Official Transcript of Proceedings

NUCLEAR REGULATORY COMMISSION

Title: Advisory Committee on Reactor Safeguards Materials, Metallurgy and Reactor Fuels

Docket Number: (n/a)

Location: Rockville, Maryland

Date: Wednesday, December 2, 2008

Work Order No.: NRC-2565 Pages 1-325

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NUCLEAR REGULATORY COMMISSION

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ADVISORY COMMITTEE ON REACTOR SAFEGUARD

SUBCOMMITTEE ON MATERIALS,

METALLURGY AND REACTOR FUELS

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WEDNESDAY, DECEMBER 2, 2008

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ROCKVILLE, MARYLAND

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The Advisory Committee met at the Nuclear Regulatory Commission, Two White Flint North, Room T2B3, 11545 Rockville Pike, Rockville, Maryland, at 8:30 a.m., J. Sam Armijo, Chairman, presiding.

COMMITTEE MEMBERS PRESENT:

J. SAM ARMIJO, Chairman

SAID ABDEL-KHALIK, Member

MARIO V. BONACA, Member

CHARLES H. BROWN, JR., Member

DANA A. POWERS, Member

HAROLD B. RAY, Member

WILLIAM J. SHACK, Member

JOHN D. SIEBER, Member

ACRS STAFF PRESENT:

CHRISTOPHER BROWN, Designated Federal Official

NRC STAFF PRESENT:

SHER BAHADUR, NRR

MICHAEL BENSON, RES

PAUL CLIFFORD

RALPH LANDRY, NRO

RALPH MEYER

BILL RULAND

HAROLD SCOTT, RES

JENNIFER UHLE

CHRIS VAN WERT, NRO

JOHN VOGLEWDE, RES

ALSO PRESENT:

JOHN ALVIS, ANATECH

MIKE BILLONE, ANL

GORDON CLEFTON, NEI

MAUREEN CONLEY, Platts/McGraw Hill

BERT DUNN, Areva

KURT EDSINGER, EPRI

NAYEM JAHINGER, UNF

YANG-PI LIN, GNF

ROBERT MONTGOMERY, EPRI

TOM RODACK, Westinghouse

RICHARD SCHOFF, Westinghouse

ALSO PRESENT (Continued):

AL STRASSER, Aquanus Services

ROBERT TSAI, Exelon Generation Co.

KEN YUEH, EPRI

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P R O C E E D I N G S

(8:30 a.m.)

CHAIRMAN ARMIJO: Good morning. The meeting will now come to order.

This is a meeting of the Materials, Metallurgy and Reactor Fuels Subcommittee. I am Sam Armijo, Chairman of the Subcommittee. ACRS members in attendance are Jack Sieber, Bill Shack, Mario Bonaca, Harold Ray, Dana Powers, and Said Abdel-Khalik. Mr. charles Brown will be a little late and possibly, Mr. Bley, Dennis Bley and John Stetkar will also join us a little later.

The purpose of the meeting is to receive an update on the rulemaking activities and technical regulatory challenges related to the revision of 10 CFR 50.46(b). We will hear presentations from representatives of the Office of Nuclear Reactor Regulation, Argonne National Laboratory, and the Nuclear Regulatory Search, RES.

In addition, presentations will be heard from the Electric Power Research Institute, AREVA, Westinghouse, and Global Nuclear Fuels.

The Subcommittee will gather information, analyze relevant issues and facts, and formulate proposed positions and actions as appropriate for

deliberation by the full Committee.

The rules for participation in today's meeting were announced as part of the notice of this meeting previously published in the Federal Register on November the 18th, 2008. We have received no written comments or requests for time to make oral statements from members of the public regarding today's meeting.

A transcript of the meeting is being kept and will be made available as stated in the Federal Register notice. Therefore, we request that participants in this meeting use the microphones located throughout the meeting room when addressing the Subcommittee. Participants should first identify themselves and speak with sufficient clarity and volume so that they can be readily heard.

We will now proceed with the meeting and I will call upon Mr. Bill Ruland of the Office of Nuclear Reactor Regulation to introduce the presenters.

MR. RULAND: Thank you, Mr. Chairman.

And good morning, everyone. A decade ago the NRC staff embarked on a rulemaking campaign aimed at revising the fuel oxidation criteria in 10 CFR 50.46, Paragraph B. Now, the Office of Research

conducted a significant research program to understand cladding embrittlement during loss of coolant accidents and documented the results of that research in NUREG/CR-6767 and referenced it in a recent Research Information Letter, RIL-801.

This research firmly established the link between cladding embrittlement and the hydrogen concentration in that cladding.

We are now on the threshold of using that research to start the process of changing our regulations in 50.46, the ECCS acceptance criteria. The first step in this process is to evaluate the adequacy of the technical basis supporting the potential rule changes.

NRR, who is the office that does the rulemaking, needs a sufficient technical basis before rulemaking can proceed. This is reflected in our documented internal processes.

In July of this year, NRR issued a Federal Register notice soliciting public and industry comments on the technical basis documented in that NUREG/CR and in the RIL. Significant comments were received and were discussed at a public workshop on September 24th.

During today's presentation, NRR staff

will present conceptual changes to the structure of 50.46. We're still in the conceptual stage of this rulemaking campaign. As such, specific language of the rule is still being developed.

At this time the staff does not need a written response to a draft strategy or conceptual rule changes. However, as always, the NRR and Research staff welcomes the Committee's comments on a proposed approach that we will be describing today.

And if there's no further questions, I'll turn it over to Paul.

MR. CLIFFORD: Good morning. My name is Paul Clifford. I work in the Division of Safety Systems in NRR, and I'll just take a few minutes to kick off this meeting to kind of answer the question why we're here today and how we got here.

I'll be discussing a few background documents, which are important.

First off, the current regulation, 10 CFR 50.46, is limited in applicability to Zircaloy or ZIRLO. In April of 2000 NEI submitted a petition of rulemaking requesting that this language be revised to allow new cladding materials other than Zircaloy or ZIRLO without the need for exemption.

At that time, in 2000, AREVA had submitted

and gotten approval for their zirconium alloy M5. However, the application of M5 required an exemption. That's one of the reasons behind the request from NEI.

In March of 2002, the staff issued SECY-02-0057, which recommended modifying 50.46 to make the rule more performance based.

One year later, the Commission approved the staff's recommendation on the performance based aspects of 50.46. In response, the Office of Research updated the high burn-up research plan to develop the technical basis. The results of that effort are NUREG-6967 and RIL-0801.

Somewhat separate from that effort, in March of '07, the staff received a petition for rulemaking, requesting that the NRC modify 50.46 to specifically address the thermal effects of CRUD and oxidation layers on fuel cladding and to establish a maximum allowable level of hydrogen within the fuel cladding.

In June of 2008, the Office of Research provided the technical basis supporting this rulemaking campaign as documented in NUREG/CR-6967 and RIL-0801. The staff is now evaluating the adequacy of the technical basis and is considering a request to

provide a few more bits of research to supplement the technical basis documented or addressed in those documents. These additional research items will be discussed in a subsequent presentation.

This Subcommittee has received briefings in 2002, September 2003, July 2005, and January 2009 on the ongoing progress of the Argonne local research program.

With this background information presented, I'd like to turn it over to Dr. Meyer.

DR. MEYER: Well, I think Mike is going to go first.

MR. CLIFFORD: Okay. Mr. Mike Billone of Argonne National Labs.

MR. BILLONE: I'm going to ask to give a very, very brief introduction of the kind of work that we do before we get into the data. So let me just try with a few toys, and then we'll do the slides.

We do what we call LOCA integral tests which are segments that are about this long. They're filled with fuel. They're pressurized. We heat them in steam until they burst, continue to oxidize. The cladding gets more brittle as it oxidizes.

We cool at a prescribed rate and then we quench, and then following quench, we do bend tests to

determine strength and ductility of the material.

That's Chapter 6 of the NUREG report. We can't do that work anymore because the alpha gamma hot cells that we did the work in are closed to programmatic work. So there are other hot cells that will be doing that in the future.

Most of what I'll be talking about will be short, de-fuel cladding segments this long, and they were exposed to steam on the inside and the outside, and, again, same thing: ramping temperature and steam, holding, and then cooling and quench. And we look at fresh cladding alloys, such as what I have in my hands right here, prehydrided material and high burn-up material.

After we do that, we cut this sample into several rings, and then we just simply squeeze the rings, and to the extent that the ring can go from circular to oval after release the load, such as what I'm holding in my hand, that's a measure of ductility. The same way the Venn test when you release the load looks like that, that's ductility.

So that's just a brief overview of it. Today I'll be talking only about the tests with the short segments, the cladding embrittlement tests, and let me get my little toy.

There are a lot of slides in the morning presentation that really pertain to the afternoon presentation. So bear with me as I skim over some slides because I'm coming back to them.

MEMBER SIEBER: I have a question.

MR. BILLONE: Yes.

MEMBER SIEBER: Where did you get the test samples from?

MR. BILLONE: The high burn-up ones or the --

MEMBER SIEBER: All of them.

MR. BILLONE: Okay. The vendors were very nice. GNF supplied the Zirc-2. AREVA supplied some Zirc-4 and 5. Westinghouse supplied Zirc-4 and ZIRLO, and then high burn-up material came from commercial nuclear reactors.

MEMBER SIEBER: How did you assure yourself that --

MR. BILLONE: And EPRI was instrumental in getting it to us.

Pardon.

MEMBER SIEBER: How do you assure yourself that the materials you got to test are representative of what's used in the manufacture of the fuel?

MR. BILLONE: We're going to get to that

very heavily in the afternoon when we talk about breakaway oxidation tests.

MEMBER SIEBER: I'll wait. Thank you.

MR. BILLONE: Okay.

CHAIRMAN ARMIJO: Just a quick thing.

MR. BILLONE: Yes.

CHAIRMAN ARMIJO: Mike, the focus of most of your testing has been on the rings.

MR. BILLONE: Correct.

CHAIRMAN ARMIJO: And what is the main reason why you chose to do that as opposed to the bend tests, assuming that you had test capability to do them both?

MR. BILLONE: Right. Let's go to high burn-up fuel, which even de-fueled is extremely, extremely hot and difficult to handle, and let's talk about limited supply of high real estate material. If I do the LOCA integral tests, I'm using up a lot of material even if I did it de-fueled, which is difficult to do. It would be extremely hot to handle in our glove boxes and our other cells.

So out of a segment like this, which is usually what we receive de-fueled, about three inches or eight centimeters, we can get two to three LOCA integral tests. Out of each of these tests we can get

two to three rings.

So in terms of economy, in terms of being able to run a lot of tests under a lot of conditions, we chose to go with this type of sample. There are a lot of practical considerations, but worker dose was also a part of it, but really the prime real estate is limited.

DR. MEYER: I'm Ralph Meyer from the Office of Research, and I'm kind of responsible for the technical content of this program, and I want to help Mike with a different answer, and I expect that he's going to help me during my presentations today.

The ductility was the basis for the original criteria, and the ductility determination initially back in the late '60s and early '70s was determined by using these ring compression tests. It's a standard methodology for determining the transition from ductile to brittle behavior, and because it's the basis for the very rule that we were targeting with this research, it became the primary focus or experimental procedure for the work.

CHAIRMAN ARMIJO: I was just trying to get at do you get a different ductility result with a bend test --

MR. BILLONE: No.

CHAIRMAN ARMIJO: -- than you do from --

MR. BILLONE: It's the subject of the afternoon's presentation, but the answer is no.

