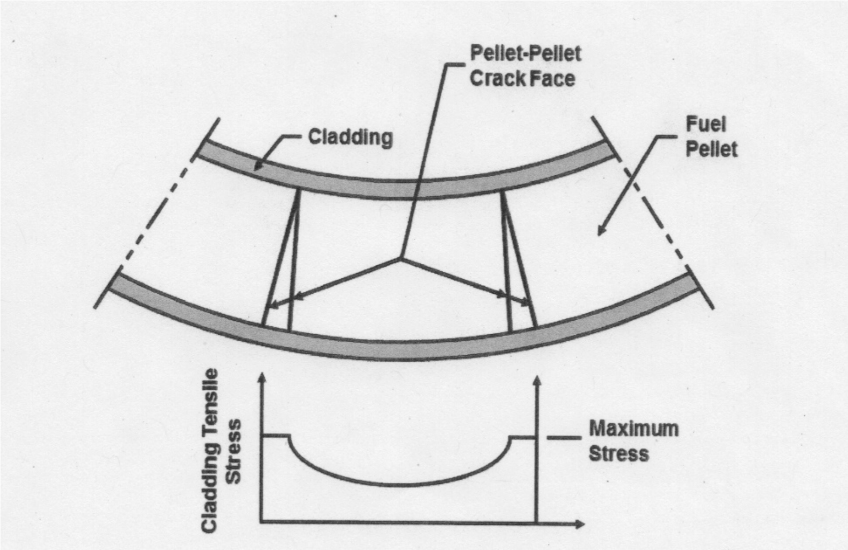


Cladding-Pellet Interface

Pellet-Pellet Interface

Variation of Cladding Tensile Stresses

- The region of the fuel rod weakest in tension is at the pellet-pellet interface
- When the pellet-pellet interface cracks in bending the tensile stress in the cladding at the crack face will increase significantly
- The high tensile stresses at the crack face decrease with distance from the crack
- Thus, cladding tensile stresses will vary significantly along the length of the rod



Average Cladding Tensile Strain

- Even though this behavior is known to occur, only the average tensile bending strain can be calculated from the static test results because the measured curvature is the integrated average curvature over the measured length (gauge length) of the rod

- The average tensile strain in the cladding, ε, along the gauge length is equal to the curvature, κ, multiplied by the distance to the neutral axis, which is equal to the outside radius of the rod, r. (This is the convention that has been adopted here and in NUREG/CR-7198, Revision 1 even though it is known that the neutral axis will vary along the gauge length)

- Cladding strain, $\varepsilon = (\kappa)(r)$

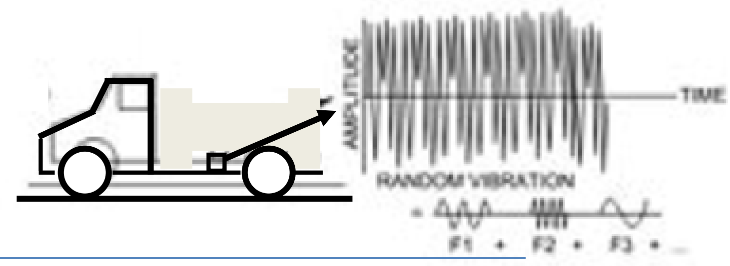
Calculation of Cladding Strain Using Cladding-Only Properties

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

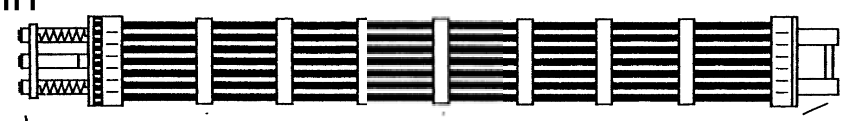
- Cladding stress, strain and flexural rigidity have always been calculated for HAC events using only the properties of the cladding, which is very conservative
- To remove this conservatism a factor was developed, based on the static test results, to convert the cladding-only stress, strain and flexural rigidity to the stress, strain and flexural rigidity in a fully fueled rod
- $(EI)_{\text{HBU rod}}$ = factor $(EI)_{\text{Clad only}}$ = 1.25 $(EI)_{\text{Clad only}}$
- $\kappa = M / (EI)_{\text{HBU rod}} = M / (1.25\ (EI)_{\text{Clad only}})$
- $\varepsilon = \kappa\, r \qquad \sigma = \varepsilon\, E_c$ Strain and stress in the HBU rod will be less than in the Clad only rod

Fatigue during Normal Conditions of Transport (NCT)

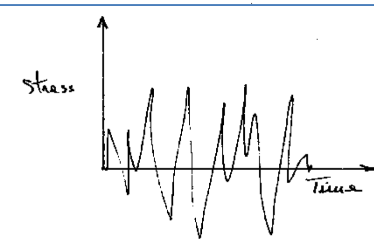
A transportation cask will experience some level of oscillation due to normal conditions of transport



