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2 NUCLEAR REGULATORY COMMISSION

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4 ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

5 (ACRS)

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7 METALLURGY AND REACTOR FUELS SUBCOMMITTEE

8 + + + + +

9 THURSDAY

10 AUGUST 22, 2019

11 + + + + +

12 ROCKVILLE, MARYLAND

13 + + + + +

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

18 COMMITTEE MEMBERS:

19 RONALD G. BALLINGER, Chair

20 WALTER L. KIRCHNER, Member

21 JOSE MARCH-LEUBA, Member

22 DAVID PETTI, Member*

23 JOY L. REMPE, Member

24 PETER RICCARDELLA, Member

25

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DESIGNATED FEDERAL OFFICIAL:

CHRISTOPHER BROWN

ALSO PRESENT:

TAE AHN, NMSS

KRISTINA BANOVAČ, 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

1 RICARDO TORRES, NMSS

2 KEITH WALDROP, EPRI

3 BERNARD WHITE, NRC

4 VERONICA WILSON, NMSS

5 JOHN WISE, NMSS

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12 *Present via telephone

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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

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

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

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

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

1 in-only mode.

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

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

12 Chris?

13 MR. REGAN: Thank you, Mr. Chairman.

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

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

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

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

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

20 Next slide, please.

21 So, speaking of which, back in 2015, the
22 NRC did issue a draft regulatory information summary
23 to provide some guidance to industry on where the
24 Agency was with respect to issues associated with high
25 burnup spent nuclear fuel. We were, in parallel, and

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1 at that time, still conducting experiments and tests
2 to continue development and refine our approach, our
3 regulatory approach, on how we address these issues.
4 This eventually got to a point where we pulled that
5 information from the regulatory information summary
6 and the test results and analysis and developed this
7 NUREG-2224.

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

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

25 All right. Next slide, please.

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

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

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

23 Thank you.

24 MEMBER REMPE: So, could I interrupt?
25 Because I think this question may take a while to get

1 an answer to. Are you aware of NUREG/CR-7260 by Alden
2 Research Laboratory and its findings? It's titled, "A
3 CFD Validation of the Vertical Dry Cask Storage
4 System". And I came across it because of some other
5 work ACRS does.

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

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

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

24 MEMBER REMPE: That would be good.

25 MR. REGAN: As we work through it, maybe

1 that will become apparent.

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

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

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

9 Thanks.

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

14 MR. BJORKMAN: The scope of the scenario
15 was specifically up to 60 years.

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

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

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1 CHAIR BALLINGER: Sufficiently evasive.

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

4 (Laughter.)

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

7 MR. BJORKMAN: That's correct.

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

11 CHAIR BALLINGER: Okay.

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

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

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

1 (Laughter.)

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

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

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

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

25 So, we subject a fully fueled rod to

1 constant bending moment.

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

6 MR. BJORKMAN: Correct.

7 MEMBER MARCH-LEUBA: Okay.

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

10 MEMBER MARCH-LEUBA: All right.

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

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

22 Okay. This is the actual CIRFT
23 instrument. The fully developed instrument is on the
24 slide or the picture to the extreme right. You can
25 see that the load cells apply both inward and outward

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1 loads. Those are the green arrows. And you see that,
2 at the location of the fuel rod, the fuel rod -- it
3 says, "test segment," -- the location of the test
4 segment is under there. And you can see that there
5 are three displacement transducers, and these
6 displacement transducers measure the displacement at
7 three points along the circular arc. And from those
8 displacements, we can then calculate the radius of the
9 circular arc, and therefore, the curvature.

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

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

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

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

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

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

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

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

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

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

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

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

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

20 MR. TORRES: Yes.

21 MEMBER RICCARDELLA: Radial/axial, right?

22 MR. TORRES: Yes. So, there is a
23 distribution. It fluctuates. I mean, these are
24 platelets and they fluctuate in various directions,
25 but, as you see here, you have more in the radial

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1 orientation after drying operations. And here you
2 have circumferential orientation.

3 MEMBER RICCARDELLA: It's all basically
4 laminar.

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

8 MEMBER RICCARDELLA: Thank you.

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

13 MR. TORRES: So --

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

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

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

25 MEMBER MARCH-LEUBA: Is it in 5?

1 MR. TORRES: Yes.

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

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

12 MEMBER RICCARDELLA: Yes, yes, yes.

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

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

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

22 MEMBER RICCARDELLA: Okay.

23 MR. TORRES: Yes.

24 MEMBER RICCARDELLA: Thank you.

25 MR. TORRES: You're welcome.

1 MR. BJORKMAN: Great. Next.

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

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

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

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

22 MEMBER RICCARDELLA: Loading/unloading,
23 yes.

24 MR. BJORKMAN: Yes. We can only take this
25 to a certain curvature because of the fact that the

1 test apparatus is limited in its displacement
2 capability.

3 MEMBER RICCARDELLA: Yes, yes.

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

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

11 MR. BJORKMAN: Yes, correct. Correct.

12 MEMBER RICCARDELLA: Which -- okay.

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

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

21 Now this supports the pre-test expectation
22 that, because the bending tensile stresses in the
23 cladding are parallel to the plane of both the radial
24 and circumferential hydrides, the presence of the
25 radial hydrides would not significantly alter the

1 flexural response.

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

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

18 (Laughter.)

19 MR. BJORKMAN: Yes.

20 MEMBER RICCARDELLA: Yes.

21 MR. BJORKMAN: Exactly.

22 MEMBER MARCH-LEUBA: How sensitive were
23 your samples? I mean, you only picked four samples,
24 right? And were they treated with a temperature
25 transient to optimize the radial or were, yes, picked

1 out at random, whatever happened to the PNNL?

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

7 MEMBER MARCH-LEUBA: Yes.

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

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

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

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

25 MR. TORRES: That's correct.

1 MEMBER MARCH-LEUBA: Or likely bounding?

2 MR. TORRES: Yes.

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

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

9 MR. TORRES: Thirty-five, yes.

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

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

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

19 MR. TORRES: Yes.

20 MEMBER RICCARDELLA: Okay. Thank you.

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

23 MR. TORRES: Correct.

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

1 MR. TORRES: Well, M5 --

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

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

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

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

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

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

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

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

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

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

3 CHAIR BALLINGER: But those grid spacers
4 have springs.

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

7 CHAIR BALLINGER: Okay. And that would
8 decrease --

9 MR. BJORKMAN: Correct.

10 CHAIR BALLINGER: So, this is
11 conservative?

12 MR. BJORKMAN: Correct.

13 CHAIR BALLINGER: So, probably
14 considerably conservative?

15 MR. BJORKMAN: Yes, it is.

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

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

24 MEMBER RICCARDELLA: Does that apply --

25 MR. BJORKMAN: That's because you have a

1 gap.

2 MEMBER RICCARDELLA: Yes.

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

5 MEMBER RICCARDELLA: Yes.

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

8 MEMBER RICCARDELLA: Yes.

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

12 MEMBER RICCARDELLA: Right, right, right.

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

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

16 CHAIR BALLINGER: Because of the springs.

17 MEMBER RICCARDELLA: Okay.

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

20 MEMBER RICCARDELLA: Gaps.

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

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

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

3 MEMBER RICCARDELLA: With no gap?

4 MR. BJORKMAN: With no gap.

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

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

10 MEMBER RICCARDELLA: I understand.

11 MR. BJORKMAN: -- what the response is.

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

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

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

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

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

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

8 MR. BJORKMAN: And it's about 34.

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

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

19 MEMBER RICCARDELLA: Uh-um. Okay.

20 MR. TORRES: And I'll also highlight that
21 the Department of Energy right now is doing additional
22 testing. Actually, they've conducted significant
23 testing to evaluate normal conditions of transport,
24 but they've also been doing additional testing to put
25 accelerometers and strain gauges during drop

1 accidents, the 30-foot drop. They've been doing some
2 testing in Germany.

3 MEMBER RICCARDELLA: Yes.

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

6 MEMBER RICCARDELLA: Right.

7 CHAIR BALLINGER: Well, these tests are
8 for, roughly, round numbers, 70 gigawatt days per
9 metric ton. For 40, which is currently the maximum,
10 45, or less than 45, you get the same results if you
11 do these tests?

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

17 CHAIR BALLINGER: Right, but my question
18 is --

19 MR. TORRES: I'm sorry.

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

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

1 loads for the specific --

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

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

10 CHAIR BALLINGER: Right, yes.

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

13 CHAIR BALLINGER: Yes, yes.

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

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

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1 the fuel rod in this drop event.

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

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

7 CHAIR BALLINGER: Cold work.

8 MR. TORRES: -- stress relief --

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

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

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

23 Now the region of the fuel rod weakest
24 intention is at the pellet-pellet interface. And you
25 can see on the diagram at the right, it's at the

1 pellet-pellet interface that, when the pellet-pellet
2 interface cracks in bending, the tensile stress in the
3 cladding at the cracked face will increase
4 significantly. So, at the cracked face, you see from
5 the cladding stress diagram below that at the cracked
6 face the cladding tensile stress is high, and that the
7 high tensile stress at the cracked face decreases with
8 distance from the crack. Thus, cladding tensile
9 stresses will vary significantly along the length of
10 the rod. Okay.

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

19 Now the average tensile strain in the
20 cladding, epsilon, along the gauge length is equal to
21 the curvature multiplied by the distance to the
22 neutral axis, which is equal to the outside radius of
23 the rod. Now this is the convention that has been
24 adopted here and in NUREG-7198, even though it is
25 known that the neutral axis will vary along the gauge

1 length. For example, at the crack the neutral axis
2 will be almost equal to the diameter; whereas, between
3 the cracks, the neutral axis will be approximately
4 equal to the outside radius. Okay.

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

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

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

25 So, the equation is the EI minus the

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

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

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

21 MR. BJORKMAN: Go ahead.

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

24 (Laughter.)

25 MEMBER MARCH-LEUBA: And I wonder why.

1 (Laughter.)