CHAIRMAN ARMIJO: Because the bend test I'd expect that you'd tend to put more likelihood of circumferential cracking than actual cracking.

MR. BILLONE: Let's look at it a different way. Let's look at the core of the metal, which we call the prior beta layer. We'll get into that. If there's too much hydrogen, too much oxygen, it is brittle. Now, if I squeeze it, I'm inducing hoop bending stresses. If I do this, there are axial bending stresses. The material is brittle, you know, transverse to this direction and transverse to the hoop stresses. So you get about the same answer in terms of ductile to brittle transition with both.

CHAIRMAN ARMIJO: Will you show us that at some time, if not off line?

MR. BILLONE: I can quote my French and Russian colleagues who did extensive studies, but again, it will be this afternoon. It's a question of it's coming up.

CHAIRMAN ARMIJO: Okay. I'll reserve.

MR. BILLONE: Okay. We did our testing at less than the licensing limit basically as fabricated

material in a wide range because we included break away oxidation.

I apologize.

Free hydrided cladding and high burn-up cladding. We wanted to determine the ductile to brittle transition, oxidation level at high cladding temperatures in the range of 1,000 to 1,200, and a time at lower temperatures at which you get what's called breakaway oxidation, cracking of the oxide layer, hydrogen pickup, and embrittlement.

So there are really two temperature ranges we focused on, and we want to quantify the decrease in embrittlement with temperature, hydrogen content, and from a variety of sources.

The materials we used were Zircaloy-2, which is zirc lined on the ID. We had three types of Zirc-4 with standard ZIRLO, and we had M5. The high burn-up tests were done with commercial fuel cladding using Zirc-4, ZIRLO, and M5.

All right. Next slide please.

All right. I wanted to limit myself to one slide in the executive summary, but we will move beyond the executive summary, and this particular slide is the summary of our high burn-up results for M5, Zirc-4, and ZIRLO, plus the as fabricated material

coming out of the factory.

And the way to interpret these results is please note that this is pre-test hydrogen. This is what we measure when we take a slice, a ring of the material with the corrosion layer still on it, and measure the total amount of hydrogen and normalize to the weight. That's one thing that's important.

The second thing is at these oxidation levels for these hydrogen contents, the intent was that at these points you are still ductile. If you go one percent higher than oxidation level, you're brittle. So rather than less than these points to stay ductile, it's less than or equal to these points.

Now, I want to talk more about this hydrogen scale and go on to the next slide, please.

CHAIRMAN ARMIJO: Mike, before you go.

MR. BILLONE: Yes.

CHAIRMAN ARMIJO: Where is the Zircaloy-2 data? Is there any?

MR. BILLONE: We don't. The Zircaloy-2, we only had 70 ppm of hydrogen in it. We used it for early oxidation studies. We didn't use it for these particular tests.

CHAIRMAN ARMIJO: How about the irradiated or high burn-up Zircaloy?

MR. BILLONE: Zircaloy-4 is what we used from the H.B. Robinson plant. We didn't use Zircaloy-2 for the high burn-up.

CHAIRMAN ARMIJO: I thought you had some Limerick fuel rods, BWR.

MR. BILLONE: All of our LOCA integral testing was with Limerick, but the embrittlement tests were not.

CHAIRMAN ARMIJO: Okay.

MEMBER SHACK: Mike, just on this, your quench and your no quench, so no quench is your slow cooled to room temperature?

MR. BILLONE: Right, and it's really fast cooled to 800 degrees C. and it gets slower and slower.

MEMBER SHACK: Now, where would the CEA tests come in on here with their slower cooling at the higher temperature?

MR. BILLONE: Again, I've put that in. It's in Chapter 4, and I put that in the afternoon session.

MEMBER SHACK: Okay.

MR. BILLONE: But I'll show you a quick slide to give you an idea. I think it is part of this presentation.

So okay. I think I've covered most of this material, but I do want to go down here to the embrittlement threshold versus ZIRLO post test hydrogen content, which means a measurement of hydrogen after you've run through the LOCA tests.

And one thing that happens is your corrosion layer tends to flake off. If there's hydrogen in the corrosion layer which is not relevant to embrittlement, you would bake that off, and we get a significant difference between the pre-test hydrogen measurements and the post test hydrogen measurements, at least 108 parts per million. And we believe that difference is due to how much hydrogen for this particular material is in the corrosion layer.

So next slide.

All right. So --

CHAIRMAN ARMIJO: I'm trying to understand the significance of what you just said.

MR. BILLONE: Go ahead back.

CHAIRMAN ARMIJO: So you lose hydrogen in the course of the test.

MR. BILLONE: Well, it's only hydrogen in the metal that's going to contribute to the embrittlement. If it happens to be in some of the corrosion layer, which is in this case about 40

microns, that would not go into the metal. It would go off into the steam.

So this is what governs embrittlement. This is what you standardly measure in a hot cell.

CHAIRMAN ARMIJO: So the data points are for the post test hydrogen or the pre --

MR. BILLONE: Go back to the previous one.

CHAIRMAN ARMIJO: Yeah, I'm just -- because it looks like they're about --

MR. BILLONE: If you look at these points, this is pre-test hydrogen, and for M5 we don't get much of a difference. It's the small oxides that we're not worried about. But ZIRLO we get a very significant difference, and you'll see these are plotted at higher hydrogen contents than 540, and it makes it look like ZIRLO is better than Zirc-4 high burn-up when you look at that curve.

But if you go one, two -- okay. Now what I'm doing is all of these data points remain the same except for ZIRLO. I've moved the data points to 540 weight parts per million, and you'll see that the Zirc-4 and the ZIRLO are almost identical, and the cooling without quench is also very close.

This is the one I prefer. I t appears in the summary at the end, but again, this is not the

standard way that hot cells measure hydrogen. They don't boil off or evolve the hydrogen from the corrosion layer. So that's why we chose that first graph in the executive summary, to be consistent with how most researchers measure hydrogen. It doesn't mean that hydrogen is all in the metal, and that's a very important point as I go along, and I'll elaborate on it.

CHAIRMAN ARMIJO: But this is the relevant hydrogen.

MR. BILLONE: This is the relevant hydrogen. The question is: what is the best way to measure the relevant hydrogen?

Next slide, please.

Okay. This you can read. This is how you standardly measure hydrogen from small rings, about one to two millimeters long; low masses, .1 to .2 grams; and that's what we use for our pre-test measurements. That would be the stuff coming out of the reactor with the full corrosion layer on it of about 40 microns.

Post test we did a variety of sample sizes up to a gram. So post test we have a lot more material that we're characterizing. We have a lot more confidence in those values.

Okay. That's one point, and I'll elaborate on that in my next slide. The other point is it's a reality as far as we're concerned. The high burn-up ZIRLO and Zirc-4 we have with the higher hydrogen contents of 500, 800 ppm of hydrogen. They all have very significant variations in the circumferential direction of hydrogen, as much as from a low to a high of 300 to 400 ppm.

That's a reality supported by metallography. That hydrogen will move across the thickness or the wall thickness of the material during these short time tests that hydrogen will not move very far axially or circumferentially. So what you see before the test is essentially what you have after the test. You have to live with that.

Next slide about the hydrogen.

So this is an eight centimeter long sample, approximately three inches, and these are the pre-test hydrogen readings in blue, and all of this is very close. This is like a one inch sample, 25 millimeters, and here are the post test readings which are significantly lower than the pre-test readings. And that I want to use to support the notion that some of the hydrogen is evolved. It won't come out of the metal. The metal is protected with an oxide layer,

and it has a high affinity for hydrogen, but it will come out of the corrosion layer.

So that's a hypothesis. I think it's strongly supported by data.

CHAIRMAN ARMIJO: Have you done something as simple as just grinding off the oxide layer and--

MR. BILLONE: Oxide layer, yes, we have, but I'll show you what the problem is with that.

Next slide.

Just in terms of variation of hydrogen around a simple ring like this, you can see it varies from about 300 to 600 weight parts per million. These are the two failure locations. This happens to be a ductile ring because it was slow cooled after the oxidation. No, I'm sorry. This was quenched, but it was ductile.

So that's a reality of the material that we're going to deal with somehow by some averaging technique.

Next slide.

CHAIRMAN ARMIJO: Mike, you're moving really fast, and I appreciate that because you've got a lot of slides, but in this picture, you have red or certain kinds of hydrogen and black --

MR. BILLONE: It's just high versus low.

CHAIRMAN ARMIJO: There's that much variability?

MR. BILLONE: Yes.

CHAIRMAN ARMIJO: From 500 parts per million down to as low as 300 parts per million?

PARTICIPANT: Six hundred to 300.

MR. BILLONE: Right.

CHAIRMAN ARMIJO: Six hundred to 300?

MR. BILLONE: It will come up again in my afternoon presentation about is prehydriding a good surrogate for high burn-up fuel, and the question is do you uniformly prehydride at 400, 500, or 600 in order to get the same results. And I'll raise that and address it this afternoon.

So that is a reality, and whenever we want more detail about the failures -- happen to be two cracks at that location and that location --it makes sense in terms of hydrogen content. We'll cut the ring after the ring compression tests.

CHAIRMAN ARMIJO: Later I'd like to hear from the industry guys about this variability in the hydrogen.

MR. BILLONE: If I show you metallography just to support --

CHAIRMAN ARMIJO: Yeah, I believe what

you're saying. I'd just like to understand why it's accurate to --

MEMBER SHACK: Yeah, I have another question though, Mike.

MR. BILLONE: All right.

MEMBER SHACK: Suppose you oriented that specimen a little different. Have you had gone back to calculate just how much that would have changed your measurement of the ductility?

MR. BILLONE: It would change the measurement of the ductility, but actually if I cut two rings adjacent to each other and randomly put them in there, in the ductile range I could get ten percent or I could get 30 percent, but it's not the same sample, meaning the variability for this eight millimeters is different than the variability of that eight. That's how fine it is.

So, yeah, one would prefer to do multiple tests, but you never step in the same stream twice. You never can get three samples that are identical even if they're right next to each other. You can in the laboratory if you prehydride.

CHAIRMAN ARMIJO: I just want to nail it down whether this variability that you're seeing is a result of a test that you performed or is it the way

the fuel cladding came in?

MR. BILLONE: It's the way the fuel cladding came in because --

CHAIRMAN ARMIJO: And since it's fracturing at the highest hydrogen concentration points, that's pretty good news. It's fracturing where it's supposed to.

MR. BILLONE: Right.

CHAIRMAN ARMIJO: But I'd like to understand why, in fact, there are two variability or such short distances, and maybe the industry guys can help us there.

MR. BILLONE: Yeah, let's go to the next. You've got to look at the metallography. So next slide, please.

Now, this is too small for you to see, but this is eight images going around the circumference, and basically the variability is in this dense -- I'm sorry. This is the corrosion layer out here. This is the dense hydride rim, and then more dilute hydrides. It's systematic, meaning it goes from thick to thinnest as you go around. It could be caused by circumferential temperature variation. If you have edge rods, if you have corner rods, if you have rods next to guide tubes and you add up all the rods that

you have that are not your perfect modeling axisymmetric heat generation and cooling, you definitely do have axial variations -- circumferential variation of temperature.

It seems like the corrosion layer thickness is not very sensitive to that, meaning you might get 40 -- for this picture it's 43 microns plus or minus two microns of corrosion. So corrosion layer thickness is not very sensitive to small changes in temperature. I can't prove it, but the hydrogen seems to be.

Now, if you go to the next slide I'm going to blow up this one and that one. This is just the maximum hydrogen region and the minimum. So what we measure is supported by what we see. The explanation I will leave to someone else as to why it's that way.