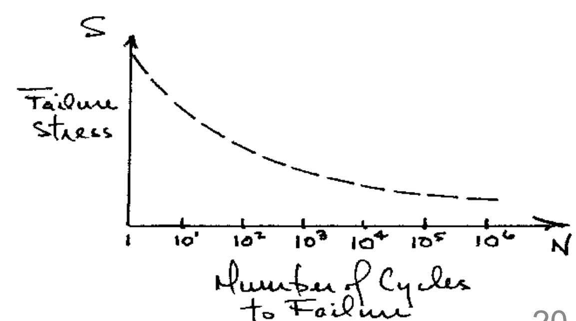
That oscillation will be transmitted in some way to the contents of the cask, the fuel elements



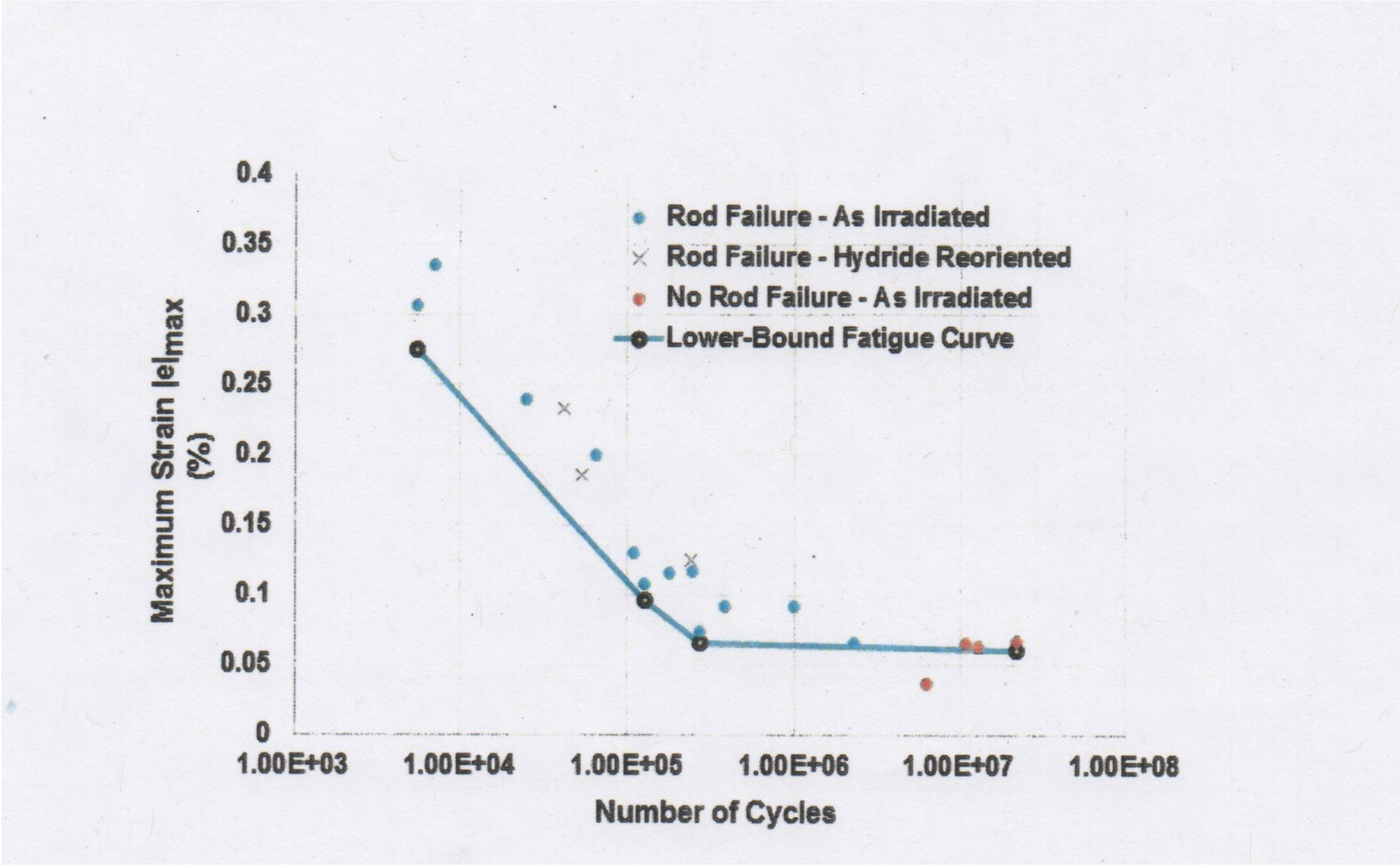
The oscillation transmitted to the fuel elements will result in local stresses in the fuel rods



Large number of cycles during transport may result in cladding failures due to fatigue, even if the maximum stresses are far below the yield stress of the material. Therefore, need to develop S-N curve



Fatigue Test Results



Fatigue Damage Rule by Miner

- For failure, the linear damage rule is:

$$S_i \; n_i/N_i = n_1/N_1 + n_2/N_2 + n_3/N_3 + \ldots. = 1.0$$

Where:

n_i = number of strain cycles at strain level e_i

N_i = number of strain cycles to produce failure at e_i, based on the fatigue curve