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

7 MR. BJORKMAN: Oh, we know --

8 MEMBER RICCARDELLA: Yes.

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

11 MEMBER RICCARDELLA: Yes.

12 MR. BJORKMAN: -- integrated over the
13 length.

14 MEMBER RICCARDELLA: Yes.

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

18 MEMBER RICCARDELLA: Yes, or strain
19 gauges.

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

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

25 MR. BJORKMAN: Correct.

1 MEMBER RICCARDELLA: Okay. All right.

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

4 MEMBER RICCARDELLA: Good. Thank you.

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

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

25 Now the fatigue test results. At the top

1 you see rod failure for the as-irradiated rods.
2 That's the light blue dots, and you see where they
3 fall. And you see the hydride reoriented rods. Three
4 of those were tested, and those are the "X's". And
5 you see that, basically, they're failing at
6 approximately the same levels as the as-irradiated
7 rods. And then, we see the red dots at the far
8 extreme to the right; we see no failure. And these
9 are the as-irradiated rods with no failures.

10 And what I've sketched in here are three
11 line segments giving a lower bound fatigue curve.
12 Okay. Fatigue damage rule. We're using the fatigue
13 damage rule developed by Miner. It's a linear damage
14 rule. And the way it works is that you sum up, for
15 example, $\frac{n}{N}$, where n supplies
16 the number of strain cycles at strain level E_i ,
17 so many cycles. And you divide that by the number of
18 strain cycles to produce failure at a strain level E_i ,
19 based on the fatigue curve. So, based on the number
20 of cycles at a given frequency and a given stress
21 level, you add up these fractions, and if you get to
22 1, you have failure. If you're above 1, obviously you
23 have failure. But you want to stay below 1. And, in
24 fact, in the document itself we suggest using a value,
25 rather than 1, of using .7, because based on extensive

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1 test results using Miner's Law, that the lower bound
2 value using the linear damage rule. Okay.

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

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

10 MEMBER RICCARDELLA: This is a lower bound
11 curve.

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

16 MEMBER RICCARDELLA: Yes, yes.

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

20 MEMBER RICCARDELLA: I understand.

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

25 MR. BJORKMAN: Yes, load controlled.

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

5 MR. BJORKMAN: Yes. Absolutely.

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

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

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1 approach.

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

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

14 CHAIR BALLINGER: Okay.

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

21 CHAIR BALLINGER: Thank you.

22 MR. BJORKMAN: Okay. Conclusions
23 regarding fatigue endurance limits. Hydride
24 reorientation of high burnup spent nuclear fuel rods
25 failed at similar equivalent strains of the non-

1 reoriented high burnup fuel rods specimens. We saw
2 that with, on the fatigue test results, the light blue
3 and with little "x's". They were basically in the
4 same range.

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

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

14 MR. BJORKMAN: Five hertz.

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

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

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

24 MR. BJORKMAN: Right, yes, yes.

25 MEMBER RICCARDELLA: It would take a long

1 time at 5 hertz.

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

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

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

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

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

1 backfill helium environment with --

2 MEMBER RICCARDELLA: Pretty much inert, an
3 inert environment.

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

6 MEMBER RICCARDELLA: Okay, good.

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

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

12 MEMBER RICCARDELLA: Well below that 30 --

13 CHAIR BALLINGER: Yes, well below.

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

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

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

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

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

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

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

8 MEMBER RICCARDELLA: Your curve looks like
9 it does.

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

12 MEMBER RICCARDELLA: I understand, yes.

13 CHAIR BALLINGER: Three data points does
14 not make it.

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

17 CHAIR BALLINGER: Sure.

18 MR. TORRES: Okay.

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

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

25 MEMBER MARCH-LEUBA: You're just liking

1 it. This is your --

2 MEMBER RICCARDELLA: Pardon me?

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

5 (Laughter.)

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

8 MEMBER PETTI: Yes.

9 CHAIR BALLINGER: Okay, good. Thanks.

10 MEMBER PETTI: I can hear very well.

11 CHAIR BALLINGER: Good.

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

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

19 So, as Chris mentioned, NUREG-2224, the
20 draft report for comment was issued back in August of
21 last year for a 45-day public comment period. We
22 received multiple letters from stakeholder groups
23 requesting additional review time. Therefore, we
24 issued the document once again for a second period of
25 comment. And all the comment submissions you can find

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1 via this link, the NRC's electronic reading room, or
2 the Federal eRulemaking Portal.

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

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

25 So, the way we have provided guidance to

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

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

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

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

3 MR. TORRES: No.

4 MEMBER MARCH-LEUBA: That's only
5 accidents?

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

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

14 MR. TORRES: Yes, anticipated occurrences,
15 yes.

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

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

25 MEMBER MARCH-LEUBA: Yes, but after this,

1 can you really --

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

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

14 MR. TORRES: So, that's an upcoming
15 effort. So, there's a couple of initiatives that we
16 have in-house. We have now a work, starting work with
17 Research to look adding some sort of tolerance to that
18 400 degrees Celsius. And what we're looking at is
19 effectively reevaluated all the degradation phenomena
20 that we looked at in the MAPS report, delayed hydride
21 cracking, all these phenomena, just at slightly higher
22 temperatures.

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

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

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

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

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

17 MR. TORRES: Absolutely. Absolutely, yes.

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

25 MR. TORRES: Yes. So, I was just about to

1 talk into that. So, ISG-11 looks at primarily two
2 phenomena, cladding creep and hydride reorientation.
3 Cladding creep has historically been considered as the
4 phenomena that can lead to cladding thinning and
5 potential cladding ruptures. And that's been really
6 the focus.

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

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

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

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

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

1 focus will be.

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

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

17 MEMBER RICCARDELLA: With respect to that
18 400 degrees C limit, and you say we're approaching it,
19 are these temperatures monitored in any way or are
20 these just analyses that are submitted as part of the
21 licensing?

22 MR. TORRES: Yes, they're analysis
23 submitting, CFD analysis, and we run our own
24 confirmatory analysis just to verify that those
25 temperatures are acceptable. There are some licensees

1 that measure temperatures on the -- during vacuum
2 operations, I think that they do at the outlets of the
3 vacuum. I mean, they measure at certain locations,
4 inside the cask --

5 MEMBER RICCARDELLA: Nobody puts
6 thermocouples on the rods.

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

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

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

17 MEMBER RICCARDELLA: Yes.

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

20 MR. TORRES: That's correct.

21 MEMBER RICCARDELLA: You're talking low?

22 CHAIR BALLINGER: A lot lower.

23 MEMBER RICCARDELLA: Yes.

24 MR. TORRES: But we're learning.

25 MEMBER RICCARDELLA: I'm with you.

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

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

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

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

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

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

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

14 In Chapter 2, you will see an introductory
15 section and a discussion on the setup used by or
16 developed by Oak Ridge National Laboratory under our
17 sponsorship. It has separate discussions on the
18 static bending results, discussions on the performance
19 of the composite behavior of the spent fuel rod, how
20 to calculate cladding strengths, just like Gordon
21 discussed earlier today, and the applicability of
22 those results to the evaluation of design basis drop
23 accidents in dry storage and transportation. It has
24 a separate discussion on fatigue, on the fatigue test
25 data, on the dynamic bending data, how to build that

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1 lower bound curve that Dr. Bjorkman discussed, the
2 implementation of a fatigue cumulative damage model,
3 Miner's Rule, and the applicability of that to dry
4 storage and transportation.

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

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

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

18 MR. TORRES: That's a good clarification
19 question. So, we are departing from the guidance that
20 we've provided. We have specific guidance on fuel
21 classification, and that's in ISG-1, Revision 2,
22 currently. And we have definitions for "undamaged,"
23 intact, which is no hairline cracks, no pinholes,
24 "undamaged," may have hairline cracks, pinholes, and
25 "damaged" which means it just cannot fulfill

1 adequately the functions without additional
2 containment inside the dry storage system or
3 transportation package. So, we've been consistent
4 with our own facts.

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

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

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

23 So, the ways Chapter 3 and Chapter 4 are
24 structured is there is a discussion on leak-tight
25 designs, per ANSI N 14.5; non-leak-tight designs. And

1 in this case, we actually expand the technical basis
2 in the current Standard Review Plans to provide
3 release fractions, bounding release fractions that
4 applicants may use for non-leak-tight designs when
5 transporting or storing high burnup spent fuel.

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

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

18 And if an applicant chooses not to follow
19 that approach and not rely on the data from a
20 confirmation program, then they can do supplemental
21 safety analysis. But what we're looking here is for
22 confirmatory data. The majority of the work that
23 we've done is separate effects testing, accelerated
24 tests. And like you said, there is sometimes
25 synergistic effects associated with different

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1 degradation phenomena occurring over time. So, what
2 we're looking here is confirmatory data that
3 demonstrates that our conclusions continue to be
4 acceptable beyond 20 years.

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

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

18 MEMBER REMPE: Right.

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

25 You can demonstrate ready retrieval by

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

3 MEMBER REMPE: Okay.

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

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

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

18 MR. TORRES: You're welcome.

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

21 MR. TORRES: So, the staff has endorsed
22 the use of ANSI N 14.5, which provides criteria for
23 defining what's -- it actually determines what's a
24 leak-tight or non-leak-tight design. There is
25 specific leakage rate for leak-tight systems. So,

1 once you demonstrate that you are leak-tight, if you
2 cannot demonstrate that your system meets that
3 criteria, then there are additional analyses for those
4 consequences that need to be performed, assuming
5 release back, potential releases through the canister.

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

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

19 And in the document, we've also provided
20 a discussion on how to account for the flexural
21 rigidity of the pellet. That's that 1.25 factor that
22 Gordon discussed for Zircaloy-4. Once DOE is
23 obtaining additional data on static bend testing, once
24 that data is obtained for other cladding alloys, we
25 expect that the same approach that we discussed here

1 for Zircaloy-4 can be replicated with the high burnup
2 fuel with other cladding alloys.

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

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

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

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

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

19 With respect to the specific comments of
20 NUREG-2224, in Chapter 1, as I said, it's a lot of
21 history and discussion about creep and hydride
22 reorientation. We had a number of comments and
23 clarifications on end-of-life rod internal pressures,
24 and we made some revisions just to better reflect
25 accurately the hoop stresses that would be expected

1 during dry storage and transport, per the acceptance
2 criteria in ISG-11, Rev 3. We received some comments
3 to reevaluate the acceptance criteria in ISG-11, Rev
4 3, to potentially go higher, but that is beyond the
5 scope of this document. There's our parallel efforts
6 that we are taking on to address that. We pointed
7 that out in the document.