The problem with grinding off this oxide layer is invariably you end up grinding off some of the hydride rim, and so really you want to bake the hydrogen off. You want to heat it in the furnace to maybe 600 degrees C. We don't know yet. We have to play around with this, and then put it in the LeeKo machine which heats the material up to melting and measures the remaining hydrogen coming off.

But mechanical grinding is a real issue.

You have an interface between the oxide and the corrosion layer and the metal that is so dense in hydrogen. You're invariably going to remove some hydrogen.

We do this for mechanical properties tests. We remove this, and we keep grinding away until we get electrical conductivity. Invariably those samples will do less.

Okay. Next slide, please.

All right. I just want to point out that we did not pick the most pessimistic samples that we had available to us because we were kind of looking for an arrangement where we can measure some ductility. If all you measure is embrittled material, you don't know where the transition is.

So there are four. We chose areas of 70 micron corrosion layer, which was near the mid-plane of our sample, our fuel rod, and the pre-test hydrogen is 550 plus or minus 100. At that location we did not really focus on the high hydrogen contents of 770. We didn't find any ductility.

And quickly, for the ZIRLO, we had corrosion layer thicknesses of 20 to 70 microns. We chose samples in the range of 40 to 45, expecting about 400 ppm of hydrogen, and yet our post test

values were considerably higher. Our pre-test values were even higher.

The M5 doesn't change very much axially. So those samples were 12 microns, corrosion layer in about 110 weights parts per million of hydrogen.

I think I'm going to skip a few slides. Next. All right. Next slide.

I'm going to go over this in the afternoon, Bill, but in terms of CEA data, they have about a 25 degrees C. ramp, 1,000 degrees to 1,200. The drop the sample in a large resistance furnace. Most of their tests are essentially isothermal. So about four percent CP-ECR, and they quench from 1,200 degrees C. That's one type of test.

A limited number of tests were done with no quench. So they left it in the furnace, turned the furnace off, and so to go from 1,200 to 800, you're way off scale. It takes about 1,000 seconds. So 1,000 seconds versus about 40 seconds for --

MEMBER SHACK: Now, did they have a rationale for the 1,000 seconds other than the furnace?

MR. BILLONE: No, the furnace was incapable of doing what our furnace does. There's no rationale.

MEMBER SHACK: Okay. They're not arguing that there's some hidden slow cooling mechanism here.

MR. BILLONE: No, no, no. It's just the limitation.

MEMBER SHACK: Just the limitation of their furnace.

MR. BILLONE: It is very important if you're trying to prepare data sets.

MEMBER SHACK: Yes.

CHAIRMAN ARMIJO: No, the numbers there of the percentages cladding, that's calculated, right?

MR. BILLONE: It's calculated, correct.

CHAIRMAN ARMIJO: And why is it important on that chart? I mean, what are we supposed to take away from 6.6 and 400 --

MR. BILLONE: Well, because most of the data I'm going to show you for high burn-up ZIRLO with quench, it embrittles in this ramp region, and this ramp is kind of a reasonable upper bound to a LOCA ramp. This ramp is much more excessive.

CHAIRMAN ARMIJO: Okay.

MR. BILLONE: So I'm going to come back to this when we ask the question about higher hydrogen contents. All you do for higher hydrogen contents is you're going to drive your embrittlement threshold

down this temperature slope.

I want to use it this afternoon, but I put it up here because Bill asked me something about the CEA tests.

CHAIRMAN ARMIJO: So if you wanted to measure the properties of the material at, let's say, 2.9 percent --

MR. BILLONE: This would be the test --

CHAIRMAN ARMIJO: -- you would run the test only up to that time and then terminate there?

MR. BILLONE: Right, and then I would follow this cooling and quench curve at this point.

CHAIRMAN ARMIJO: Okay, okay.

MR. BILLONE: Just to give you a feeling of whether you were in the ramp region or you're at the 1,200 degrees C. region.

CHAIRMAN ARMIJO: Okay.

MR. BILLONE: And the M5 tests were beyond this. The ZIRLO tests were down in this region.

Next slide. We'll skip this one.

MEMBER SHACK: Now, Mike --

MR. BILLONE: Back.

MEMBER SHACK: -- you were sort of here. If this were a truly prototypical one, how long would this whole thing last?

MR. BILLONE: How long would a LOCA list?

MEMBER SHACK: Yeah.

MR. BILLONE: These temperatures would be more characteristic of a high break LOCA. I'd let industry decide. I mean, our tests are on the order of 100 to 200 seconds basically to define embrittlement at 1,200 degrees C. with high hydrogen content, and then longer test times for the M5 with lower hydrogen content.

So if you take the full range, it's up to 400 seconds for the as fabricated cladding to embrittle like 100 to 200 for the high burn-up with high hydrogen.

MS. UHLE: This is Jennifer Uhle from the staff in Research.

And typically a LOCA large break LOCA transient is over within a few minutes, three minutes to five minutes.

MEMBER SHACK: Yeah, I mean, that's what I would think, that I'd be somewhere in the order of four to five minutes.

MS. UHLE: A little less than that actually, but I mean, depending on the system design and then, you know, location of the break, what have you, and small breaks obviously are a different story.

They can take quite a while.

MR. BILLONE: I think another way of answering it -- and that's the best answer -- is for our tests this is a faster ramp rate than you probably would see in the LOCA. We wanted to get up to about 1,000 degrees C. and have all of our oxidation temperatures occurring between 1,000 and 1,200. So this would take longer perhaps.

This is a very fast cooling rate. The cooling would be slower, more like one degrees C. per second, and so the real thing would be extended in time, but the oxidation level, what we found is the calculated oxidation level seems to dominate as long as you take into account differences in ramp rates from one test to another test.

CHAIRMAN ARMIJO: Why do you start this chart at 500 seconds instead of zero, even though when it starts to heat up?

MR. BILLONE: We took the sample of 500 seconds at 300 degrees C. to stabilize the system. So there's a boring 500 seconds before this curve if you're at 300 degrees C.

CHAIRMAN ARMIJO: But where this embrittlement takes place is in this 500 to 700.

MR. BILLONE: Yeah. You just do the --

CHAIRMAN ARMIJO: I can subtract. I just wondered why you do it that way.

MR. BILLONE: Well, that's a real test time, meaning that's where we stabilize the steam flow and the test temperature at 300 degrees C. before we ramp, and I'm only showing you the interesting part, which was the ramp.

Okay. Next slide.

All right. Let's now put together what's in Chapter 4 of the LOCA NUREG and what's in Chapter 5. Five is high burn-up for prehydrided, and let's just see what happens.

So in red is the high burn-up Zirc-4. In black is the prehydrided Zirc-4, two types, 117 by 17 modern -- I'm sorry -- 17 by 17 modern Zirc-4 and the older H.B. Robinson type Zirc-4, and in this case I tagged it at 17 percent. I'm not interested in a best fit of fresh alloys. The hydrogen kind of dominates, and this is what I would expect from here to here roughly if we or industry had done testing at all of these different hydrogen levels. I'd expect answers within plus or minus one percent in that line.

So interpolation is not too bad. I mean, you've got three different types of materials: ZIRLO, Zirc-4 and M5, and they seem to fall in a line.

Now, as I said, when you get beyond this point, you go to lower oxidation levels. You're going to lower temperatures before you embrittle. So the actual curve if we continued our test would flatten out only because your temperature would be dropping from 1180 to 1130 to 1030, and so forth. So we did not test in this range. It wasn't meaningful for us, and that's a subject for this afternoon. So let's go on.

Let's skip this and just dragging about.

MEMBER SHACK: But just coming back to this, Mike, you get very different hydride distributions from your prehydride than you do in the actual high burn-up fuel, right?

MR. BILLONE: Right.

MEMBER SHACK: But it doesn't seem to make a difference in this plot.

MR. BILLONE: In this plot it doesn't seem to make a difference. It starts to make a difference up around this range, meaning if we target the average value when we get the average plus or minus 30, we get a different answer than if we get the average value plus or minus 100, and usually the plus or minus 100 we reject those samples. We just happened to test a couple of them.

So the question really lies in here. The lower hydrogen levels, again, high burn-up cladding you expect to see less circumferential variation in terms of weight parts per million at the lower hydrogen values, and so these points might become much more valid. The question is down around here.

CHAIRMAN ARMIJO: Now, in the course of your test, when you take irradiated cladding with, let's say, 500 ppm hydrogen with a lot of variability --

MR. BILLONE: Right.

CHAIRMAN ARMIJO: -- circumferentially, in the course of your test does that redistribute?

MR. BILLONE: No, it moves --

CHAIRMAN ARMIJO: It starts out with a circumferential hydride ring and after you do your test, you still have that same?

MR. BILLONE: Yeah, and you verify that with prehydrided cladding where you don't have the complication with the corrosion layer. You put so much hydrogen in. You measure the distribution before the test. You put it through the test. You measure the distribution after, and both axially and circumferentially you get about the same variation.

CHAIRMAN ARMIJO: And you confirm that

with metallography, post test metallography.

MR. BILLONE: If you can't see the hydrogen post test. Once you go up the high temperature, the beta phase, the hydrogen is all finally --

CHAIRMAN ARMIJO: So it has redistributed.

MR. BILLONE: Across the radius.

CHAIRMAN ARMIJO: That's what I was talking about.

MR. BILLONE: Oh, I'm sorry. Immediately, seconds, it will go -- as soon as you go into the beta phase, which is a high affinity --

CHAIRMAN ARMIJO: It moves.

MR. BILLONE: -- it moves faster than diffusion.

CHAIRMAN ARMIJO: So that could be an explanation why there's not much difference between prehydrided --

MR. BILLONE: Right.

CHAIRMAN ARMIJO: -- and the irradiated because all of the hydrogen goes into the beta phase and you come down --

MR. BILLONE: And this figures uniformly across the thickness. The difference would be in the circumferential variation. It moves very fast.

This was just bragging about each of those data points involves many, many tests to get a single ductile to brittle transition point.

Next slide.

This is an example of about eight percent ECR. We held the oxidation level constant. We varied the hydrogen content. We started out with modern Zirc-4 and ran out of that material and switched to the H.B. Robinson type, the older type, and I'm going to use this in the afternoon also, but please notice that the older cladding has lowered ductility, percent strain as a function of hydrogen and the more modern cladding, but they both embrittle at about the same point.

So whatever advantages you had with this modern classing over this older cladding that you started with coming out of the factory, you lost it putting hydrogen in and you come up with about the same answer.

CHAIRMAN ARMIJO: Then these two charts are a little out of sequence. The way you do it is you run a series of these tests.

MR. BILLONE: Right.

CHAIRMAN ARMIJO: And then from this test somewhere out that curve --

MR. BILLONE: You only get one data point from this, and that's where this goes from ductile to brittle.

CHAIRMAN ARMIJO: From that chart how would you pick the data point at --

MR. BILLONE: Oh, from this chart I would set two percent as the limit, but this is offset strain that you would standardly measure in the laboratory from a low displacement curve.

Really how we determine that point are in tables, and I don't plot it very often, but it's the measure of permanent strain, which if it's greater than one percent or at a change in diameter, then we're out of the noise and we're confident that we're ductile.

So these are good for showing trends because for every single test, you get an offset strain, but you only get a permanent strain if you get a single type crack, and then you could do a reasonable measurement afterwards. So there are more of these data points to show trends. For everything I've shown you except the implied data point we use permanent strains, the difference in diameter before and after the test.

CHAIRMAN ARMIJO: So for every data point

in the previous chart, this great line, CPR versus hydrogen, for every one of those data points there's a series of these kinds of tests that have been done from which you pick a strain.