Fatigue Damage Evaluation

- NUREG-2224 provides applicants and industry with the methodology to develop a lower-bound fatigue curve from fatigue test data and a fatigue damage rule that can be used to evaluate the accumulation of fatigue damage

Assessment Conclusions Static Bending (Zircaloy-4)

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

- The static test results showed that there was a significant safety margin against fuel rod failure under a HAC side drop event
- CIRFT results for HBU SNF rod specimens confirmed that hydride reorientation does not impact the fuel's flexural rigidity for expected bending moments due to drop accidents
- Hydride-reoriented HBU SNF rod specimens showed markedly higher bending moment resistance compared to the cladding-only response
- Proposed new approach for crediting flexural rigidity of the pellet in the drop accident safety analyses (all cladding types)

Assessment Conclusions Fatigue Endurance (Zircaloy-4)

- Hydride-reoriented HBU SNF rod specimens failed at similar equivalent strains than non-reoriented HBU SNF rod specimens

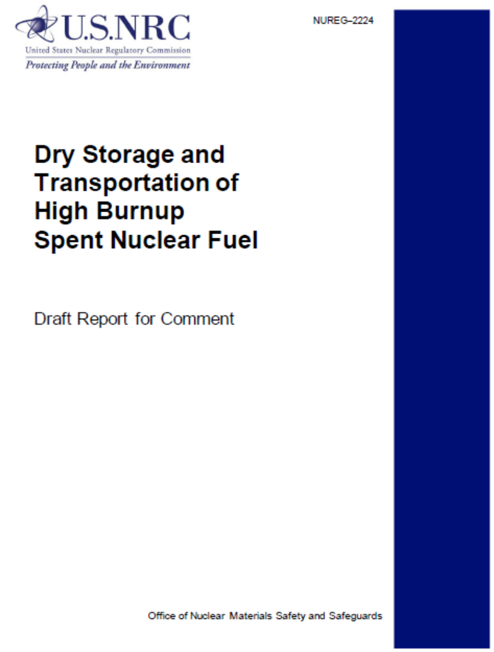
- Lower-bound fatigue S-N curve developed per NUREG/CR-7198, Rev. 1 results

  – Approach can be replicated with CIRFT dynamic test data obtained for other HBU SNF cladding types

  – DOE to acquire additional HBU SNF materials performance data under their ongoing Sister Rod Program

NUREG-2224
Draft Report for Comment

- Initial period of comment
  - August 9 – September 24, 2018
- Second period of comment
  - October 10 – November 9, 2019
- Comment submissions available via:
  - NRC's Electronic Reading Room
    - http://www.nrc.gov/reading-rm/adams.html
  - Federal e-Rulemaking Portal
    - http://www.regulations.gov
    - Docket No. NRC-2018-0066


U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment
NUREG-2224

Dry Storage and Transportation of High Burnup Spent Nuclear Fuel

Draft Report for Comment

Office of Nuclear Materials Safety and Safeguards

Safety Review Objectives
Spent Fuel Assemblies

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

Heat Removal

Fuel temperature ↔ Cladding stresses

↓

Structural Performance

Maintain analyzed configuration
Ready retrieval

Subcriticality

Unsustainable fission reaction

Radiation Shielding

On-site worker and public dose limits

Confinement / Containment

No release of radioactive material

Review Guidance Framework
Cladding Performance

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

Fuel temperature ↔ Cladding stresses

ISG-11, Revision 3

Cladding Considerations
(Peak Cladding Temperature / Thermal Cycling)
Dry Storage / Transport

NUREG-2215

Standard Review Plan
Dry Storage

NUREG-2216

Standard Review Plan
Transportation

NUREG-2214

Managing Aging Processes
in Storage

NUREG-2224

Dry Storage / Transportation
High Burnup Fuel

ISG-11, Rev. 3
Cladding Considerations

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

- Defines SNF cladding temperature limits that provide reasonable assurance that creep and hydride reorientation will not compromise SNF cladding integrity during transportation and dry storage

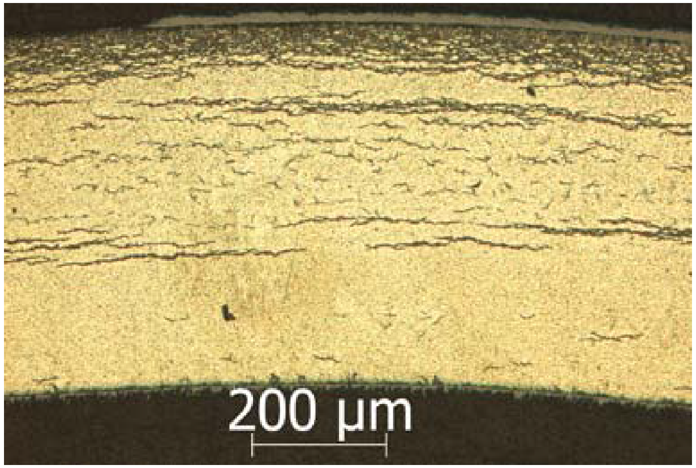
- Research conducted since issuance of ISG-11, Rev. 3, suggested that hydride reorientation could not be prevented in HBU SNF cladding