8 We received some clarifications on Chapter
9 2, on the specifications of the specimens that we
10 tested; on the basis for the radial hydride treatment
11 that we chose; the stresses and the number of cycles
12 that we did for reorientation.

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

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

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

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

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

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

20 MR. TORRES: So, that was a comment
21 specific from NEI, I believe, that comment. And I
22 think I'll leave that to -- I think I would point to
23 management on how we effectively managed that. But I
24 think a decision was made that we had held a public
25 meeting on this, this subject, and we requested

1 feedback and we took questions. And it wasn't very
2 clear what clarification is really needed.

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

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

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

13 MEMBER REMPE: Okay.

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

16 MEMBER REMPE: Thanks.

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

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

23 MR. TORRES: Yes. So, we had a couple of
24 comments on this. And we believe that, to the extent
25 that engineering judgment can be used to risk inform,

1 we have taken steps to do that. An example is for the
2 static bend testing. We only tested one specimen
3 under static bend testing to demonstrate that up to 35
4 newton meter there was no change due to hydride
5 reorientation, which corresponds to the 100 G's that
6 Gordon talked about. But, then, we made a comparison
7 with the cladding-only response, and we saw how
8 markedly higher that response is. And we said, well,
9 now you don't even need to provide cladding
10 properties. You can continue to use cladding-only
11 properties, but you don't even need to account for
12 hydride reorientation.

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

21 And we concluded that, with respect to the
22 risk-informing, we made that conclusion for all
23 cladding alloys. Because of the hydride reorientation
24 treatment that we chose, we feel that it's
25 conservative on the types of specimens, the burnups,

1 the hydrogen content. We feel that it reasonably
2 balanced the rest of the cladding alloys.

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

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

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

1 MEMBER REMPE: Okay.

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

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

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

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

25 MEMBER REMPE: So, the Alden NUREG/CR was

1 just one of several organizations participating in it,
2 and EPRI will respond to that?

3 MR. TORRES: Yes.

4 MEMBER REMPE: Okay. Thank you.

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

10 MR. TORRES: Yes.

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

15 MR. TORRES: Yes.

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

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

24 We also have some additional work on
25 trying to identify the right metric to -- because

1 there's some discussion on what's the right metric
2 that should be chosen.

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

11 MEMBER RICCARDELLA: Thank you.

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

14 (No response.)

15 Dave, do you have any questions?

16 MEMBER PETTI: No, I'm okay.

17 CHAIR BALLINGER: Thanks.

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

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

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

25 And I don't know who's going to go first

1 and who's going to go second. Are you going to go?

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

4 CHAIR BALLINGER: Oh, that's better.

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

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

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

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

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

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

13 So, you did receive comments. The NRC did
14 receive comments from four industry entities: NEI,
15 EPRI, Holtec International, and NAC International.
16 That's significant. Usually, you just see comments
17 consolidated by NEI. It's one of the things we do.
18 Sometimes when it's really technical or when EPRI
19 needs to exercise an independent scientific opinion,
20 you'll see NEI comments and EPRI comments. But the
21 fact that two of our three suppliers, dry storage
22 supplier companies, endeavored to comment, I think
23 that tells you a little bit about the value of this
24 tool, because they don't normally do that. They want
25 to make it work. They are doing things where they see

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1 having the knowledge, better knowledge, of what high
2 burnup fuel is and how behaves in storage is important
3 to their business. And as they are our member
4 companies, we want to represent that.

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

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

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

24 (Laughter.)

25 -- and maybe aren't meaningful.

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

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

17 So, when we got into this, obviously, we
18 took a very cautious approach. I have always in these
19 forums liked to remind that Part 72 follows Part 71
20 because we thought we were going to transport before
21 we thought we were going to dry store. Obviously, on
22 the road you take a very cautious approach. You're
23 not inside a reactor facility. You're not inside our
24 fences. You're not inside our zones which we control.
25 So, that cautious approach translated over to the dry

1 storage, but I think now we understand things better
2 and maybe it is time for a different approach.

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

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

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

23 One bullet I'll highlight in here is we
24 calculate we have approximately 1300 casks that have
25 at least one assembly of high burnup fuel. We

1 actually stopped counting a couple of years ago when
2 we were up to 800 because we realized that just about
3 every cask that's loaded now pretty much has high
4 burnup fuel. So, this 1300 is 800 plus the number of
5 casks we've loaded since we stopped counting.

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

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

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

23 And, of course, I think the sister rod
24 program was referred earlier. Those rods, high burnup
25 rods, that were captured and found their way into a

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1 hot cell are also gold mines of information.

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

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

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

25 And I also say this against the background

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

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

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

15 MR. McCULLUM: Right.

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

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

1 MEMBER REMPE: Thank you.

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

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

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

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

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

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

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

1 improvement in the works there.

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

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

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

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

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

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

23 But we're going to, using the same
24 information and some other things in some areas, we're
25 going to try to quantify that safety margin. And

1 again, that will let us step back and say, what are we
2 focusing on here?

3 This is why it matters. Remember what I
4 said back here when I was scrolling through.
5 Disposition of low safety-significant issues quickly.
6 And I talked about all the information that has to
7 cross the licensing threshold now. This is not
8 dispositioning low safety-significant issues quickly.
9 What this slide says is that we have -- over the last
10 25 years, there are 15 CoCs that have been amended 74
11 times. We have to amend them so frequently because
12 there's a lot of detailed information that's not
13 safety significance that has to cross the boundary for
14 NRC approval.

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

22 So, really, the question I leave you with
23 is, are the differences between high burnup fuel and
24 low burnup fuel really meaningful? And if they are
25 not, why are we doing a lot of what we're doing? And

1 what could we be doing with the resources that we're
2 doing it with right now? I think we're close to some
3 answers here, and I encourage this Committee to
4 continue to focus a sharp eye on this.

5 And that leaves me open for questions at
6 this point.

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

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

18 MR. McCULLUM: Yes. No, I agree.

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

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

1 MEMBER MARCH-LEUBA: No.

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

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

15 MR. McCULLUM: Yes.

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

21 MR. McCULLUM: I generally agree
22 wholeheartedly, yes.

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

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

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

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

11 MR. McCULLUM: Yes.

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

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

22 MEMBER REMPE: Yes.

23 MR. McCULLUM: And this spider or bubble
24 chart, this is not unique to dry storage. This is
25 what Doug True is talking to the NRC, his counterparts

1 at NRC, on the reactor side about. That's exactly,
2 what you just described is exactly what's at the top
3 here. Disposition of low safety-significant issues
4 quickly.

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

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

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

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

24 MR. McCULLUM: Yes.

25 MEMBER REMPE: -- bounding conditions.

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

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

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

7 MR. WALDROP: Do we need to change?

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

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

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

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

25 And there's some that leave some future

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

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

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

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

25 So, the report in 2005, the number here on

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

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

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

25 MR. WALDROP: Their analysis was still,

1 the testing was cladding-only.

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

5 MR. WALDROP: No.

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

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

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

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

17 MR. BJORKMAN: That's correct.

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

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

1 get the effect of the fuel pellet.

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

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

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

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

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

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

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

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

12 MR. WALDROP: Okay, yes.

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

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

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

25 MR. WALDROP: That was what was evaluated

1 in the report in 2005, what we are looking at. Again,
2 the point, just showing how much the pellet provides
3 resistance.

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

6 MR. WALDROP: Yes.

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

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

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

16 MR. WALDROP: This is a pinch load.

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

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

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

24 MEMBER RICCARDELLA: Oh.

25 MEMBER MARCH-LEUBA: Of course you're

1 going --

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

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

8 MEMBER RICCARDELLA: Okay. All right.

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

12 MR. BJORKMAN: That's correct.

13 MEMBER MARCH-LEUBA: All right, but --

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

16 MEMBER RICCARDELLA: Yes. Okay.

17 MEMBER MARCH-LEUBA: All right.

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

25 We have lack of material property data on

1 high burnup fuel. And there's a limited understanding
2 of the effect of what hydride reorientation does under
3 realistic conditions. So, with those questions out
4 there, the NRC initiated the test program that they've
5 described in the NUREG and really looking at what
6 those results did.

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

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

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

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

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1 there to support this.

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

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

18 The EPRI comments, again, we appreciate
19 having the draft NUREG out there, the ability to
20 review it and provide some comments. We feel that the
21 comments have largely been addressed, and some were
22 not addressed at this time. I'll talk to a couple.
23 But I think that that's appropriate. I think we can
24 still move forward with the NUREG as it is, and we
25 have an opportunity to maybe further update the

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1 guidance in the future. But this NUREG as it is
2 provides guidance that is needed right now.

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

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

19 In the end, there's no result to the NUREG
20 or its conclusions. What happened was that higher rod
21 internal pressure for IFBA rods drove the NRC to pick
22 a much higher rod internal pressure for their hydride
23 reorientation treatment. So, it's bounding, it's
24 really bounding. But, in the end, the conclusion,
25 that hydride reorientation doesn't need to be

1 accounted for when using cladding-only properties,
2 that conclusion remains valid. So, there was no
3 impact to the overall conclusions.

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

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

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

24 And that's appropriate for what they
25 wanted to do. The ring compression test, they wanted

1 to isolate the effect of hydride reorientation only
2 and not include other competing effects. So, it's
3 just been clarified in the text.

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

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

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

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

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

25 Now I'm moving on to some comments that we

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

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

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

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

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1 just beginning that will provide some data for that in
2 the future.

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

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

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

22 MEMBER RICCARDELLA: But enough to touch
23 during the drop?

24 MR. WALDROP: Through the grid.

25 MEMBER RICCARDELLA: Oh, through the grid?

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

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

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

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

14 MEMBER MARCH-LEUBA: Starting from zero
15 velocity?

16 MR. WALDROP: From zero velocity --

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

19 MR. WALDROP: A 9-meter side drop.

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

22 MR. WALDROP: We've talked a little bit
23 about this, but another comment that we made was,
24 overall, there's excessive reduction. So, the testing
25 was done. The pellet provides some rigidity, but the

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1 section that goes through that, basically, continues
2 to take piece after piece away.