MR. BILLONE: Post hydride, right.

CHAIRMAN ARMIJO: Okay.

MR. BILLONE: And we looked at five percent, about eight percent, and about ten percent. We're the only ones that did this, and I won't go into why. Fixed oxidation level variable hydrogen, and it's interesting because as burn-up increases hydrogen increases. So there's some interest to a plot.

And also let's go to the next slide. If you have questions about statistical validity of the data or what happens when you run multiple tests, I'll go over these two slides. If you don't have questions about that, I'll skip it.

CHAIRMAN ARMIJO: Well, you'd better do it. Jack already asked you.

MR. BILLONE: Okay. For one cladding type we did multiple tests of fresh material to see how good our broad brush approach is. The broad brush approach is we take the fresh cladding and you oxidize it at these oxidation levels for this older type material, and then you just extrapolate between 13 and

15 percent and you get about 14 percent for embrittlement.

We tried a focused approach in which we ran a lot of tests in a narrow oxidation range, 13 to 16 percent. There were nine oxidation quench tests, 18 ring compression data points, and we had 1,200 and 1,204 degrees C. is variable. We had the true HBR archive from 1977 and the 1980s version of that material, and the broad brush approach is -- I'll show you the curve -- gave us about 14 percent as a transition. That's based on one data point that was brittle.

The focused approach gave us 15.6 as opposed to 14.3. So the really, really detailed, doing a lot of work which we would recommend that someone do this, there was about a 1.3 percent difference. If you're doing rounding off, it would be 16 percent for the focused approach, 14 percent for the broad brushed approach, and that would be about a two percent difference.

This was the worst cladding we had. So this is the most variability.

CHAIRMAN ARMIJO: But the focused approach gave you a higher --

MR. BILLONE: In more data points, yeah.

Let's look at the graph and I'll show you why.

Now I am plotting permanent strain, which is the difference in diameter, and this is really how we determine the transition point.

So our previous testing, we got values down here. Embrittlement was based on this one data point, which was below the one percent line. When we went back and retested very carefully, we got data points in this range, and you can see at 15.2 percent ECR we had a number of data points, and basically you can take the average minus one standard deviation, which is what we chose to do, and it's ductile here and it's brittle here if you take the average minus one standard deviation.

So the answer is somewhere, is about 15.6 if you want to get real picky. You would round that off to 16 percent.

So, again, one, two, three, four would be the broad brush approach. This data point turned out to be not very reliable, and this is the result of multiple data points. So we did that for one alloy only.

Next slide.

Okay. Breakaway oxidation. Let me see if I can speed this up. When we went into our studies,

they were extensive studies, and again, breakaway oxidation, what we really care about is embrittlement. We don't care how much the weight gain is. We don't care how thick the oxide layer is. All we care is how much oxygen diffuses in the metal and how much hydrogen gets through the cracks in the breakaway oxidation layer. That's what determines embrittlement.

So if you go back to Leistikow and Schanz, they're using old, 1970s version of Zirc-4. If you take their data, and it only takes 1,800 seconds for that older material to pick up 200 ppm of hydrogen. That's our criterion, and I can tell you why it's 200 ppm later if you'd like.

We did some testing at 1,000 degrees C. back in 2003. They were not intended to be breakaway oxidation studies, but essentially we got very low hydrogen pick-up after about 3,400 seconds. That's as high as we went back in 2003.

Our French colleagues in 2005 published results for low tin Zirc-4 with belt polished surfaces in outer surface, grit polish inner surface,a nd they get about 5,400 seconds after two --

MEMBER SHACK: Mike, I hate to interrupt. Can you go back to that previous graph?

MR. BILLONE: Sure.

MEMBER SHACK: Why do you get such seemingly different trend lines? I mean, you know, I can understand a one percent difference in the permanent strain, but if I'm drawing a curve through those two, I get what would look like a dramatically different curve.

MR. BILLONE: Well, it looks dramatic because I've narrowed the scale, first of all, but, yeah, there is a difference in the trend. I'll say one difference, a possibility, is back in 2003-2004 when we did these tests, we were relying on S-type thermocouples purchased from the company with a certificate saying this is 1,200 degrees plus or minus three degrees, and then we used weight gain as the check, which is not perfectly reliable.

We got a bad batch of thermocouples in 2005 and then starting in the fall of 2005, we purchased our own NIST standards. We did our own NIST calibration of the thermocouples. I would say these temperatures are more reliable at the time we did these than these, and we may be only talking about ten degrees.

Suddenly the ones coming from the factories started to be ten or 20 degrees off even

though the certificate. Plus this material is kind of scrap. You know, they had trouble finding this material for us. This is old material that's not used anymore. I can't guarantee you that, you know, a slab from one fuel rod is the same as the slab from the other fuel rod.

MEMBER SHACK: Okay. So when you say HBR type, you're really speaking rather broadly that this may not be the same cladding.

MR. BILLONE: It's not this material.

MEMBER SHACK: Oh, okay.

CHAIRMAN ARMIJO: But if you want to say, okay, the data I really believe is most relevant, most reliable is the one going through the archives at an angle coming down and crossing somewhere around 16 percent --

MR. BILLONE: Right.

CHAIRMAN ARMIJO: -- as opposed to those data points down at 12 and 13 percent, those are kind of --

MR. BILLONE: Well, we saw no significant difference between the cladding made in 1977 and the cladding made in the '80s within the scatter of these data points. We didn't really see a significant difference. We have very limited archive material.

We could only run a few tests.

So what's different about these tests is we're much more confident that when it says 1,200 it is 1,200 plus or minus ten degrees circumferential variation. These tests might have been 1,206, 1,207. I'm not sure because at that time we weren't paranoid about what we received. We paid 75 bucks per thermocouple extra to have the company do the comparison of the NIST standard and give us a piece of paper that certified that these thermocouples were perfect, and that piece of paper was worthless basically.

So now we do our own calibration of every thermocouple we receive, and that is one difference between back then and here.

CHAIRMAN ARMIJO: Well, either the quality of the data is the same for that chart and you've got a lot of scatter or some of the data points aren't as good and you ought to just get rid of them.

MR. BILLONE: I don't think this one data point is good. Yeah.

CHAIRMAN ARMIJO: So if you were going to draw a line through there, what line would you draw?

MR. BILLONE: These are the data, I believe, because we ran --

CHAIRMAN ARMIJO: Okay.

MR. BILLONE: -- this through multiple tests.

CHAIRMAN ARMIJO: This curve here.

MR. BILLONE: We made sure each sample was right next to each other. We weren't taking samples from one rod as fabricated and comparing them to another rod. We measure the wall thickness in all of them, and the diameters of all of them. We did as good a job as we possibly could.

MEMBER SHACK: But this sort of raises some question about how much -- you know, whether this is a good comparison of your broad brush versus focused approach --

MR. BILLONE: Right.

MEMBER SHACK: -- since your broad brush tests you're telling us aren't --

MR. BILLONE: Well, partly based on this experience, when we -- and it's in the report -- for Zirc-4, modern Zirc-4 and then ZIRLO and M5, we did end up running multiple tests in the range of 17 percent because we know of this.

In terms of QA, in terms of what did we really receive from the vendor, this is our worst material, and I'm just trying to show you that in

terms of embrittlement, I mean, the data look extremely different. The difference between this interpolation and this interpolation is 1.3 percent.

MEMBER SHACK: But this goes back to Paul's original statement about well documented, comprehensive test procedures. Is this the sort of thing we're talking about?

CHAIRMAN ARMIJO: And materials.

MR. BILLONE: Yeah, sure. So we only had time to do it for one alloy, but you could get a different answer if you do obviously a lot more tests and generate data. A lot depends on whether you want it to a decimal point or whether you're willing to settle with 15 plus or minus one percent in transition.

Next slide, please.

Okay. Breakaway oxidation, and then I do have to speed it up. We did have previous results. Everything is previous except for this. This is Zirc-4. So we have a range of 1,800 seconds for Zirc-4 up to 5,400 seconds. As you go from the '70s to modern time what you're doing is you're going from rough surface cladding with pickling, with HF containing acid as a final cleaning step, to modern belt polish cladding without the pickling, and it makes a huge

difference in when that oxide layer breaks away.

CHAIRMAN ARMIJO: Well, especially if you have residual fluoride on this stuff.

MR. BILLONE: That's exactly right.

CHAIRMAN ARMIJO: So the question I want to get at is somewhere along the line 200 parts per million hydrogen is important, and you're using some sort of a --

MR. BILLONE: Metric.

CHAIRMAN ARMIJO: -- metric for breakaway oxidation. Somewhere in the presentation I'd like to understand why it's 200 rather than 400 or 600.

MR. BILLONE: Sure. Let's go to the next slide. Well, this is more for understanding.

This is a ZIRLO corrosion layer. this is the metal. For all of the modern Western alloys, for all of the Western alloys a precursor to getting breakaway is to have this scallop surface as Leistikow and Schanz call it, "rugosity" as our French colleagues call it, and so at earlier times you had a flat interface between the oxide layer and the metal. What this does as a precursor, it creates regions of compressive and tensile stress. The tensile stress tends to drive the oxide towards the monoclinic phase, and that's the classical view. That's the OD, the

outer surface.

If you look at the inner surface back in 2003, that did break away, and after you break away you can see it's much thicker than this. This is the same cross-section of the material. You can see cracks in the material, but when the ID breaks away, which is not relevant to licensing applications, the hydrogen pickup was only 100 ppm. You get the high hydrogen pickup from the outer surface.

So this is just for understanding. E110, by the way doesn't behave this way at all. It breaks up through the impurities of the surface. All zirconium alloys break up, if they don't have impurities like fluorine, break up in this fashion.

So this is precursor, you know, a couple hundred seconds, 500 seconds more, and you'll get breakaway which looks like this with cracks in the oxide. You go a longer time and you'll get this. This just happens to be at the same time, but different surface finish for the ID of the cladding and the OD.

The next slide answers Sam's question, and the next slide, that's M5. Let's go to the next slide.

Okay. Let's talk about the 200 ppm.

First of all, breakaway is an instability phenomenon. You could have no breakaway at 3,800 seconds and low hydrogen content and 100 seconds later you can jump to 1,300 ppm and have significant breakaway.

So what we know about 200 is we know the material remains ductile at 200. We know it embrittles somewhere between 450 and 550. So let's call it 500. Breakaway being instability, once it starts it either takes off fast or goes a little bit slower, and that's why you want to pick something low as a metric for when you initiate breakaway oxidation.

Again, if you look at this case, it doesn't really matter whether I pick 550, which is where it would embrittle, or 200 because it's only 100 seconds difference, and that wasn't quite the case for the modern Zirc-4. At 5,000 seconds we got about 300, and at 5,400 we got 400. So these are both ductile materials. However, beyond 5,000 seconds you're out of the range of the LOCA. So we're not going to be too scientific about this.

And then the Zirc-4 remain basically lustrous black, no breakaway up to our testing limit of 5,000.

So this is pretty easy to pick 3,800 seconds as a breakaway time because when we have 39

you're beyond it.

CHAIRMAN ARMIJO: Okay, and how do you explain the Zircaloy-2?

MR. BILLONE: Don't pit me one vendor against another.

CHAIRMAN ARMIJO: No. I mean, these are normally the same kinds of alloys.

MR. BILLONE: No, no. Everything hinges on surface finish, which is vendor specific. They don't share that with us, and there's light pickling you could do, and then if you belt polish you get rid of the fluorides. It depends on the order of your steps.