- Both NRC and DOE have conducted extensive testing to understand the effects of hydride reorientation on the mechanical performance of HBU SNF

Acceptance Criteria
Maximum (peak) calculated fuel cladding temperature should not exceed 400 °C (752 °F) - normal conditions - short-term loading operations (e.g., drying, backfilling with inert gas, and transfer operations).
Repeated heatup/cooldown cycles limited to less than 10 cycles, with cladding temperature variations less than 65 °C (117 °F), each.
Maximum cladding temperature should not exceed 570 °C (1058 °F) - off-normal conditions - accident conditions

Hydride Reorientation

- What is it?
  - Hydrogen in the cladding dissolves during drying/short-term loading operations
  - As the fuel cools down, hydrides precipitate in a different orientation
- Why has it been a concern?
  - Impact to cladding mechanical properties
  - Fuel performance per expected design-basis loads
- How has NRC addressed it?
  - Draft Regulatory Information Summary (2015)
  - Separate-effects testing (NUREG/CR-7198, Rev. 1)
  - NUREG-2224 (2018)



Purpose of NUREG-2224

- Updates NRC staff's technical basis on HBU SNF cladding performance
  - Provides an engineering assessment of results on mechanical performance of HBU SNF following cladding hydride reorientation
- Efficiency in the preparation and review of storage renewal applications
  - Provide example licensing/certification approaches for dry storage and transportation of HBU SNF

Contents of NUREG-2224

Front Matter

1. Introduction
2. Assessment of Static Bending and Fatigue Strength Results on HBU SNF (per NUREG/CR-7198, Rev. 1)
3. Dry Storage of HBU SNF (licensing/certification)
4. Transportation of HBU SNF (certification)
5. Conclusions
6. Glossary
7. References

Introduction

- Background / Regulatory requirements
- Staff review guidance on fuel cladding performance
- Cladding creep
- Hydride reorientation
  - Dissolution / Precipitation
  - Fuel cladding fabrication effects
  - End-of-life rod internal pressures / Cladding hoop stresses
  - Ring compression testing (RCT)
  - Staff's assessment of RCT results

Assessment of Static Bending / Fatigue Strength Results

- Introduction / CIRFT background
- Application of static test results
  - Spent fuel rod behavior in bending
  - Composite behavior of spent fuel rod
  - Calculation of cladding strains
  - Applicability to dry storage and transportation
- Application of fatigue test results
  - Lower bound fatigue S-N (strain vs no. cycles) curves
  - Fatigue cumulative damage model
  - Applicability to dry storage and transportation

Assessment Conclusions Licensing and Certification

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

- Developed example licensing and certification approaches based on the assessment conclusions per NUREG/CR-7198, Rev. 1 results (see Tables 3-1 and 4-1, NUREG-2224)
  - Ensured consistency with new consolidated SRPs for dry storage (NUREG-2215) and transportation (NUREG-2216), and Managing Aging Processes in Storage Report (NUREG-2214)
  - Approaches vary depending on the condition of the fuel (undamaged vs. damaged) and length of time in dry storage
- Applicants may propose and demonstrate alternative approaches to be acceptable

Licensing and Certification Example Approaches

- Uncanned fuel (intact and undamaged fuel)
  - Leaktight designs
  - Non-leaktight designs (HBU SNF release fractions)
  - Dry storage/Transportation (up to 20 years)
  - Dry storage/Transportation (beyond 20 years)
    - Results from confirmatory demonstration (NUREG-1927, Rev. 1)
    - Supplemental safety analyses (per NUREG/CR-7203)
- Canned fuel (damaged fuel)

Conclusions

- NRC has assessed results on mechanical testing of hydride-reoriented HBU SNF rod specimens and confirmed that current approaches for evaluating drop accidents are conservative
- NRC expects that additional data obtained under complementary research programs will provide additional confirmation and needed results to assess vibration normally incident to transport
- NUREG-2224 improves the existing technical basis supporting the staff's conclusion that radial hydride reorientation will not compromise HBU SNF cladding integrity during transportation and dry storage up to 60 years

Questions in *Federal Register* Notice

- Are NRC's assumptions regarding the performance of other cladding alloys based on data obtained from HBU SNF with Zircaloy-4 cladding for evaluating design basis drop accidents reasonable? If not, please explain why not.
- Are the described licensing and certification approaches easy to follow and practical? If not, please explain why not.
- Is the proposed approach for evaluation of vibration normally incident to transport clear? If not, please explain why not.
- Are the discussions on consequence analyses due to hypothetical fuel reconfiguration clear and meaningful? If not, please explain why not.

Questions in *Federal Register* Notice

- Are there any potential conflicts between NUREG-2215, Standard Review Plan for Spent Fuel Dry Storage Systems and Facilities, Draft for Comment (ADAMS Accession No. ML17310A693) and this document? If so, please describe any conflicts.

- Is the NRC's reassessment of the ductility transition temperature as measured by ring compression testing of defueled HBU SNF specimens reasonable? If not, please explain why not.