3 So, initially, like we talked about,
4 cladding-only versus fuel with the pellet, they did
5 that testing and found about a factor of 2 more rigid.
6 And that factor of 2 did use what few data points they
7 had to do a 98 percentile 2 sigma to reduce that to
8 1.96.

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

21 But, then, in the end, it was a factor of
22 one. So, the end conclusion was use cladding-only
23 properties and take no credit for the rigidity. And
24 that last step was taken because the testing was only
25 done on Zirc-4 fuel, but, yet, they're saying we think

1 the reorientation treatment was applicable, was
2 bounding of all types. But, again, the end result is
3 there's no credit given for the rigidity whatsoever.
4 But you can use cladding-only properties and you don't
5 have to account for hydride reorientation.

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

10 And how we get there is ongoing in future-
11 related work that we're looking at doing that,
12 including realistic approaches. One area where we've
13 learned a lot is the DOE-EPRI high burnup demo. We're
14 finding there that the cladding temperatures as
15 measured are low, such that we are not getting
16 significant hydride reorientation in any high burnup
17 fuel cask loaded. Agreed, the temperatures in the
18 high burnup demo were even lower, but Oak Ridge went
19 back and did some more best-estimate analysis on all
20 the casks out there and found that it's in around the
21 320-325 C range, such that there would be no
22 significant hydride reorientation whatsoever.

23 MEMBER REMPE: Is this a good place to
24 interrupt and ask you to talk about this analysis
25 effort and what I mentioned earlier to the staff? I

1 mean the staff had this effort that they sponsored
2 with all the laboratories, and they said there wasn't
3 enough instrumentation to have a high fidelity CFD
4 type of validation done. Is that what others are
5 finding that did this effort?

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

9 MEMBER REMPE: Right.

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

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

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

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

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

25 MEMBER REMPE: Well I'm just wondering

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

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

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

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

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1 question addressed by this EPRI report?

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

8 MEMBER REMPE: Thermal couples --
9 (Simultaneous speaking.)

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

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

21 MR. WALDROP: Yes, I think absolutely.

22 MEMBER MARCH-LEUBA: Is any of this
23 analysis involve any kind of Monte Carlo simulations
24 to determine where the uncertainties actually are and
25 what are the important ones? This PIRT thing is just

1 a sort of elicitation, right?

2 MR. WALDROP: Yes.

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

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

8 MEMBER MARCH-LEUBA: It's a multivariate.

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

11 (Simultaneous speaking.)

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

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

21 MR. CSONTOS: Hi. This is Csontos from
22 EPRI. So I just want to make a couple of points. One
23 was the purpose of the high burnup demo, you know,
24 benchmarking study, it wasn't there to do a CFD model
25 validation. This is a real canister or a real cask,

1 okay, that we outfitted with real thermal couples to
2 get real data, okay.

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

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

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

23 But when what he was mentioning is that
24 Oak Ridge went back and did a recalculation of all the
25 available data, of all the canisters that have been

1 loaded to date, okay, did a best estimate calculation,
2 and what we found is that only about less than one
3 percent of the claddings that were at the highest
4 temperature, okay. The vast majority of it is even 30
5 to 40 degrees lower than that when you look at the
6 histogram.

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

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

24 So in this way we're trying to get a best
25 estimate, to make the best decisions possible. I

1 think that's kind of where -- and Ron, to your
2 question about Monte Carlo simulations, no one has
3 done that yet, okay. We're not planning to do that
4 right now. What we're doing is we're trying to
5 identify all the different -- because there's a nexus
6 between fuel, temperature, decay heat, fuel and
7 performance and also temperature modeling, we're doing
8 a PIRT to look at all three of those simultaneously.

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

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

25 MR. CSONTOS: Yes.

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

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

5
6 CHAIR BALLINGER: I think.

7 (Simultaneous speaking.)

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

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

18 MEMBER REMPE: Okay, thank you.

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

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

6 (Simultaneous speaking.)

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

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

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

23 I do that, and then I'm a decommissioning
24 plant. Right now the business models for
25 decommissioning are advancing very rapidly, and a key

1 component of those business models is get the fuel out
2 of the pools more quickly. Get into dry storage and
3 then get down to tearing the plant down faster. That
4 really uses the decommissioning trust funds a lot more
5 effectively. But if I've got to submit an amendment
6 to load hotter fuel, because that means loading hotter
7 fuel.

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

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

25 Another thing we're looking at is, you

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

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

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

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

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

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

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

9 MR. McCULLUM: Exactly. If I have --

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

12

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

15 MEMBER MARCH-LEUBA: That complicates your
16 licensing.

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

22 MEMBER MARCH-LEUBA: Well then you need
23 data.

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

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

3 MR. McCULLUM: We want NUREG-2224.

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

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

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

13 MR. McCULLUM: 400 degrees is an arbitrary
14 limit.

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

17 MR. McCULLUM: Right, yes. So if I know
18 --

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

25 MR. WALDROP: Again, what we want to do is

1 understand the margin and then determine what might be
2 the best application of once we understand what it is.
3 Increasing the temperature limit, that is, you know,
4 from maybe we load hotter, maybe we go above 400 and
5 we -- but we -- going above 400 C for a peak clad
6 temperature limit is going to open up a bit of
7 Pandora's box.

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

13 MEMBER MARCH-LEUBA: I'm a computer guy
14 and analysis guy. Whenever you start to do your
15 calculations, you know, that you can see the
16 calculations are conservative. I have a joke about
17 conservative calculations. They're in error on one
18 direction. But do better calculations, stay within
19 400 and then you don't have to change the regulatory
20 basis.

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

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

4 (Simultaneous speaking.)

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

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

8 MR. McCULLUM: Well, we'll see. That's
9 where this white paper and this PIRT are going to take
10 us next, is I think you can take the information in
11 2224 and combine it with some other things in getting
12 there. I'm not saying we have to revise 2224.

13 MR. WALDROP: The 400 degrees is in ISG-11
14 and now the SRP. So it wouldn't necessarily impact
15 2224, but again that's a -- it's not a foregone
16 conclusion that we want to go above 400.

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

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

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1 forward-looking here.

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

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

15 MEMBER MARCH-LEUBA: Per plant?

16 MR. CSONTOS: Per plant, per plant.

17 (Simultaneous speaking.)

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

25 You're going to go to higher burnup fuel,

1 which is going to be hotter. And so we're, you know,
2 we're trying to expand the operational flexibilities.
3 But I completely agree with what you're saying, which
4 is you're asking for possibly more -- it looks like
5 we're looking for more regulatory burden, and that's
6 not -- that's not what we're --

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

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

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

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

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

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

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

25 MR. CSONTOS: They want to put -- so some

1 of the utilities want to put more, you know, blankets
2 on there. But they're limited because of the thermal
3 counts to be able to put more --

4 MEMBER MARCH-LEUBA: To put blankets for
5 --

6 MR. CSONTOS: Shielding blankets.

7 MEMBER MARCH-LEUBA: Shielding.

8 MR. CSONTOS: Shielding blankets, right.

9 MEMBER MARCH-LEUBA: Lead blankets?

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

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

16 MR. CSONTOS: Exactly.

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

19 (Off mic comments.)

20 MEMBER MARCH-LEUBA: Microphone,
21 microphone.

22 MEMBER RICCARDELLA: I think, you know,
23 I'd refer back to Ron's comment about I think the way
24 to get to where you want to go is through quantifying
25 what the distributions are on all these, and maybe

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1 this will come out of your PIRT and then do a Monte
2 Carlo analysis that shows hey, I only have ten to the
3 minus 3rd probability that any point in the fuel is
4 going to exceed 400 degrees.

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

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

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

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

3 MEMBER KIRCHNER: Well, may I make an
4 observation?

5 CHAIR BALLINGER: Of course.

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

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

23 And so I feel it's a problem that's
24 amenable to bounding through that kind of uncertainty
25 analysis, and then you could go I think to a more

1 generic approach to the cask licensing or
2 certificates, so that's you're not constantly forced
3 to have an amendment for every change of fuel loading
4 in that cask.

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

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

22 CHAIR BALLINGER: Another member's
23 opinion. I've been personally pushing on the fact
24 that we've got the cart before the horse from the
25 beginning, that we've not done the consequence

1 analysis which should have been done first. One
2 person's opinion.

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

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

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

10 MR. WALDROP: Right.

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

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

15 (Simultaneous speaking.)

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

22 CHAIR BALLINGER: Yes.

23 MR. WALDROP: Yeah.

24 MEMBER KIRCHNER: The building becomes an
25 economic question for either the government or for the

1 industry.

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

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

12 MR. McCULLUM: Right.

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

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

25 MR. McCULLUM: That's exactly where we're

1 trying to be.

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

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

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

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

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

1 that defines confinement, right.

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

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

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

8 CHAIR BALLINGER: Yeah, that's true.

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

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

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

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

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

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

18 You know, making a rule that codifies
19 exemptions that are already being issued is a fairly
20 simple thing. That rulemaking started in 2014. It's
21 2019 and it's still not done yet. When I look at the
22 decommissioning projects that may want to load hotter
23 fuel, when I look at our country is about to get its
24 first four-unit PWR, we don't want four units all on
25 18 month cycles at the same site, you know. These

1 problems are more urgent than rulemaking will support.

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

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

8 CHAIR BALLINGER: Yeah.

9 (Laughter.)

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

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

22 So does that open the door that maybe we
23 don't need to do a fatigue limit analysis for normal
24 conditions of transport from what we learned there?
25 And also there's ongoing -- there's recently-initiated

1 work looking at the mechanisms of hydride
2 reorientation to better understand that. Like I said,
3 pinch load testing.

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

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

20 But I think we've got future opportunity
21 to consider what, how can we evaluate more realistic
22 conditions, take credit, real credit for the structure
23 of the pallet? Hydride reorientation, maybe it's not
24 a concern after all given the temperatures and hoop
25 stresses we're seeing. What about the loads of normal

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1 conditions at transport being very low? How can we
2 implement that?