CHAIRMAN ARMIJO: Maybe I know a little bit more about that than I need to know, than I can talk about, but I just don't understand the very big difference in hydrogen pickup between the Zircaloy-2 unless you're attributing it to the liner.

MR. BILLONE: Well, again, this is AREVA. This is old AREVA cladding when it was Siemens, and this is GNF cladding. Those people know more about what they do with the surface finish than we do. Their surface roughness is that these two are comparable. They're about .1 micron surface roughness. This is about .3. That's really all we

can measure. So I don't know why this is behaving better.

CHAIRMAN ARMIJO: Okay. So these times to break away are in the order of 3,600, 5,400 seconds.

MR. BILLONE: This is a scratch sample. So I'm going 3,800 unscratched, 3,800 to 5,000.

CHAIRMAN ARMIJO: Thirty-eight hundred to 5,000.

MR. BILLONE: The greater than 5,000.

CHAIRMAN ARMIJO: And compared to a small break LOCA time, what are we talking about?

MS. UHLE: I mean, NRR can also chime in. This is Jennifer Uhle from Research end.

Small break LOCAs, I mean, again, it's going to depend on the system and the break size. They can hang up for, you know, 3,600 seconds as calculated, but I mean, right now all of the small break LOCA calculations are Appendix K calculations. There is no best estimate small break LOCA calculation. So these are very conservative, stylized types of calculations. So to say realistically what the hang-up time would be, NRR had taken a look at that and was assured that these temperatures are not a problem.

So I would say maybe 1,000 seconds or so,

and then it was quenching. But, again, the Appendix K calculation would show you 3,600 for like the worst case scenario.

CHAIRMAN ARMIJO: So on a very strict Appendix K criteria, even these would be acceptable because you didn't get into breakaway corrosion.

MS. UHLE: Yes.

MR. BILLONE: Yeah, let me go to the next one which is the Zirc-1 niobium alloys.

The next slide, please.

These are word slides. Okay. For ZIRLO, which now is a different alloy, we saw differences between the stuff we received in 2003 and what we've seen in 2006. This is not the date that was made. It is the date that was sent to us. We're now working on ZIRLO 2008.

We got breakaway times as low as 3,000 seconds, and if we take everything we did, which is we scratched samples on purpose, we filmed them with a fine oxide layer. Actually Westinghouse did that for us, and we took the bare cladding and ran tests.

If you take all of the results, you get about 3,100 seconds in the temperature range of 70 to 985. This is a temperature range that nobody explores. Leistikow and Schanz did the most extensive

study. You go in 50 degrees C. increments. You go 900, 950, 1,000, 1,050.

We had no published data on ZIRLOs. So we happened to drop our temperature from 1,000 to 985, to 970, to 950, and then do one at 800. So 3,000 is starting to get close to the conservatively calculated small break LOCA.

Now, I want to point out that Westinghouse doesn't get the same results, and we're working on resolving what the differences are. They get about the same results for Zirc-4, and this is Westinghouse Zirc-4. They get 4,400 seconds. They get greater than 5,500 seconds in what they claim is this temperature range.

So we've exchanged samples, Argonne clean samples versus Westinghouse clean samples. It may come down to the large resistance type furnace that they're using and having a very uniform temperature distribution, whereas we have like a ten degree variation in temperature. So if we're testing 970, as you go around the circumference, you're testing 965 to 975.

So we're working on these differences. However, we've done the tests three times, three different points in time, and we've always gotten this

early breakaway for the ZIRLO compared to the Zirc-4 results.

Next slide. I've got to get finished.

Okay. This is very recent in that we exchanged samples. Westinghouse uses a detergent from their alconox. We use an organic solvent, ethanol. It really should not matter, but the niobium alloys can be very sensitive to what you do to them, particularly if you etch them with HF containing acids, but we didn't really expect to see a difference.

If you go 4,000 seconds at 1,000 degrees C., these samples look very different. The yellow or tan regions, you're well beyond breakaway by the time you see it on the outer surface. This one looks pretty good, but there are yellow spots that you can't see, and actually the average hydrogen pick-up was 120 weight parts per million.

So if we go underneath one of these yellow spots, which is the next slide --

CHAIRMAN ARMIJO: Mike, before you go --

MR. BILLONE: Yeah.

CHAIRMAN ARMIJO: -- go back to that. Now, let's say you did your sample preparation and you did the test, 4,000 --

MR. BILLONE: Seconds for both.

CHAIRMAN ARMIJO: -- second to 1,000 Centigrade. then you do the squeeze to check for embrittlement or you just --

MR. BILLONE: When it's interesting.

CHAIRMAN ARMIJO: When it's interesting just to verify that.

MR. BILLONE: The problem is you've got a huge circumferential variation in hydrogen with black oxide on the other side of this, and then you've got a huge circumferential used (phonetic) axial. So if we get samples in the range of 450, 550 where we have no data, then we'll do the ring compression to fill in the data.

CHAIRMAN ARMIJO: But for these particular samples, you would expect it to be ductile, right? Even for --

MR. BILLONE: No, this one we did, the ring that we cut, we did this for Harold and Michelle not thinking it would be interesting, but if you cut a ring, eight millimeter ring, it had like 550 weight parts per million, and that's off the center location. That was extremely brittle at 135 degrees C. test temperature. So we happened to cut this one and do it. This one we just did the hydrogen.

And we would expect this one to be ductile.

CHAIRMAN ARMIJO: Well, it's very non-uniform.

DR. MEYER: I'd like to make a comment here. I'm Ralph Meyer.

When breakaway occurs, then hydrogen absorption becomes very rapid, and you go very quickly to brittle material. So basically, you need to avoid breakaway because if breakaway occurs, game is over as far as the ductile-brittle transition is concerned.

So there are two distinct regimes that we're testing here. We're looking for breakaway as sort of a boundary. You don't want to go there, and then for cladding that hasn't experienced breakaway but goes to high temperature, you want to see how long can you cook it before it turns brittle.

Now, the two phenomena have at their root two different processes, and if you can latch onto this, they'll help you keep them separate. The oxidation process which is where the breakaway occurs, oxidation is controlled by oxygen diffusion through the oxide, whereas the high temperature embrittlement of the metal is controlled by oxygen diffusion in the metal.

Now, the oxide is an ionic crystal, and oxygen diffusion in an ionic material is very sensitive to impurities because they affect the defect concentration. The oxygen diffusion in the metal is interstitial diffusion of oxygen in the metal, and it's kind of insensitive to all of these things.

So what you end up finding is that oxidation and the breakaway process are very susceptible to fabrication details and surface contaminants, whereas the high temperature embrittlement is insensitive to those things.

So early in his presentation you saw all of those materials falling on the same line, and then when he switched subjects to talk about an oxidation related process you saw great differences even within a given alloy, depending on whether you pickle it or polish it or use some other surface preparation technique that might contaminate it or give you a different surface finish.

CHAIRMAN ARMIJO: Yeah, but what I'm still struggling with, Ralph, is the mechanism of what is the source of hydrogen when you go into breakaway oxidation.

MR. BILLONE: Okay. Can I show my next slide?

CHAIRMAN ARMIJO: Because you're saying the hydrogen is starting to be picked up very rapidly even though you have localized, very high oxidation rates going on somewhere.

MR. MEYER: In the oxidation process.

CHAIRMAN ARMIJO: Your hydrogen is coming from the oxidation process.

MR. BILLONE: Turn that slide on a second.

CHAIRMAN ARMIJO: Okay. Show us that.

MR. BILLONE: All right. If I take the dark sample that looked pretty good but had yellow spots, this is the ID, the inner surface, and you see the corrugated interface. There's no breakaway. There's no circumferential or radial cracks in this.

If you go to the OD, you have clearly breakaway oxidation. As a matter of fact, this one point is a little beyond initiation, and for this segment, the hydrogen content is about 300 ppm, but you've got circumferential cracks, and eventually you have circumferential and radial cracks, and that's where the hydrogen comes in.

Now, this is early in the process. In other words, this is one spot going around the circumference. If I go another 200 seconds, this whole outer surface becomes yellow and this picture

now, instead of this small, little segment, occurs over the whole region.

So it spreads rapid. Its instability initiates. It spreads rapidly.

CHAIRMAN ARMIJO: Well, the mechanism is some sort of fracturing of the normally protected oxide.

MR. BILLONE: It's a modified oxide.

CHAIRMAN ARMIJO: No longer and you can't form another protective oxide and it just takes off.

MR. BILLONE: Right. This is weak.

MR. MEYER: If you have the normal protective tetragonal oxide, you can go up to high temperatures, and all of the hydrogen that is released from the steam oxidation is just swept away. But if the oxide starts cracking up, it will suck it into the metal right through those cracks.

CHAIRMAN ARMIJO: It doesn't reestablish a protective oxide once it --

MR. BILLONE: E110 does, but it's so weird you just have to talk about all other alloys and then E110.

CHAIRMAN ARMIJO: Yeah, I agree with that.

MR. MEYER: And there's a difference between old E110 and new E110.

CHAIRMAN ARMIJO: I understand.

MR. BILLONE: Do I have any more?

CHAIRMAN ARMIJO: Okay. I think I understand what you're saying.

MR. BILLONE: Okay. I don't know if I answered your question satisfactorily, but many of them will come up in the afternoon session when I have more time to address them.

Thank you very much.

CHAIRMAN ARMIJO: All right. Before you go, this is something I probably should have raised last time we talked. In the ring test you have these free ends, you know. You have an eight millimeter long sample of tubing that's been gone through this high temperature transient. It has picked up a lot of what started with either dehydrided or irradiation induced hydrogen pickup, but you cut this thing and you then take it through that transient, and then you come up with this ring sample that you squeeze.

MR. BILLONE: Yes. We're using a longer sample to oxidize and go through the transient. then we cut the ring.

CHAIRMAN ARMIJO: Right. So you don't have material that has been on the ends that has been --

MR. BILLONE: No, we cut that off.

CHAIRMAN ARMIJO: You cut that off, but mechanically, I would expect that the ends will still have an influence on the initiation cracks that wouldn't exist in, let's say, a long fuel rod that doesn't have ends or fracture surfaces.

Have you done tests to show the sensitivity of your results as a function of sample length, like eight millimeters, 16 millimeters.

MR. BILLONE: We've done tests, and our Russian colleagues have done tests, and basically what we find is if it's ductility you're interested in, which is change in diameter or offset strain, the length is not critical. Now, if it's load, the longer your sample the higher the load it takes before you can --

CHAIRMAN ARMIJO: Stick with the same load application service, you know, the same little integer, only make the samples longer and longer and longer so that you definitely don't have end effects. Will you still get the same results?

I just expected --

MR. BILLONE: It wouldn't make sense to take a sample this long and then just apply compressive stress between my fingers. I mean, the

rest of the material really doesn't matter so much.

We're not trying to simulate an actual load in the reactor. We're trying to assess ductility and ductile to brittle transition, and a question of --

CHAIRMAN ARMIJO: You're looking for material property.

MR. BILLONE: Yeah.

CHAIRMAN ARMIJO: And my question is: is this material property you're measuring a function of your sample length influenced by end effects?

MR. BILLONE: And the answer is no with respect to the ductility, and we've done extensive FE finite element analysis by Mujumdar of these samples.

CHAIRMAN ARMIJO: And test data that's supported?

MR. BILLONE: And test data that's supported, and we probably did more with the ring tests than it deserves.

CHAIRMAN ARMIJO: Could you give me and maybe any of the other Committee members who might want it some documents or, yeah, references that we could take a look at?

MR. BILLONE: Okay.

CHAIRMAN ARMIJO: I'd appreciate that.