Generic Public Comments (not specific to NUREG-2224)

- Requests for extension of comment period
- Editorial and clarification
- Generic Comments
  - Information supporting the safety of HBU SNF – e.g.,
    - Concerns about insufficient technical basis
    - Concerns about risks relative to low-burnup fuel
    - Concerns about pyrophoricity / flammability of HBU SNF
  - Application of safety standards to HBU SNF – e.g.,
    - Concerns that safety standards are being relaxed
  - Generic concerns on transportation of HBU SNF – e.g.,
    - Concerns of transport of SNF after extended dry storage
    - Concerns over nation's railroad infrastructure
  - Miscellaneous

Technical Public Comments (specific to NUREG-2224)

- Chapter 1 – Introduction
  - Clarifications on end-of-life rod internal pressures
  - Requests to reevaluate acceptance criteria in ISG-11, Rev. 3
- Chapter 2 – Assessment of Static/Dynamic Bending Results
  - Clarifications on specifications of tested specimens
  - Clarifications on basis for radial hydride treatment
  - Clarifications on SNF rod behavior as non-homogeneous solid
  - Clarification on position regarding fatigue endurance limit
  - Clarifications on how the conclusions were risk-informed

Technical Public Comments (specific to NUREG-2224)

- Chapters 3 and 4 – Licensing and Certification
  - Clarifications on ready-retrieval implications
  - Clarifications on leaktight vs. non-leaktight designs
  - Clarifications on failure rates/release fractions for non-leaktight designs
  - Clarifications on applicability of reconfiguration scenarios
- Chapter 5 – Conclusions
  - Clarifications on implications of future research on HBU SNF

Abbreviations

- °C: degrees Celsius
- °F: degrees Farenheit
- ACRS: Advisory Committee on Reactor Safeguards
- ADAMS – Agencywide Documents Access and Management System
- CIRFT: Cyclic Integrated Reversible-Bending Fatigue Tester
- DOE: Department of Energy
- HBU: high burnup
- ISG: interim staff guidance
- No.: number
- NRC: Nuclear Regulatory Commission
- RCT: ring compression testing
- Rev.: revision
- SNF: spent nuclear fuel
- SRP: Standard Review Plan

References

- 10 CFR Part 71, “Packaging and Transportation of Radioactive Material,” Washington, DC.
- 10 CFR Part 72, “Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High Level Radioactive Waste, and Reactor-Related Greater than Class C Waste,” Washington, DC.
- NRC, “A Quantitative Impact Assessment of Hypothetical Spent Fuel Reconfiguration in Spent Fuel Storage Casks and Transportation Packages.” NUREG/CR-7203, Washington, DC, 2015, ADAMS Accession No. ML15266A413.
- NRC, “Cladding Considerations for the Transportation and Storage of Spent Fuel,” ISG-11, Rev. 3, Washington, DC, 2003, ADAMS Accession No. ML033230335.
- NRC, “Dry Storage and Transportation of High Burnup Spent Nuclear Fuel,” Draft NUREG-2224, Washington, DC, 2018, ADAMS Accession No. ML18214A132.
- NRC, “Managing Aging Processes in Storage (MAPS) Report,” Draft NUREG-2214, Washington DC, 2017. ADAMS Accession No. ML17289A237.
- NRC, “Mechanical Fatigue Testing of High-Burnup Fuel for Transportation Applications,” NUREG/CR-7198, Revision 1, Washington, DC, 2017. ADAMS Accession No. ML17292B057.

References

- NRC, “Standard Review Plan for Renewal of Specific Licenses and Certificates of Compliance for Dry Storage of Spent Nuclear Fuel,” NUREG-1927, Revision 1, Washington, DC, 2016, ADAMS Accession No. ML16179A148.
- NRC, “Standard Review Plan for Spent Fuel Dry Storage Systems at a General License Facility,” NUREG-1536, Rev. 1, Washington, DC, 2010, ADAMS Accession No. ML101040620.
- NRC, “Standard Review Plan for Spent Fuel Dry Storage Facilities,” NUREG-1567, Rev. 0, Washington, DC, 2000, ADAMS Accession No. ML003686776.
- NRC, "Standard Review Plan for Transportation Packages for Spent Nuclear Fuel,” NUREG-1617, Washington DC, ADAMS Accession No. ML003696262.NRC. 2000.

Industry Perspectives on NUREG-2224

Rod McCullum
US NRC ACRS Subcommittee on Metallurgy and Reactor Fuel

August 22, 2019

NEI NUCLEAR ENERGY INSTITUTE

Industry interest in NUREG 2224

- Industry views NUREG 2224 “Dry Storage and Transportation of High Burnup Spent Nuclear Fuel” as an important enabling tool to improve the safety focus of dry storage licensing processes
- In the spirit of optimizing the utility of this tool, 4 industry entities commented on NUREG 2224
  - NEI
  - EPRI
  - Holtec International
  - NAC International

NEI Comments on NUREG 2224

- Industry endorses NRC's goal of expanding the technical basis in support of guidance pertaining to hydride reorientation of high-burnup (HBU) spent nuclear fuel (SNF) cladding
- Industry believes that NRC successfully captured much of the scientific and technical information which demonstrates that safety margins for the storage and transportation of HBU SNF are significantly greater than previously understood
- NEI did not answer the six questions posed by NRC, because the answers would depend on how the information is applied
- NEI expressed interest in a dialogue with NRC going forward