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

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

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

21 MS. GILMORE: This is Donna Gilmore. I'm
22 at San Onofre, Sacramento. I submitted extensive
23 comments on this NUREG. The one thing that really
24 troubles me is (audio fading) has gained on over 4,400
25 data points from real operating data on the level of

1 offsite buildup at various burnups, and I don't
2 understand, since you have so little operating data
3 which is really not even the typical operating data,
4 why you aren't using that? That's one point.

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

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

23 All these and a whole slew of other
24 issues, it seems like they should be considered, you
25 know. We're dealing with millions of people in our

1 national economy and security, and so this is more
2 than just about hopefully industry profit as being a
3 priority there. So I'd like to see this. I have a
4 lot more that I want to say, you know, cut it short
5 because I know other people may have comments.

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

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

12 CHAIR BALLINGER: Yes.

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

24 And it just seems like the cart before the
25 horse in terms of maximizing industry profit, when we

1 do not really know how this stuff is going to behave
2 over periods of time. It doesn't give me a lot of
3 confidence that we're talking about computer
4 simulations and that the sister rods study (phonetic),
5 there's questions even coming from within the industry
6 that DOE's isn't even going to be able to complete
7 that study, of actually seeing what that fuel does in
8 a short period of ten years, let alone 100 years,
9 1,000 years, 10,000 years.

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

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

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

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

3 CHAIR BALLINGER: Who? Can you repeat
4 your name?

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

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

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

25 I'm surprised that some 10,000 casks are

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

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

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

14 CHAIR BALLINGER: You sure can.

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

NEAL R. GROSS

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WASHINGTON, D.C. 20005-3701

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

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

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

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

24 MEMBER REMPE: I also appreciate the
25 presentations and the discussions. I'm not sure a

1 letter's needed on this, but the concern about not
2 opening up the high burnup demo cask if -- that's
3 something that if we want -- we might want to explore
4 further and bring it up as part of our biennial
5 research review if it's important to staff efforts.
6 So we might want to keep that in mind.

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

15 MR. TORRES: Is that on?

16 CHAIR BALLINGER: Yes sir.

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

23 MEMBER RICCARDELLA: Thank you.

24 CHAIR BALLINGER: Walt?

25 MEMBER KIRCHNER: Good presentations and

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

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

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

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

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

- 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 a 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

- 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

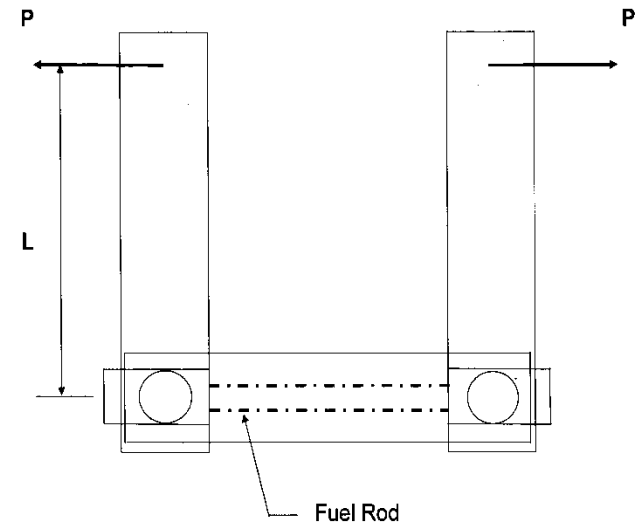
Static Bending and Fatigue Testing

- 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

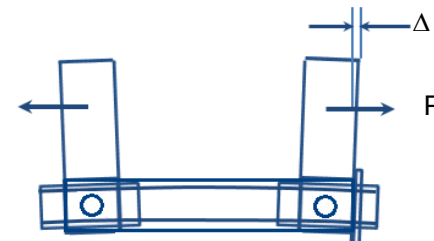
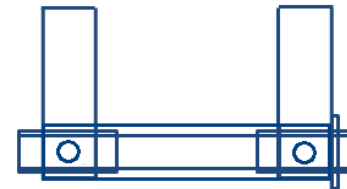
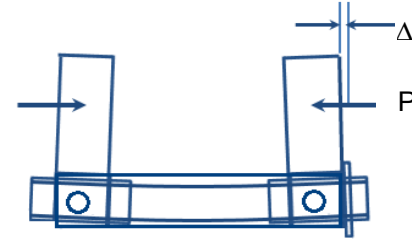
Subject a fully fueled rod to a constant bending moment

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

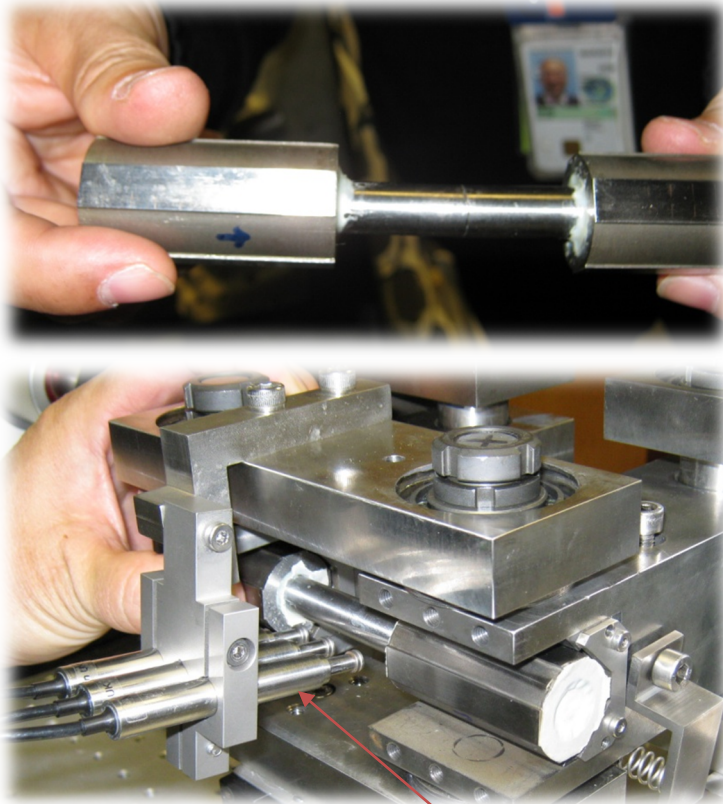
$\kappa = 1/R$ and R is the radius of the circular arc

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, $EI = M / \kappa$

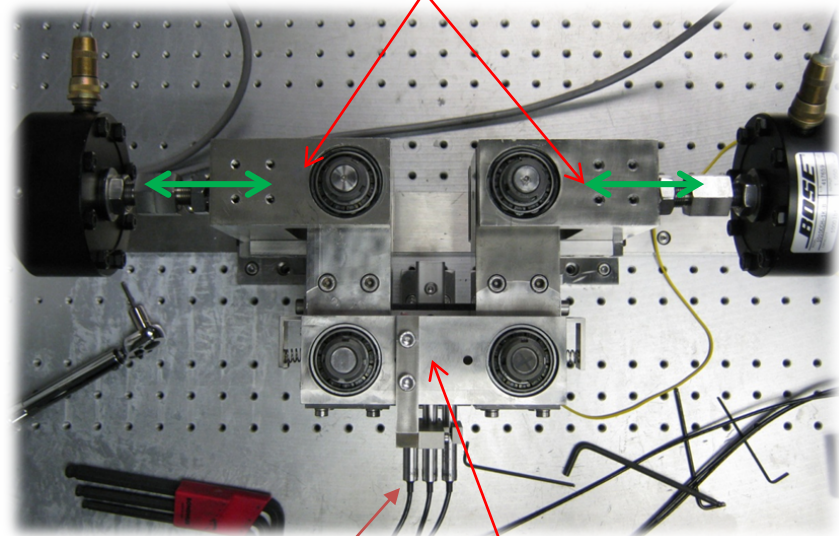


Instrumentation (CIRFT)



Three displacement transducers

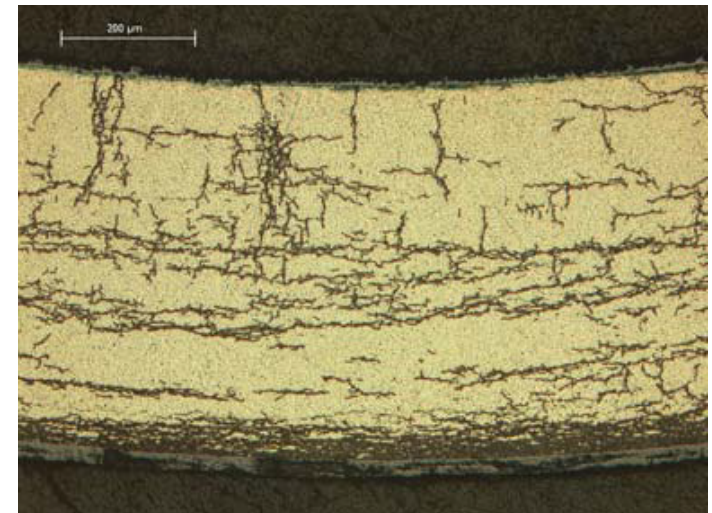
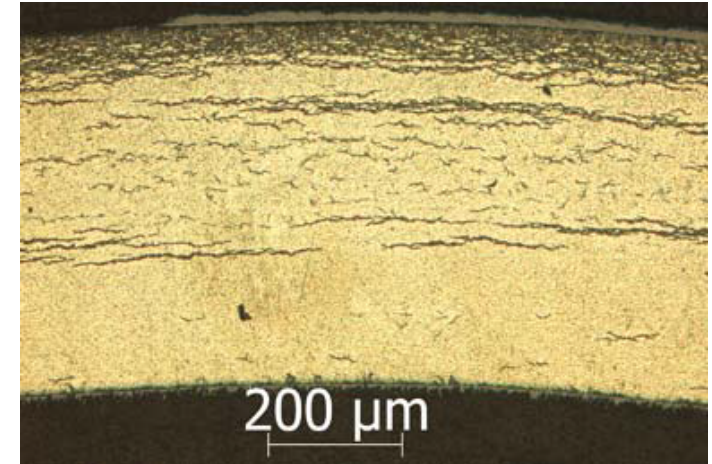
Push-pull force applied to U-Frame by the load cells results in a constant bending moment on the test segment