Okay. Moving right along.

MR. MEYER: So I'm going to back up or climb up to ten or 20,000 feet here and talk a little bit about the RIL, about the program in general, and try and bring this research material a little closer to rulemaking.

So I think hopefully you're familiar with the RIL. It has been out since May 30th, and we started on this work ten years ago, as has been mentioned. We have well documented test plans for the program. We issued a formal program plan in 1998. We updated it in 2003. These had concurrence by several program offices, and the decision was made in 2003 to update 50.46 for the criteria.

And so we have been on a steady course to make this revision to the embrittlement criteria for some time. The industry has been fully plugged into this work from the beginning. As Mike pointed out, the materials that we tested have been provided by the industry, EPRI taking the lead in this from an early time, but there was a clear understanding from the very beginning in our cooperation with the industry that we would draw a line when we got to the end of data acquisition and interpretation.

So when we reached that point where we had

all of our data this spring, the rest of the deliberations about what to do with it have gone on within the NRC and there has not been any private meetings with the industry on this aspect of using these results.

Next slide.

Now, we tend to think of the information that we're going to use for this rule modification as all coming from Argonne and documented in this NUREG report, and in fact, most of it did come from Argonne, but there are two other programs that had contributed significantly to this. One is a program that is now over with at Kurchatoc in Russia, which was jointly funded by NRC and IRSN in France, and along the way sort of invisible to us TVEL, the Russian manufacturer, got involved and added more money on the Russian side.

So for a very small amount of NRC funding, we got a very large amount of information on the Russian alloy E110, a Niobium-10 alloy E632, and a large number of fabrication variants, which led us to one of the important conclusions about the funny behavior of the E110 cladding.

Next slide.

This is a figure that appears in the RIL,

except for the little red circle and arrow that you see up here. If you look very carefully at publication dates, the RIL was issued on May the 30th when we believed that we had all of the test data and had allowed an additional month for the laboratory to finish writing its report.

During that additional month, Mike did some additional tests, and --

CHAIRMAN ARMIJO: Didn't know when to stop, huh?

MR. BILLONE: Really screwed up Ralph.

MR. MEYER: -- at this point went from 16 percent to 14 percent. I don't want to belabor this, but apparently M5 has a very gradual intercept when you make this transition from ductile to brittle behavior, and it was very difficult to decide what was the appropriate value. So Argonne did a number of additional tests on that and it pulled the number down a bit.

So that's the only difference between the current data set and what was shown in the research information letter.

On the next two slides are some specifics about the criteria that will emerge from all of this, and I'm going to go over some of these a little more

carefully than others. We've already talked about the 2,200 degree Fahrenheit temperature not being altered. It was almost an assumption of the program when we began it that we would not change the 2,200 part of the criteria, but focus on the oxidation limit.

Now, the second condition about applying these data is that you need to use the Cathcart-Pawel equation for weight gain for fresh Zircaloy,a nd at this point I want to talk just a little bit about what we're doing because it's not completely obvious. It wasn't obvious when the same thing was done 35 years ago in the original rule.

As Mike has pointed out, embrittlement is a consequence of oxygen diffusion in the metal going from the surface into the beta phase, and when you get too much oxygen in the beta phase, which is the only phase that has some ductility, even the beta phase then becomes brittle.

So you need a measure of how much oxygen has diffused into the metal and reached the beta phase. There are several ways you can do it, but all of the ways that have been considered have the same mathematical formulation. They're all Erreneous (phonetic) equations, and it was chosen before and re-chosen now to use the oxidation thickness calculation

as a surrogate for how much oxygen is diffused into the beta phase.

So we really don't care and the embrittlement process doesn't care how much oxide is really hanging on the surface as long as there's some there, and the calculated oxidation with this correlation gives you an integrated measure of time and temperature, and so it gives you a quantity of diffusion of oxygen that has taken place, and we just empirically correlate that with the embrittlement process.

So it is not the oxide on the surface that we're worried about. It's time at temperature, and time at temperature is quantified using this particular equation. So all of the data were analyzed that way and in order to apply them, you've got to go right back with the same equation.

Now, in the process, we found that the only burn-up variable that seemed to matter was the amount of hydrogen that was absorbed during the corrosion process during normal operation. So the graph that you saw is plotted as a function of hydrogen concentration, and to apply this kind of result would require the industry to come up with appropriate correlations of hydrogen as a function of

burn-up for their particular cladding.

Now, there's the matter of periodic testing, and by the way, there are four here and three on the next slide, and don't change yet, but these seven applicability statements are taken verbatim from the research information letter which is now six months old.

And our thinking has changed a little bit on the periodic testing as we continue to look at our results and figure out what they mean, and the periodic testing is definitely needed for the breakaway oxidation but may not be needed for the high temperature embrittlement process itself.

So just keep that in mind and --

CHAIRMAN ARMIJO: I want to ask you about that.

MR. MEYER: Sure.

CHAIRMAN ARMIJO: Because looking at the various documents you provided, it seems the material that's driving this breakaway variability is a material we don't use. It's that E10 (phonetic). It's highly susceptible surface properties and treatment and maybe chemistry. I don't know, alloy chemistry.

PARTICIPANT: Chlorine.

CHAIRMAN ARMIJO: Yeah, you're right, chlorine.

But the Zircaloys, the ZIRLO, the M5, they seem to be insensitive. So why would you propose periodic testing for breakaway for materials that behave very, very differently, maybe for reasons we don't quite understand yet, but they behave very, very differently than the E10, which really does have a high variability. I don't deny that.

MR. MEYER: Well, we do understand in general terms the origin of some of the differences. The two main actors are the surface finish, which not only includes the surface roughness, but also any contaminants that are on the surface, and also the ingot type, which seems to depend on some low level impurities in the zirconium metal that's used to make the alloy.

Those two things appear to make a huge difference in the behavior of this Russian cladding. Now, you know, if we find that all of our alloys are always testing with breakaway times that are so much larger than anything we have to analyze, then you know, you can make a decision as to whether you need to make this test. But you do need to make sure that someone doesn't slip and make E110, which is easy to

do, because --

CHAIRMAN ARMIJO: I agree.

MR. MEYER: -- materials are being imported from all over the world --

CHAIRMAN ARMIJO: I agree on changes, manufacturing changes, and you're concerned about there are things that may be changes that people don't even realize are changing --

MR. MEYER: That's right.

CHAIRMAN ARMIJO: -- and can have a big effect.

MR. MEYER: That's right.

CHAIRMAN ARMIJO: And that's something we've got to think about.

But once you've qualified this material and you've demonstrated it has got -- you know, there's a great incentive to have reliable corrosion properties, just a normal operation that people spend a lot of effort on, but once you've qualified that it has got certain breakaway characteristics with a given process and a given alloy chemistry, why in the world would you have to be doing it over and over again unless you're making some conscious change in the process or the material?

MR. MEYER: Paul may want to comment, but

this is one of the topics for this afternoon.

CHAIRMAN ARMIJO: Oh, okay. I'll just hold of. I'm just --

MR. CLIFFORD: Well, I think it's important to realize that the fuel vendors don't want us regulating their shop or how they manufacture the fuel. So if we were to approve an alloy with a given surface finish and a given specific manufacturing process, then that would imply that they couldn't change it. They don't want us in their shop. They want us to give them performance requirements that they can then validate.

We're trying to be flexible.

MEMBER SIEBER: And even if you don't physically change the finishing process, it will change over time because of the change in the wear of machinery.

MR. BILLONE: The belts.

MEMBER SIEBER: The belts and different suppliers. So to me it seems reasonable what you're doing.

MR. MEYER: It's an easy test.

CHAIRMAN ARMIJO: Well, maybe it is, but there is already lots of testing going on for just general corrosion control. I mean there's a lot of

interest in that.

MR. MEYER: But this is not one of them yet.

CHAIRMAN ARMIJO: Yeah, but you've got to have a problem before you come up with a solution. It seems like the E10 is a very different material starting from they use this very high purity zirconium starting material as opposed to the sponge material. It seems like somebody else's problem is being place on the Zircaloy.

MR. BILLONE: Can I just point out that the vendors are moving in the right direction certainly, but the data I showed from back in the early '80s, you go from 1,800 seconds, which would be a problem for Zirc-4, but no one paid attention to 5,400 seconds. Things changed over that period of time, and they didn't change because of breakaway oxidation. They changed because it was coincidental to approve in reactor corrosion to avoid nodular corrosion. Certain steps were taken that helped in the breakaway.

So if you always optimize based on normal corrosion temperatures of 300 to 400 degrees C., there's no guarantee you'll get that benefit.

MR. MEYER: And, in fact, E110 had

excellent corrosion properties.

MR. BILLONE: In reactor.

MR. MEYER: I mean, we've seen high burn-up E110 with very low --

MR. BILLONE: Right, five microns.

MR. MEYER: -- corrosion, like five microns.

CHAIRMAN ARMIJO: Yeah, but it's not behaving the way the Zircaloys, the M5 behave. At least I haven't seen any data that you guys presented, but we'll hold off on that. That's an issue, but you're saying your thinking is changing partly maybe in this area, not necessarily for breakaway but for the --

MR. BILLONE: High temperature embrittlement.

CHAIRMAN ARMIJO: -- periodic high temperature testing.

MS. UHLE: This is Jennifer Uhle from the staff.

I just kind of want to add to the last bit of conversation. I think Bert Dunn from AREVA will be doing a presentation later on, and I think he will address this breakaway phenomenon from the standpoint of the vendors to a degree based on a conversation in

the hallway.

MR. DUNN: It will be global, but it will be talking mostly about it. We have positions -- I'm sorry. This is Bert Dunn from AREVA.

We have a position that differs a little bit from what we took about a month ago in that there are concerns as to the validity of the Kurchatov testing showing that it is in the billet or that it is trace element. We need to get those done.

And then I think the other concern is that we really need to consider the -- let's see. I put a phrase in now -- the actionable consequence of a failure in this type of a test, and what do you do, throw away a whole bunch of material, pile up, you know, thousands of dollars, probably not a million dollars, but certainly tens or hundreds of thousands of dollars worth of material and put it back into a billet and reprocess it?

You know, that type of review needs to get put in place and thought about before we do it.

I guess as long as I'm talking I would say --

MR. MEYER: But is that part of your normal corrosion studies? I mean, you have normal corrosion requirements, do you not? Autoclave

testing?Why does the regulatory process care?

MR. DUNN: Well, I don't know. You've got a point there, but I would think we'd want to address that on a risk basis or something like that if you actually did have a failure of the test. It's more like --

MEMBER POWERS: Fascinating. How does risk basis -- how would you do that?z

MR. DUNN: Well, it would only -- I think you would look at the probability of the event that went into this.

MEMBER POWERS: The probability of the event is now one.

MR. DUNN: No, no, the probability --

MEMBER POWERS: It failed the test. It's one.

MR. DUNN: Whether the plant experienced breakaway oxidation, if it's not in a reactor, it's not of consequence.

MEMBER POWERS: Well, what you're asking about is what you do with your material. The probability of failing the test is by hypothesis one.

MR. DUNN: You asked me how I would address the actionable consequence in terms of risk, and I would look towards the accident and the fact

that we do accept a certain amount of risking all of these accidents. We're not driving to zero situation.

MEMBER POWERS: I have no idea what you're talking about now. The question posed was what to do with material that failed the test that Ralph proposes here. You said you would address it by risk. I simply don't know how you would do that.

Your probability of failing the test is now one. You've got a bunch of material that failed. What do you do with it? I don't think the regulatory process can answer it. If you put it back in the pot and reprocess it and bring it out, it's going to be tested again.