US Used Fuel Storage Performance

Used fuel inventory*

- Approximately 82,500 MTU
- Increases 2 - 2.4k MTU annually

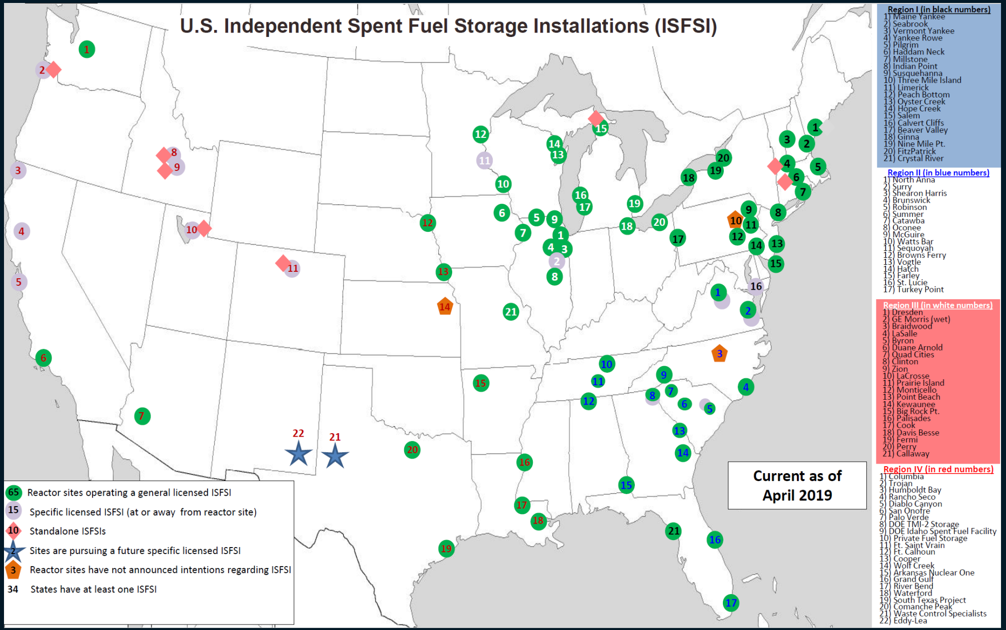
ISFSI** storage

- 134,843 assemblies
- 38,200 MTU (46% of total inventory)
- 3,069 casks/modules loaded
- 72 Operating ISFSIs
  - 70 dry storage, 1 pool, 1 modular vault
- Eventually to be deployed at 76 sites
  - Fuel from 119 reactors

Approximately 1300 casks contain at least 1 assembly of high burnup fuel

Long term commitment to ISFSIs

- Licenses being extended to 60 years
- Licenses extensions approved at 30 sites
- NRC has found 100 year storage to be safe



*As of June 30, 2019

** ISFSI = Independent Spent Fuel Storage Installation

Performance Enables Transformation

Implementation

- Piloting a graded approach CoC (RIRP-I-16-01) to reduce unnecessary licensing burden by 34%
- Improving the usability of the 10 CFR 72.48 change control process (NEI 12-04) so that things that are not important to safety do not consume licensing resources
- Implementing highly effective CoC/license renewal guidance (NUREG 1927 Rev 1, MAPS Report, NEI 14-03) so that long-term dry storage can be managed in a stable and predictable manner
- **Better understanding dry storage safety margin to identify further opportunities for improvement**
  - **Industry to submit white paper to NRC by end of year**
  - **NUREG 2224 will be a key input to this work**

Why it matters

- Over the last 25 years the 15 NRC approved dry storage Certificates of Compliance (CoCs) have been amended 74 times. Preparation of Amendments requires between two and nine months of effort on the CoC holders part and one to three years of review at NRC – although in a few cases it has taken considerably longer. The process typically involves two rounds of Requests for Additional Information (RAIs) from NRC. Staff can also issue Requests for Supplemental Information and Requests for Clarification. Normally NRC asks between one and two dozen RAIs with many RAIs having multiple subparts.

The Next Question

Are the differences between high-burnup fuel and low-burnup fuel really meaningful?

ELECTRIC POWER RESEARCH INSTITUTE

EPRI Perspectives on NUREG-2224
Dry Storage and Transportation of High Burnup Spent Nuclear Fuel