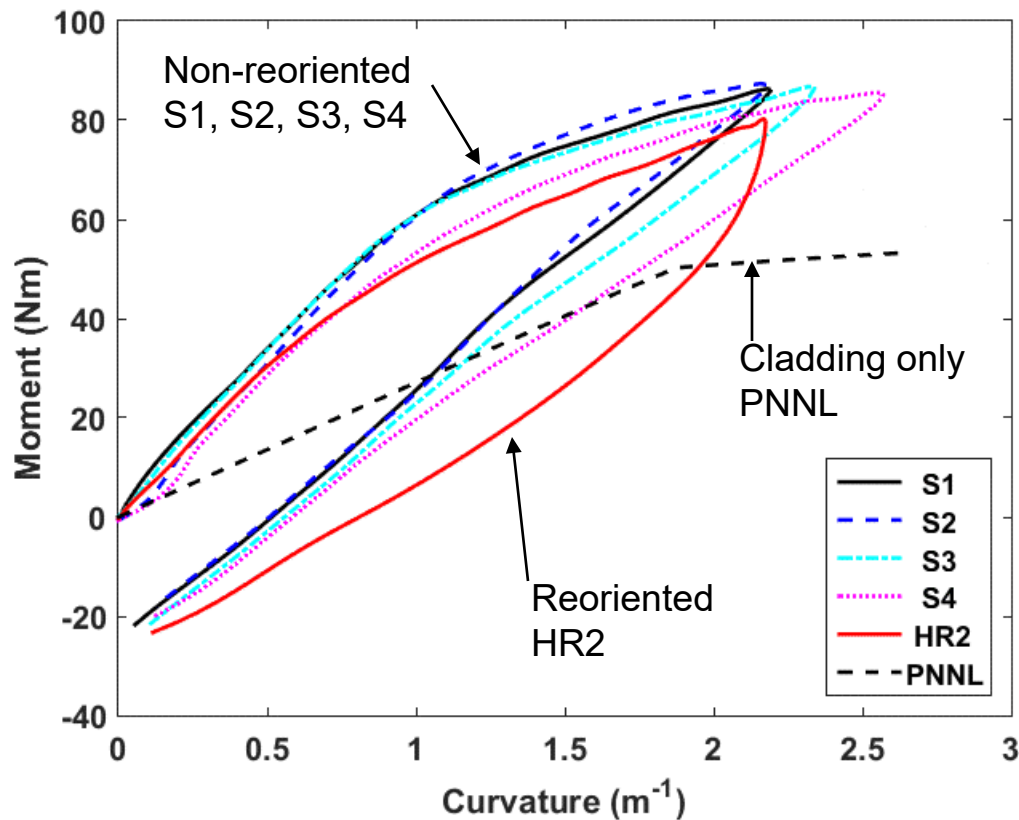
Location of test segment

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



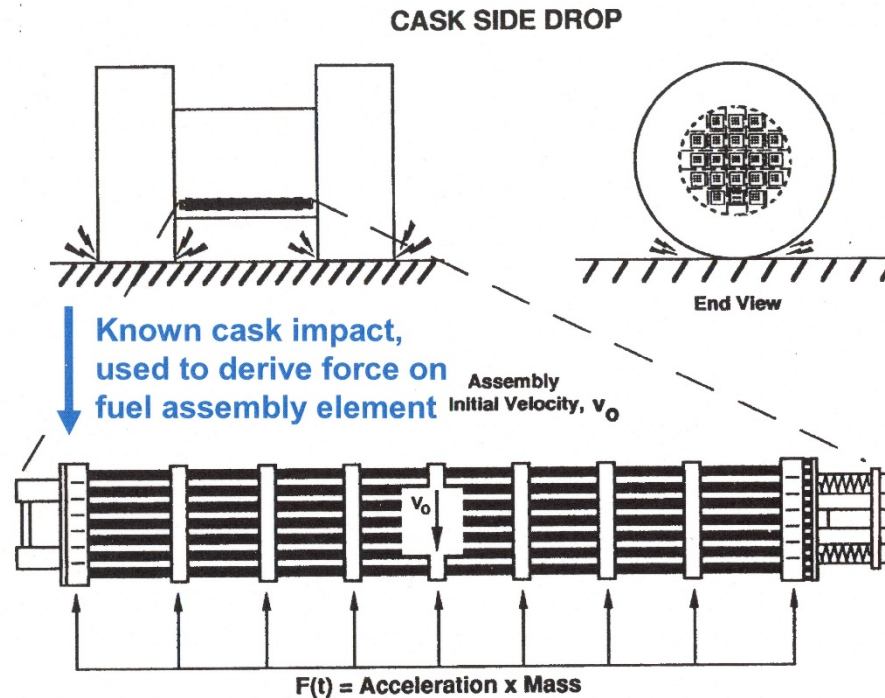
Static Test Results



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

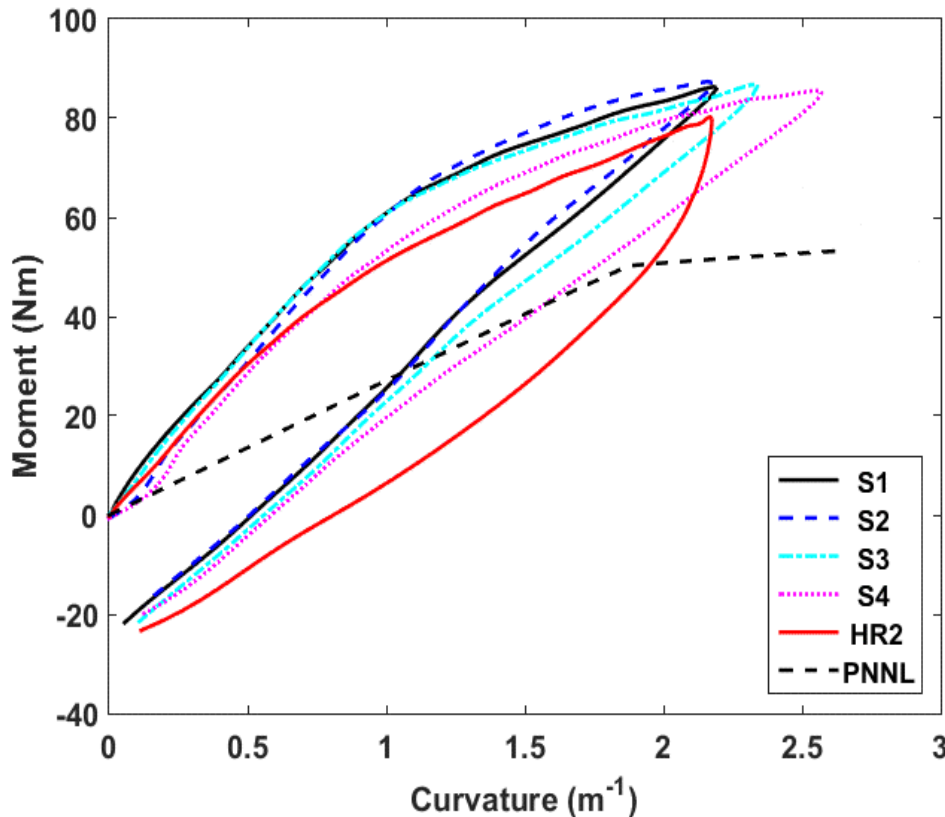
Fuel Rod Safety Margin against failure for HAC Side Drop Event



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 $\times 50g = 2.0 \times 50g = 100g$
- 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 $100g / (2.94g/N\text{-}m) = 34 \text{ N-m}$

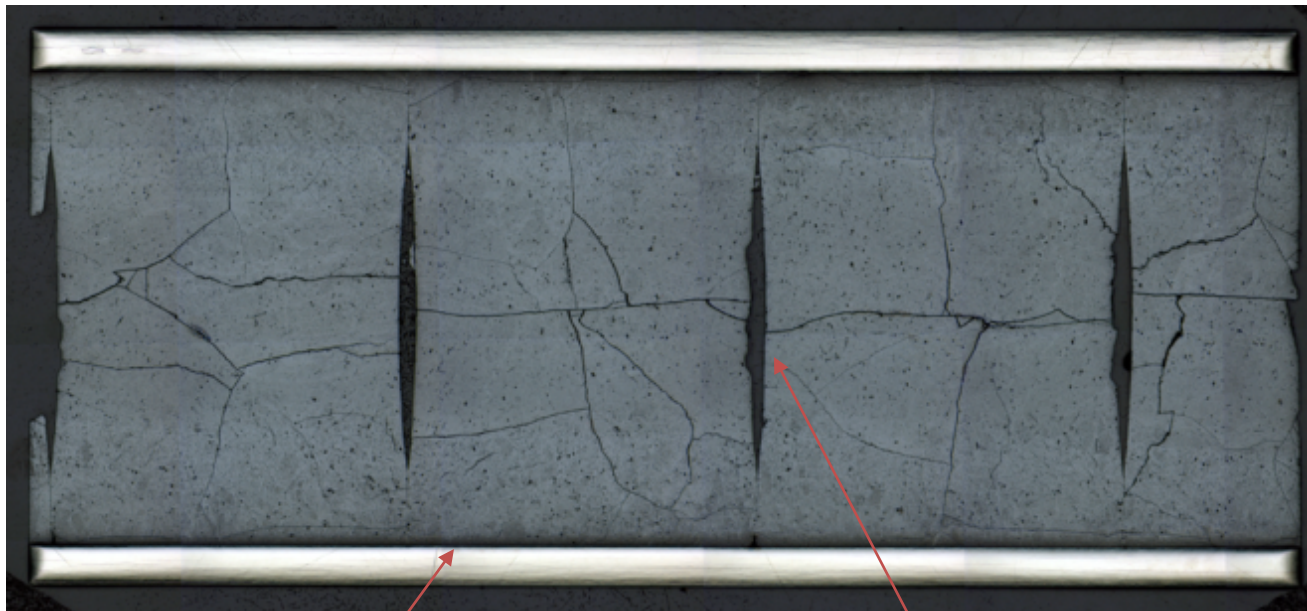
Fuel Rod Safety Margin against failure for HAC Side Drop Event