MEMBER SIEBER: I have a little experience with specialty steel where recycling is a form. It's like 20 to 30 percent. How much actual recycling based on outcomes of melts occurs? Just some kind of number off the top of your head?

MR. DUNN: I don't have that number off the top of my head. I'm sorry. I just meant to indicate that we need to consider that consequence the actionable consequence, yes.

MEMBER SIEBER: Where you scrap stuff and remelt it and add additional components to it or do whatever you need to do to dilute it down.

CHAIRMAN ARMIJO: Okay. Ralph, we probably should be moving on.

MR. MEYER: Okay. Another thing that we discovered in the process of this was that there's an oxygen source on the inside of the cladding and at high burn-up it's in good communication with the cladding metal, and so you pick up oxygen just as readily from the ID, from the bonding that goes on between the fuel, which is EO_2 with some PO_2 and then you get some CrO_2. So you get all of these oxides which can give up their oxygen to the metal, and we have found a number of different tests that confirm that this takes place.

Now, it's true that it won't take place in fresh fuel where you don't have good contact so that you could get the transfer of oxygen across the interface, but when you do have high burn-up, you would need to account for it because it's a real effect.

And we're going to come back to this one because --

CHAIRMAN ARMIJO: Yeah, we've got to come back to it because I saw some stuff on Zirc-2 high burn-up fuel that didn't have --

MR. MEYER: Well, it was patchy.

CHAIRMAN ARMIJO: -- almost no alpha phase.

MR. BILLONE: Are you talking about my NUREG report? I mean are you talking about this report?

CHAIRMAN ARMIJO: I don't remember which report I read it in.

MR. BILLONE: Yeah, that's the poor quality of image. Ralph has got data from Halden reactor that is much more dramatic.

CHAIRMAN ARMIJO: Well, we'll wait until you're ready to see that.

MR. BILLONE: Yeah. This really goes beyond this and includes international data.

MEMBER POWERS: Well, have you found high burn-up data where the oxygen concentration driving the corrosion on the ID is not buffered by the molybdium oxide equilibrium?

MR. MEYER: Not buffered by?

MEMBER POWERS: The molybdium oxide equilibrium.

MR. MEYER: I don't know about these details. What I know is that when you look at metallography and you see an alpha layer, the alpha is stabilized with oxygen, and the boundaries of the

alpha layer are determined by the oxygen concentration. So if you have an alpha layer on the ID that's the same thickness as the alpha layer on the OD, you have exactly the same amount of oxygen coming in from the ID and the OD, and that's what we see.

That was noticed in one of the early -- was it Loft or PBF?

PARTICIPANT: PBF.

MR. MEYER: One of the early PBF tests was then studied out of pile with some experiments, and we saw some low quality evidence in our own testing and then realized that one of the Halden LOCA tests should give us a good image on this. We paid Halden to do extra PIE on that test, and in every cross-section that they took, they found an equal ID alpha layer, equal to the OD alpha layer.

MEMBER POWERS: I'm trying to understand why that alpha layer is indicative of the concentration of oxy --

MR. MEYER: I'm sorry, Dana. I don't hear well.

MEMBER POWERS: I'm trying to understand why the thickness of the alpha layer is indicative of concentration?

MR. MEYER: Why it is indicative of

concentration? Mike, do you want to?

MR. BILLONE: Well, certainly you could have a steep profile across that alpha layer with higher average hydrogen content or you could have a not to steep profile. If you want to take a simple case real quickly, if I put a ten micron oxide layer as they do on the zirconium, inside or outside, and I heat it up in an inert gas, the metal steals the oxygen from the oxide layer. The oxide layer is reduced to nothing. All of the oxygen goes in, and you form an alpha layer and a beta layer.

But if you let it keep going, you have no more oxygen source, and so all of that oxygen goes into the beta layer and then the alpha layer disappears.

MEMBER POWERS: Somehow you're succeeding in totally confusing me.

MR. MEYER: You're describing a situation that he has not asked about. The oxide is what, 26 weight percent oxygen? And the beta is like one percent, ..7 percent, and everything in between is oxygen stabilized alpha.

MEMBER POWERS: I thought you were telling me that that the existence of this alpha layer was indicative of the oxygen concentration, which I'll

take as the oxygen potential. I don't understand why.

MR. BILLONE: You have metallography. You don't have oxygen.

MR. MEYER: I don't understand the question.

MEMBER POWERS: What I'm wondering is basically have you seen anything about the high burn-up fuel that's indicative of saturating out the molybdium buffering of the oxygen potential so that it's any different than medium burn-up fuel.

MEMBER SHACK: I think Ralph is just arguing he's got the alpha layer. That's his oxygen source, and if there's an alpha layer present, it's there. He can see it.

MEMBER POWERS: The alpha layer is a consequence of your oxygen. Your oxygen source is the fuel.

MR. BILLONE: There's two oxygen sources. There's the fuel cladding bond, which is the zirconium oxide bond that forms in the reactor as you increase burn-up, and any fuel that's stuck to that bond.

MEMBER POWERS: The oxygen source is still fuel.

MR. BILLONE: Yeah, correct. And whatever

you manufactured it in.

MEMBER POWERS: Well, yeah, there's some to be sure.

MR. BILLONE: It's still fuel, yeah.

MEMBER POWERS: I'm just asking if high burn-up -- up till now, I've operated under the assumption that even if high burn-up, we're still buffered by the molybdium-oxygen equilibrium with a partial pressure of oxygen at the interface.

MR. BILLONE: As you go up in burn-up, doesn't your oxygen-to-metal ratio increase, say, more available oxygen?

MEMBER POWERS: The argument is that it does not.

MR. BILLONE: Okay.

MEMBER POWERS: Because the molybdium-oxygen buffering there, but at some point that must surely get saturated.

MR. BILLONE: Yeah, okay.

MEMBER POWERS: And I'm asking if you ever see it get saturated because I never have.

MR. BILLONE: I don't know the answer to that. We didn't get to run the test that we wanted to run.

MR. MEYER: Move on?

CHAIRMAN ARMIJO: Okay, yeah.

MR. MEYER: Okay. We talked about breakaway, and finally, we have tested a lot of different alloys and the high temperature embrittlement process doesn't seem to be affected by which of these zirconium alloys that we're testing, and also, the fuel on the inside wouldn't seem to matter which oxide you're talking about, but it would matter if you were talking about a metal fuel because a metal fuel is not going to donate oxygen, and it could form eutectics. I think you'd want to say if you turned this into a rule, that it wouldn't be very dependent on the zirconium alloy as long as it was a zirconium-based alloy, and it wouldn't matter what kind of fuel was inside as long as it was an oxide.

And let's go on to the next slide.

So I'm going to finish up --

MEMBER POWERS: Well, when you make that statement, I have a variety of people talking to me now about non-fertile fuels for actinide dysphasia. Often they discuss aluminum oxide-based fuel. They disburse plutonium and burn them up, and they don't want the matrix to make more plutonium for them. So they use aluminum oxide fuel.

What if somebody came to you and said, "I

want to burn up my excess plutonium in this aluminum oxide fuel with a zirconium clad"? Would that cause you any pause?

Would you say to him, "I haven't got a clue what would happen"?

MR. MEYER: Mike?

MR. BILLONE: Well, aluminum --

MR. MEYER: Well, no. Just tell me what he said. I'm sorry.

MR. BILLONE: What if you changed fuels? It was aluminum oxide with disbursed plutonium. Aluminum oxide, but plutonium disbursed in it. Would that make a difference?

MR. MEYER: Well, we did look at the free energies of oxygen, free energies forming an oxide, and aluminum, I think, is --

MR. BILLONE: About the same.

MR. MEYER: Is it up there with the others or down there with the others?

MR. BILLONE: It's down there with ZIRLO.

MR. MEYER: So you know, the candidates, thorium, plutonium, uranium, and aluminum, I've forgotten where it is, but they're all in the same range, but I don't think it really matters that much. Zirconium has such an appetite for oxygen. As long

as it's there, it's going to take it, I believe.

CHAIRMAN ARMIJO: Atrium oxide might be more stable. That's about it.

MEMBER POWERS: But also looking at that, Spinell and things like that, these non-fertile fuel matrices, I was just asking to see if it had been given any consideration.

MR. MEYER: Can I move on? There's more interesting stuff this afternoon than this morning.

On the previous slide I just wanted to point out that the -- you want to punch me back to the previous one? -- that the original data set on which the 17 percent number was based, if you were to look at that figure that's in the RIL, it would be one point, and we have 11 points in there, and each of those points as you've found out represents a series of ductility measurements.

So while it is tempting to look at what we have and say, "Ah, you don't have enough data to do this," we've got a ton more than was used originally, and it is quite a lot. So it's just a little defensive point that I wanted to make.

(Laughter.)

MEMBER POWERS: You're anticipating something.

MR. MEYER: Oh, yeah, the industry cooperation. I think Mike has covered this well.

EPRI was our initial and major partner, and they paid for the shipping and processing of all the irradiated fuel that we have, and that was a big deal. So I wanted to mention that.

CHAIRMAN ARMIJO: Ralph, before you go.

MR. MEYER: Yeah.

CHAIRMAN ARMIJO: Back to your Slide 4, which is really the key slide. You know, you have a big gap between 100 ppm, more or less, and 500 ppm hydrogen.

MR. MEYER: Yeah.

CHAIRMAN ARMIJO: And there's no data there, and you're assuming that that's a nice, straight line.

MR. MEYER: Yeah.

CHAIRMAN ARMIJO: How do you know it doesn't get worse faster?

MR. MEYER: Two answers. One is we're going to talk about it more this afternoon.

CHAIRMAN ARMIJO: Okay. That's a good answer.

MR. MEYER: The second one is Mike has already showed you the slide that has the prehydrided

results climbing right back up there.

CHAIRMAN ARMIJO: So you're saying if I just did prehydrided systematically across the board, slow quench or slow cool or quench, I would get a straight line.

MR. MEYER: He'll show it to you again when he makes the point.

CHAIRMAN ARMIJO: You'd better because I forget quick.

MR. MEYER: Look. I can also say that we've got some more irradiated material somewhere in the middle here and we're going to test it in the next six to eight weeks.

CHAIRMAN ARMIJO: That makes me happy.

MR. MEYER: So we're going to spend a lot of time talking about industry comments. I just wanted to give a little history here because the real industry comments that we're going to talk about are the last bullet, and that's subject this afternoon.

We did early on have a discussion about whether to stay with the ductility criteria or switch to strength criteria, and we dealt with that in 2004.

There was a time when we were building a correlation that was a function of corrosion, involved a factor called the F factor, and the F factor became

very unpopular both with the ACRS and everybody else, and we changed. We dropped that approach and replaced it with the hydrogen concentration which scientifically is much better.

So I want to show that we've been responsive. That's what I'm trying to do here. So we had some low quality indications on this ID oxygen pickup. We went out and spent some more money to get additional information from Halden.

Our originally plans did not involve testing irradiated M5 and ZIRLO. We were just going to test irradiated Zircaloy and assume that the radiation effects were the same, as they're turning out to be.

But we were able to get some irradiated M5 and ZIRLO specimens from Studsvik in Sweden, and so we tested those, and we had late last year and early this year some discussions with Westinghouse about the breakaway oxidation tests. We're working on that, and there will probably be more discussion of that. And then we had these other comments that were received this summer which we'll discuss this afternoon.

So this slide is an attempt to show you that we've been responsive to the discussions we've been having with the industry all along.