Keith Waldrop
Principal Technical Leader
Electric Power Research Institute

Advisory Committee on Reactor Safeguards
Meeting of the Subcommittee on Metallurgy & Reactor Fuels
NUREG-2224, Dry Storage and Transportation of High Burnup Spent Nuclear Fuel
Rockville, MD
August 22, 2019

www.epri.com

Outline

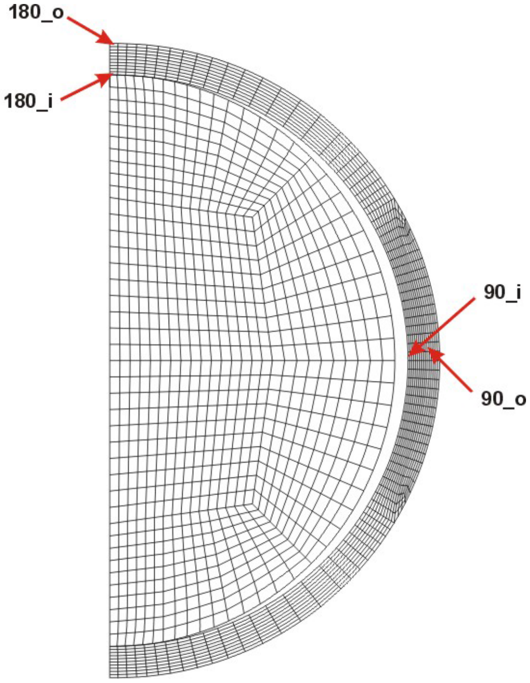
- Review of Current Regulatory Guidance and Motivation
- Overall Perspective
- EPRI Comments
- Future Opportunity
- Ongoing/Future Work
- Summary

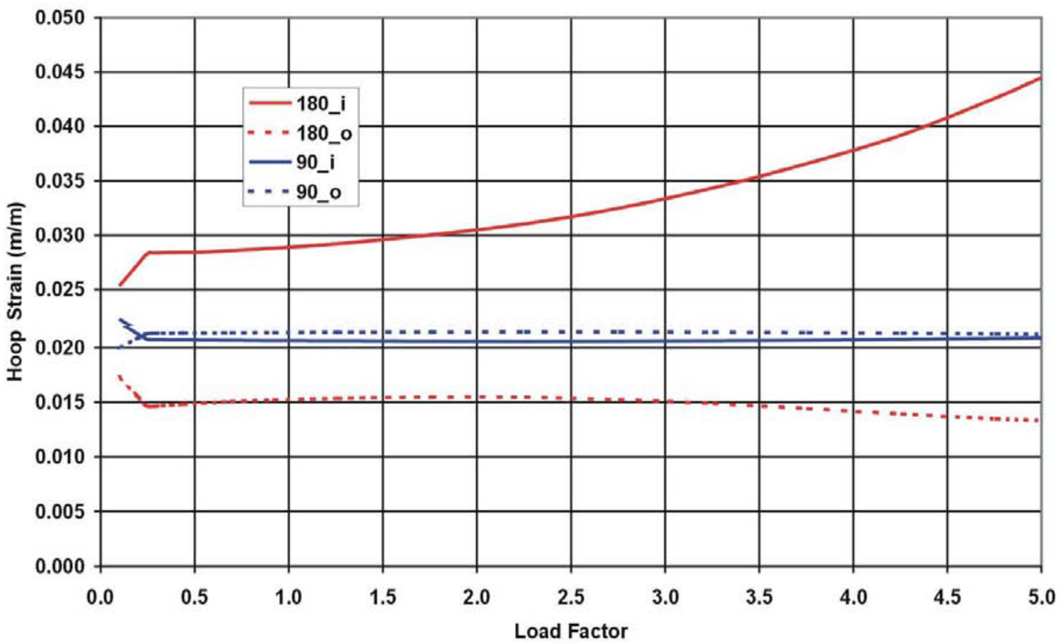
Review and Motivation

- Chronological review of current regulatory guidance
  - ISG-11 Rev 3 (2003) – Cladding considerations
    - Recommended 400°C peak cladding temperature
      - Prevent gross rupture from creep
      - Minimize effect of hydride reorientation
  - EPRI finite element analysis evaluating contribution of fuel pellet (2005)
  - ISG-19 (2013) – Moderator exclusion
    - *It is judged that,* ***at this time, there is insufficient material property information for high burnup fuel to allow this type of evaluation*** [fuel reconfiguration].

Review and Motivation

- *EPRI report* 1009929, *Spent Fuel Transportation Applications: Fuel Rod Failure Evaluation under Simulated Cask Side Drop Conditions (*2005)





Fuel pellets contribute the major load-resisting component of the fuel rod, and prevent cladding failures, with possible exception of the extreme case with rods characterized by a large fuel-cladding gap in combination with high concentration of radial hydrides

ELECTRIC POWER RESEARCH INSTITUTE

Review and Motivation

- Motivation
  - Current basis ignores credit for structure of fuel pellet
  - Analysis indicates significant support provided by fuel pellet
  - Lack of material property data on high burnup fuel
  - Limited understanding of the effect of hydride reorientation under realistic conditions

- NRC initiated test program to generate experimental data
- NUREG-2224 is the result of evaluating that experimental data

Overall Perspectives on NUREG-2224

"The purpose of this report is to expand the technical basis in support of the U.S. Nuclear Regulatory Commission's (NRC's) guidance on adequate fuel conditions as it pertains to hydride reorientation in high burnup (HBU) spent nuclear fuel (SNF) cladding."