Safety Margin is conservatively calculated to be

$$80 \text{ N-m} / 34 \text{ N-m} = \mathbf{2.35}$$

Cladding-Pellet Structure in a HBU SNF Rod

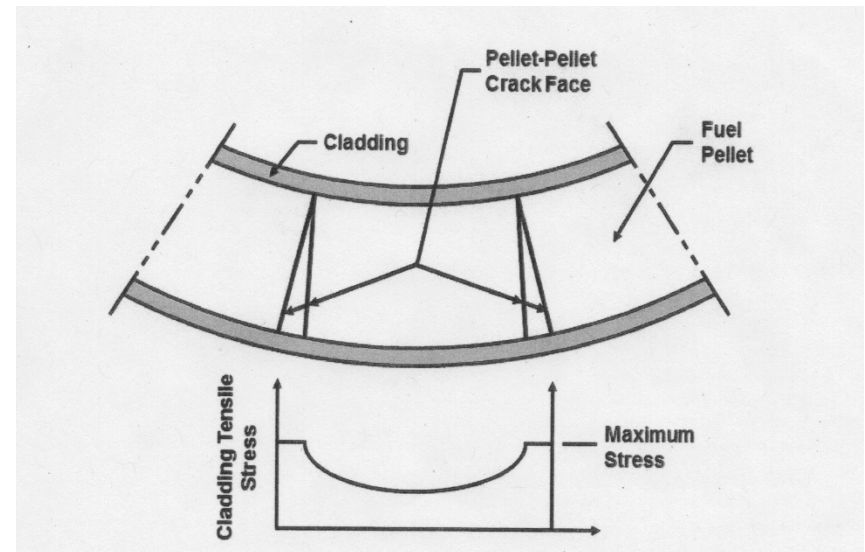


Cladding-Pellet Interface

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

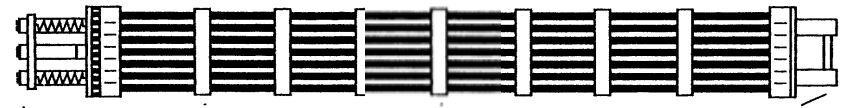
- Cladding stress, strain and flexural rigidity have always been calculated for HAC events using only the properties of the cladding, which is very conservative
- To remove this conservatism a factor was developed, based on the static test results, to convert the cladding-only stress, strain and flexural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

Fatigue during Normal Conditions of Transport (NCT)

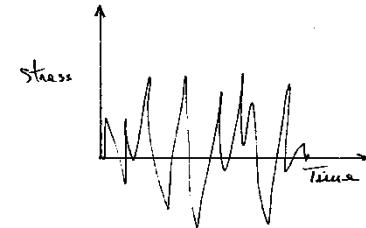
A transportation cask will experience some level of oscillation due to normal conditions of transport



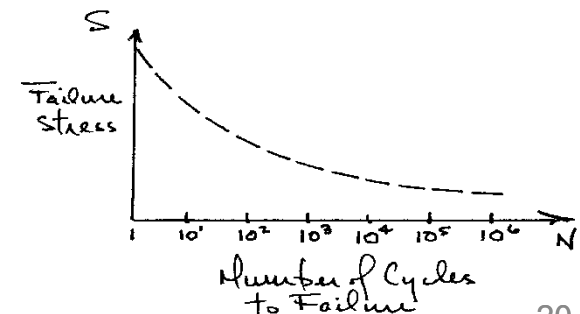
That oscillation will be transmitted in some way to the contents of the cask, the fuel elements



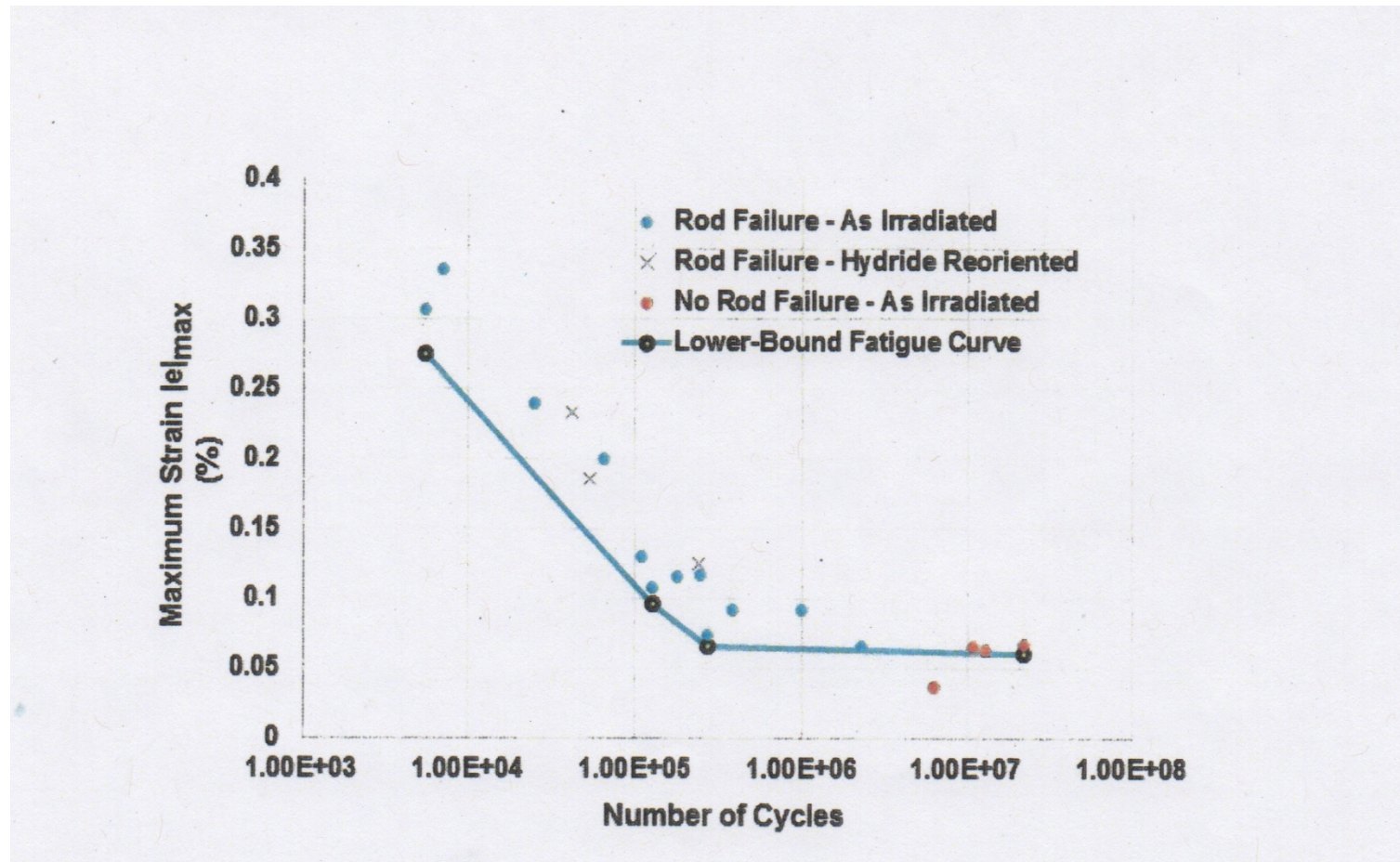
The oscillation transmitted to the fuel elements will result in local stresses in the fuel rods



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:

$$\sum n_i/N_i = n_1/N_1 + n_2/N_2 + n_3/N_3 + \dots = 1.0$$

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)

- 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

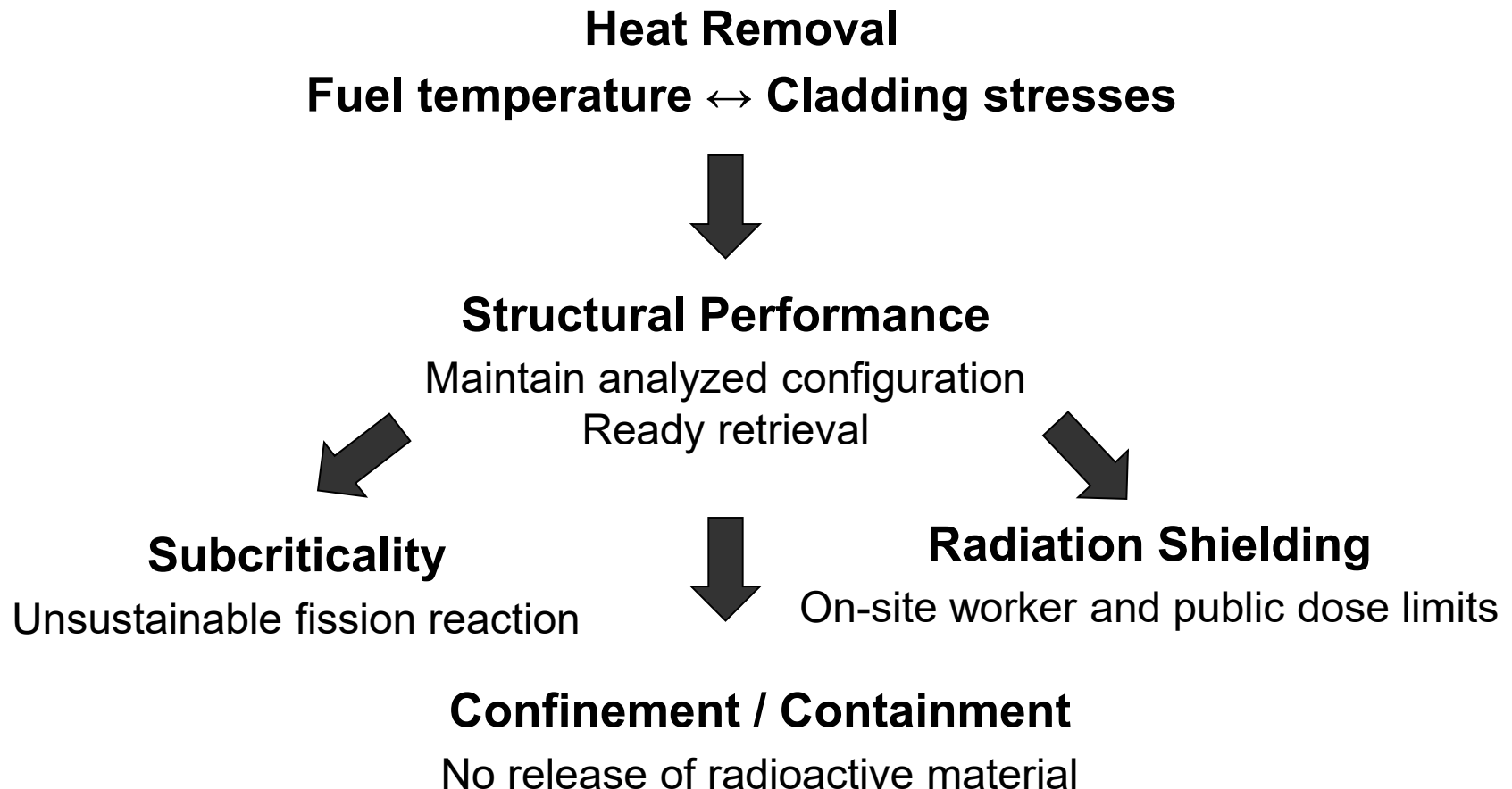
- Initial period of comment
 - August 9 – September 24, 2018
- Second period of comment
 - October 10 – November 9, 2019
- Comment submissions available via:
 - NRC's Electronic Reading Room
 - <http://www.nrc.gov/reading-rm/adams.html>
 - Federal e-Rulemaking Portal
 - <http://www.regulations.gov>
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

**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



Review Guidance Framework

Cladding Performance

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

- 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).

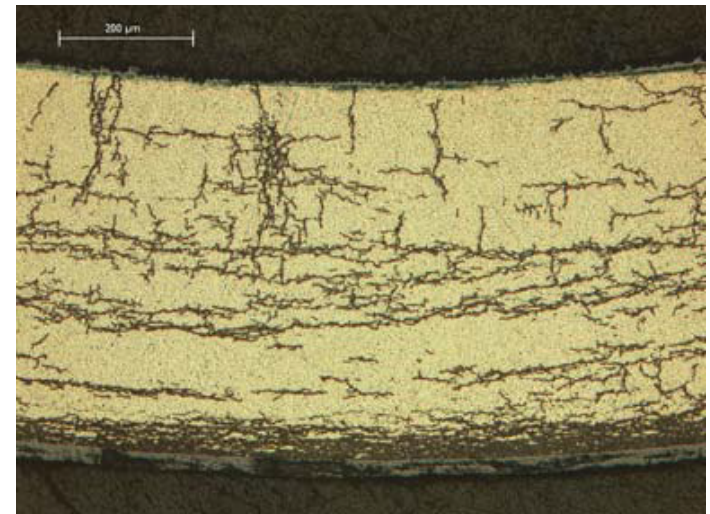
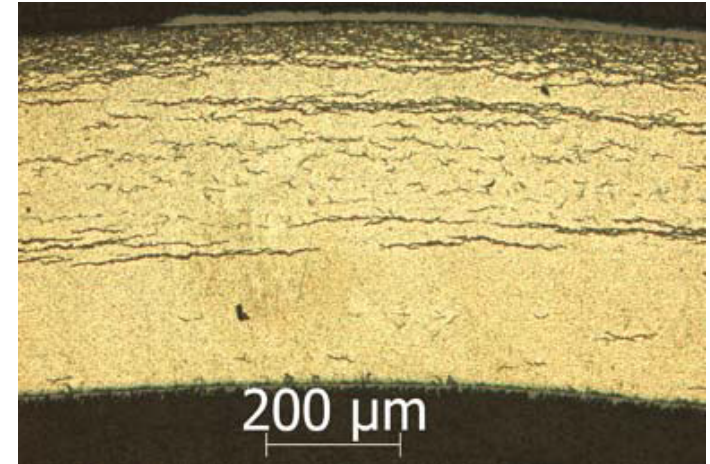
Repeated heatup/cooldown cycles limited to less than 10 cycles, with cladding temperature variations less than 65 °C (117 °F), each.

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

- 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 Fahrenheit
- 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



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

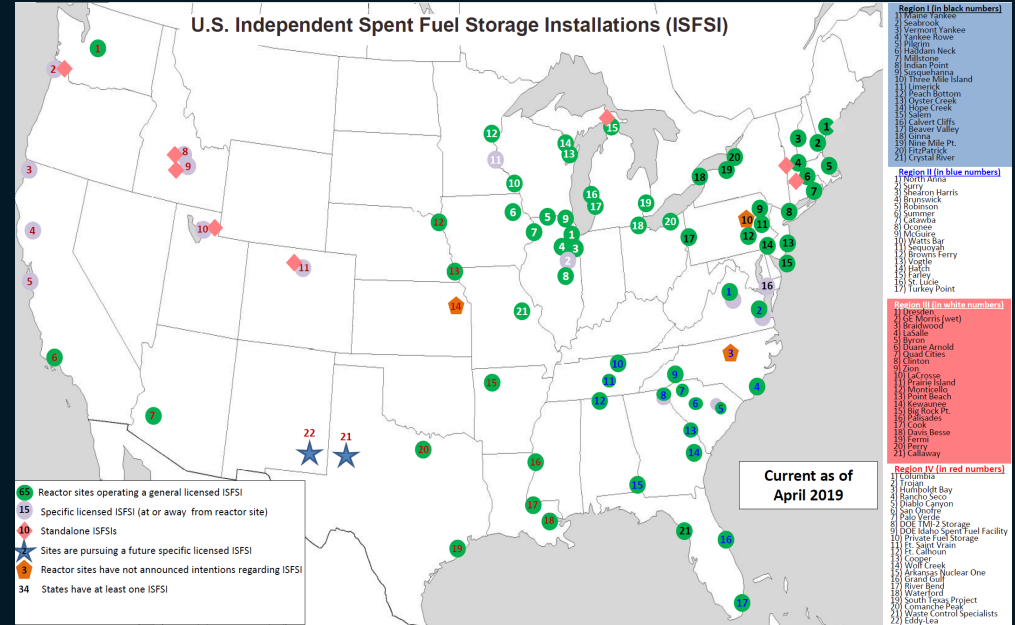
Approximately 1300 casks contain at least
1 assembly of high burnup fuel

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

Foundational Enablers

Industry
Maturity

Strong
Performance

**NUREG
2224**

Understanding
of Safety Margin

Increased
Focus on
Safety
Significance

Transformative Elements

Disposition Low
Safety Significant
Issues Quickly

Implement Graded
Reasonable/High
Assurance Standards

Implement
Performance-based
Inspection

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.

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



ELECTRIC POWER
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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



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Outline

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

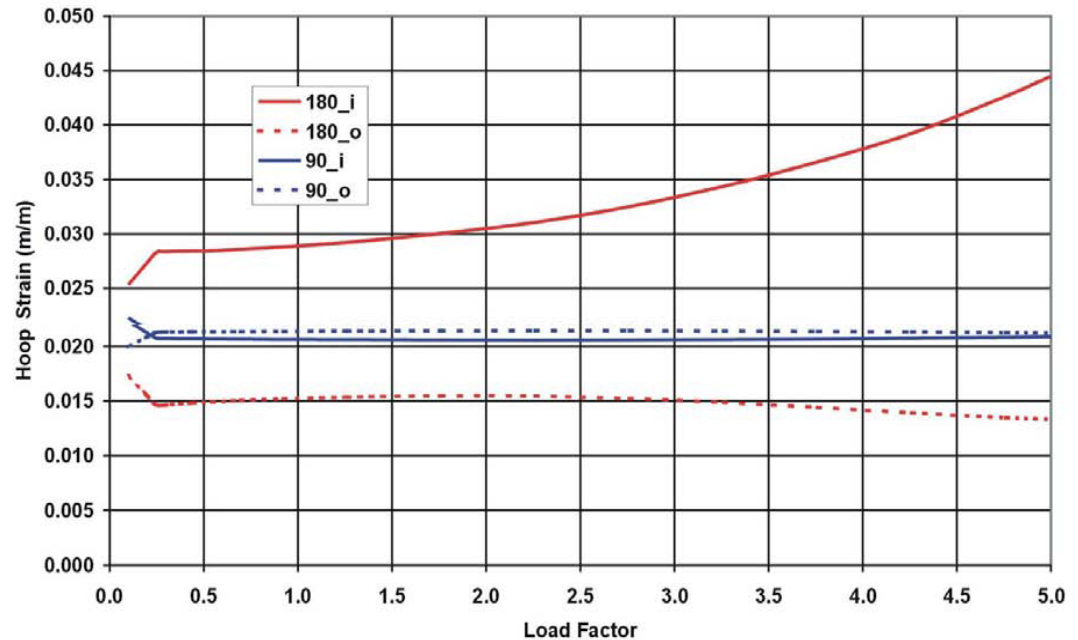
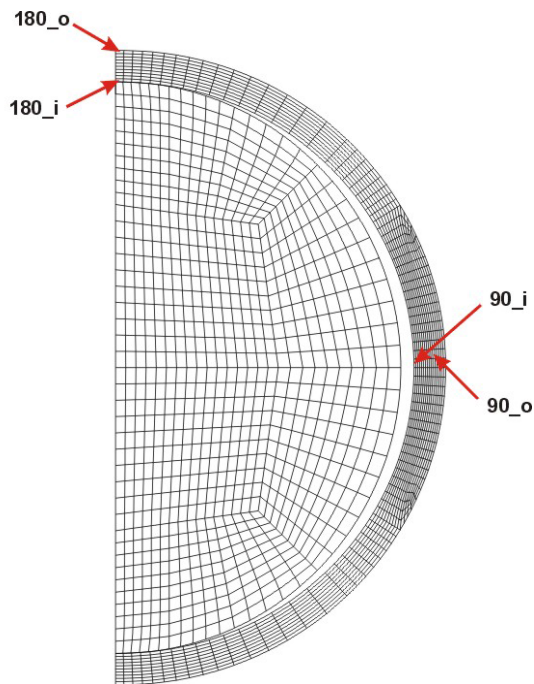


Review and Motivation

- 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

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



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