- NUREG-2224 meets this purpose

Overall Perspectives on NUREG-2224

- Includes detailed review of NRC research
  - Thorough review of current regulatory basis
  - Heavily focused on NUREG/CR-7198 results
  - Includes other research literature as appropriate
- Provides detailed explanation of thinking and logical progression through steps staff took
  - This provides useful examples for future use with new information
- Includes transportation for high burnup fuel
  - ISG-11 Rev 3 does not (case by case basis)

EPRI Comments

- EPRI appreciates being able to comment on draft NUREG
- EPRI comments have largely been addressed
- Some comments were not addressed at this time
  - Appropriate for moving forward with NUREG
    - Provides updated guidance that can be used now
  - Opportunities for improvement in the future

Selected EPRI Comments Addressed

- Faulty integral absorber rod pressure data – Comment 4.2.9
  - This led to excessively high rod internal pressure for hydride reorientation treatment (Comment 4.3.8)
  - Staff evaluated ORNL and PNNL results and identified discrepancy
  - End result is no impact to NUREG-2224 conclusions
    - Higher RIP served to further ensure a severe HRO treatment
    - Conclusion that HRO does need to be accounted for with cladding only properties remains valid
- Fission gas impact on rod pressure – Comment 4.2.23
  - End of life rod internal pressure not greatly affected by fission gas
  - Revised to note this clarification
- Retrievability - Comment 4.2.28
  - Does not factor in canister based retrievability per ISG-2 (2016)
  - Revised to include canister retrievability

Selected EPRI Comments Addressed

- Ring compression testing cooling rate – Comment 4.2.32
  - Cooling rate for RCT too fast to allow any annealing
  - Noted that RCT cooling rate includes effects of hydride reorientation only and excludes effect of annealing
- Effect of cladding liner – Comment 4.2.43
  - BWR cladding typically includes a Zr liner attracts hydrogen in solution and makes it immune to hydride reorientation
  - Added discussion of BWR liner, but did not further explain the effect on hydride reorientation
- EPRI work on support from pellet - Comment 4.2.46
  - EPRI finite element analysis work demonstrated the benefit the fuel pellet provides
  - Added reference to EPRI work, but did not add to reference list

Selected EPRI Comments Addressed

- Cladding only data used previously - Comment 4.3.32
  - Discussion of the composite behavior of fuel rod ignored that previous analysis ignored the fuel pellet
  - Discussion added to provide context that previous tests and analysis did not account for fuel pellet
- Seismic event impact on fuel - Comment 4.3.39
  - Seismic events not expected to compromise fuel
  - Revised to clarify seismic does not need to be included in cumulative damage evaluation

Selected EPRI Comments – Future Opportunity

- Structural analysis considers only inertial load – Comment 3.4.56
  - Transportation side drop accident would include pinch load on both top and bottom
  - Test program only included inertial load to determine the effect of fuel on rigidity only
    - Compared to previous work using cladding only
  - Future work should include true pinch load and account for pellet
    - Some international experimental work is being performed

Selected EPRI Comments – Future Opportunity

- Excessive reduction in rigidity provided by pellet - Comment 4.3.34
  - Cladding only vs. fuel/pellet a factor of 1.96 more rigid
    - This includes 2 sigma (98 percentile)
  - Reduced to a factor of 1.4 to account for hydride reorientation
    - Yet this is from cladding only tests
    - The pellet will limit displacement of reoriented sample
  - Further reduced to 1.25 to account for uncertainty
  - End conclusion is to use cladding only properties due to lack of data on other materials

End result is no credit given for rigidity provided by fuel

Ongoing/Future Related Work

- Include more realistic approaches supported by past, present, future work
  - DOE/EPRI HBU Demo
    - Cladding temperatures are low and no significant hydride reorientation has occurred
    - Additional sister rod testing
    - Incorporate lessons from HBU Demo into future guidance
  - Sandia/ENSA transportation test
    - Actual transportation loads orders of magnitude below cycle fatigue limit
      - Possibly justify fatigue analysis not necessary for normal conditions of transport

Ongoing/Future Related Work

- Recently initiated research
  - Mechanisms of hydride reorientation
  - Pinch load testing with fueled cladding
  - Effect of fuel-cladding bonding on hydride reorientation
  - Expert elicitation on cladding performance
    - Phenomenon Identification Ranking Table (PIRT) process

Summary (1/2)

- NUREG-2224 accomplished its objective
  - Updated guidance for high burnup fuel was needed, particularly for transportation
    - Getting closer to transporting spent nuclear fuel
    - Current regulatory guidance established 2003
    - Information collected over the past 16 years
    - NUREG-2224 begins to utilize some of this research
      - NRC/DOE experiments and EPRI analysis highlighting the contribution of the fuel column
      - NUREG still does not credit rigidity of fuel pellet
  - Comments addressed

Summary (2/2)

- Step in the right direction
  - Future opportunity to consider more realistic conditions
    - Credit for structure provided by fuel pellet
    - Hydride reorientation likely not a concern given actual temperature and hoop stress
    - Loads under normal conditions of transport very low
  - Continue research
    - Cladding performance expert elicitation
    - Hydride reorientation mechanisms
    - Pinch load testing with fuel
  - Incorporate information from ongoing research into future guidance updates

Together…Shaping the Future of Electricity