And the final slide simply acknowledges that there are some things beyond the scope of embrittlement criteria that are still related to LOCA and they have some high burn-up effects. We're interested in them. We're studying them. They don't have an impact on revising the embrittlement criteria, and these are the three subjects that were mentioned in the RIL axial fuel relocation, loss of fuel particles through a rupture opening, and ballooning and flow blockage. These are all subjects which do not impact on the embrittlement criteria in 50.46(b).

PARTICIPANT: But they would impact 50.46.

MR. MEYER: No, they don't impact on the criteria. They impact the compliance with the criteria, and so they end up getting involved in evaluation models, which are not specified in 50.46.

MS. UHLE: Jennifer Uhle from the staff.

The actual wording in 50.46 that talks about you have to have an evaluation model review and approved by the staff addresses all of the important phenomena essentially, and so then it becomes regulatory guidance that provides what exactly needs to be considered.

So what Ralph is saying is that it would not require rulemaking, rather reg. guidance

development on what phenomenon need to be considered.

CHAIRMAN ARMIJO: But in a LOCA after LOCA is done, the weakest link is that balloon region.

MR. MEYER: Yeah.

CHAIRMAN ARMIJO: And so it may be nice to know that the cladding that hasn't ballooned is brittle or not brittle, but the real fundamentals about flow blockage or release of fuel into the system is driven by the properties of that balloon region.

That's to me kind of where the real issue lies. It would be great if everything was ductile, but I would expect that that balloon region is the least ductile of the whole system.

MR. MEYER: And you generally show that in your analysis, don't you.

CHAIRMAN ARMIJO: I don't do any analysis.

MR. MEYER: And the reason is that you have this wall thinning.

CHAIRMAN ARMIJO: You've got wall thinning. You've got all of that same oxygen --

MEMBER POWERS: Well, he's more or less going to give up the balloon region.

MR. MEYER: No.

MEMBER POWERS: No?

MR. MEYER: No.

CHAIRMAN ARMIJO: Well, the question is if the balloon region is really the issue --

MR. MEYER: It's embrittle. The balloon is a long subject, and we're going to talk about that.l

MEMBER POWERS: But if it's from embrittlement, you're willing to grant it's embrittled.

MR. MEYER: No.

MEMBER POWERS: No? All that hydrogen?

CHAIRMAN ARMIJO: It's thinner. It has got all of the hydrogen, got all of the oxygen.

MEMBER POWERS: You'll have to explain that one to me.

CHAIRMAN ARMIJO: Yeah.

MEMBER SIEBER: It also was ductile.

MR. MEYER: Let me give you a hint. Let me give you a hint, and we'll discuss it as much as we discuss it this afternoon, but if you looked at the -- what we're talking about here is when you balloon and rupture, and most rods will balloon and rupture because it happens at a fairly low temperature, and then you continue on up at high temperatures. You get some steam inside the rupture, and so you get some oxidation in there. This is actual steam oxidation on

the ID of the cladding.

And when you get steam oxidation, you release hydrogen, and unlike on the outside where the hydrogen is swept away by the flow, it's trapped at the top and the bottom of this ballooned region, and you end up with a band of high hydrogen concentration above and below the rupture opening.

Okay. There was a time when we though, oh, curtains, this is bad news, and it's not good news, but Mike has pointed out that the concentration measurements show high hydrogen at these places actually almost outside of the balloon, just above and just below, and for fresh material very low hydrogen, actually no hydrogen at the rupture opening, but high oxidation at the rupture opening.

And when you break it, it breaks at the rupture opening. It doesn't break at the hydrogen band. So I think it's fairly safe to say for fresh material and perhaps low burn-up, maybe even mid-burn-up fuel that the hydrogen bands are not having a significant effect on the weakest part of the balloon, the failure. It's oxygen just like it always was.

So in that case, you could almost just ignore the hydrogen bands and say just like we always thought it was without the hydrogen it's oxidation in

the balloon and you go about calculating the oxidation in the balloon. The only thing you do now is instead of using a fixed 17 percent number, you use the number which has the corrosion related hydrogen in it because that is characteristic of all the material in the cladding.

CHAIRMAN ARMIJO: But if you have high burn-up cladding with three, four, 500 ppm hydrogen to begin with, what's your --

MR. MEYER: Well, now that's where it gets murky because we've done one test, one measurement of hydrogen in such a balloon, and the Japanese at Japan Atomic Energy Research Institute have made some measurements on balloon de-fuel tubes, and they get mixed results. In some cases you get some elevated hydrogen at the rupture mid-plane. In other places you get low hydrogen at the mid-plane.

So we're not sure. We are going to study that. You know, it's not going to make the balloon any better. So I think we're --

CHAIRMAN ARMIJO: Well, I don't expect it to be better. I'm just saying is that the weak link in the whole --

MR. MEYER: We're safe right now in simply treating the balloon in the way that it has currently

been treated, except for taking the corrosion related hydrogen into account.

Now, there's somebody behind you that's dying to make a comment.

MR. MEYER: Oh.

MR. MONTGOMERY: Mr. Chairman, may I make a comment?

CHAIRMAN ARMIJO: Yes.

MR. MONTGOMERY: For a few minutes. Robert Montgomery from ANATECH and EPRI.

I would like to just point out that when you talked about the balloon region a few minutes ago and the fact that it always breaks at the rupture openings as opposed to the hydrogen bands above and below the rupture opening, the Japanese tests have shown that it can break at the hydride rim or hydride band locations depending on the axial load, depending on the wall thickness, how much ballooning that has occurred.

So I just wanted to point out it doesn't always break in the rupture opening.

MR. MEYER: And, in fact, one of the tests on the Limerick fuel that we did broke in three places during handling. It wasn't a test intended to break the rod, but after surviving the quench, when they

went to handle the rod, it broke in three places, one at the mid-plane and one at the high hydrogen level. Where was the third?

MR. BILLONE: In between.

MR. MEYER: In between.

But I would point out that that particular test was oxidized to a value that would be significantly above the limit that would be applicable to that balloon had you calculated it using the corrosion related hydrogen reduction in the 17 percent, if you follow me.

CHAIRMAN ARMIJO: I didn't follow you, but --

MR. MEYER: That sample was oxidized to 21 percent. It really should have only been oxidized to 16 percent. Sixteen? Not even 17, but 16 because it had a small amount of corrosion related hydrogen. It was BWR-2 cladding from Limerick, which had very limited corrosion, a very small amount of hydrogen.

So I don't know whether it fractured on handling because it had too much oxygen in it or whether the hydrogen behavior in high burn-up fuel is significantly different than in the fresh material, but we do plan to study this in a program that we're trying to get launched right now. But it's not part

of this current effort.

CHAIRMAN ARMIJO: I think we really need a break here, but let me find out what our schedule is real quick.

Yeah, let's take a break. We're half an hour behind. So let's give a 15-minute break and reconvene at 10:45.

(Whereupon, the foregoing matter went off the record at 10:29 a.m. and went back on the record at 10:49 a.m.)

CHAIRMAN ARMIJO: We are reconvening.

Okay. Our next presentation is Paul on proposed strategy.

MR. CLIFFORD: Good morning. I'm here today to provide conceptual changes in the structure of 50.46(b) which capture the results of a LOCA research. As Bill mentioned at the start of this meeting, NRR is in the beginning stages of this rulemaking campaign. The purpose of this meeting here is to update the Subcommittee on where we may go in the future. As this rulemaking matures, the ACRS will have an opportunity to weigh in on the specifics, on the structure and language of the rule.

This slide provides the current regulation as it appears today. The focus of the LOCA research

was on post quench ductility, specifically the criteria within Paragraphs B(1) and B(2).

The mission statement for our research and campaign is following Commission directives, develop a performance-based rule which captures the results of the Argonne program and enables licensees to use cladding materials other than Zircaloy or ZIRLO without the need for an exemption.

The main objective of the rulemaking is to replace the prescriptive 17 percent ECR criteria with the performance-based requirement. That's in Paragraph B(2), and we're considering adding the flexibility of an optional test program.

In addition, we will introduce new performance requirements related to breakaway oxidation, and we will also change the rule text to allow materials other than Zircaloy or ZIRLO.

I think it's important to note before I go on to some specifics that this is the first time the industry has really seen the structure of this rule. They have been allowed to comment on the technical basis, and I think that's important going forward, that we are just at the beginning stages here and things are somewhat fluid.

Should the NRC await further research

prior to beginning rulemaking? This is always a question that comes up, is how much is enough. When do you start? Do you delay it until every little aspect has been investigated to its full extent or do you begin the process?

The LOCA research program conducted at Argonne was developed to investigate potential alloy and burn-up effects on the current regulation. Tests have conclusively shown that the current prescriptive 17 percent ECR is not adequate or not always adequate for preserving post quench ductility.

A sufficient technical database will soon be available for revising and expanding the current regulation. So the answer to the question is no. It is prudent to revise the regulation today or to begin the process of revising the regulation to day and restore its margin of safety.

The next few slides will walk through the strategy in each section within 50.46. The first section would be applicability of the rule, which is stated in Paragraph A(1). We would consider replacing the terminology Zircaloy or ZIRLO as it appears in the rule with less specific terminology, such as "an approved zirconium alloy."

And the basis for this change would be the

extensive empirical database that covers a wide range of zirconium alloys. Consistent with current practice though, the applicability to new alloys would need to be demonstrated by testing.

The peak cladding temperature is defined in Paragraph B(1). Based upon tests conducted at Argonne, there's no need to change the existing criteria. It's adequate and it maintains the post quench ductility. No change is planned.

CHAIRMAN ARMIJO: What do you mean by that, Paul? Does that mean that you're not going to test at any higher temperature?

MR. CLIFFORD: Mike can speak to this, but the testing that was done at 2,200 degrees showed that ductility was lost in a relatively short time frame such that testing above, say, 2,300 it would be of such limited time duration that it wouldn't be practical.

CHAIRMAN ARMIJO: But if you had fuel that could not achieve those kinds of cladding temperature, would you permit testing at lower temperatures to demonstrate that?

MR. CLIFFORD: I will get into that.

CHAIRMAN ARMIJO: Okay.

MR. CLIFFORD: Specifically get into that.

The next criteria is local oxidation limits within Paragraph B(2). New post quench ductility criteria would be specified within the rule, and that this new criteria would replace the constant 17 percent ECR, and that would be replaced with a figure similar to what you've seen here, and this is just for illustration purposes.

In addition to this prescribed function or limit, which we believe would be allowable Cathcart-Pawel calculated ECR versus pre-transient hydrogen content, there would be the flexibility of an optional test program for defining more alloys or temperature specific post quench ductility criteria, and I'll get into that on my next few slides.

MR. DUNN: Mr. Chairman, this is Bert Dunn, AREVA.

Could I ask Paul a question?

CHAIRMAN ARMIJO: Well, yeah. Paul, if you don't mind. I don't mind as long as it's quick.

MR. DUNN: I think it's quick.

You're allowing or you're going to talk about allowing different oxidation curves for different materials if a vendor or at different temperatures, say, at 1,100 or 1,000 degrees. If a vendor comes in with a cladding material that could go

to 2,400 degrees without inducing embrittlement, why wouldn't that be the same thing as what you're doing with the other curves?

MR. CLIFFORD: I agree, but the 2,200 is tied at the hip with the local oxidation. The way we envision is we would maintain the 2,200, but we do need to consider that, what you're saying. In theory, you should have the flexibility of providing test data.

MR. DUNN: Yes, that vendor would have to supply a lot of test data.

MR. CLIFFORD: I mean, it is a performance based requirement. We need to consider that because right now the way we're drafting the rule that would be an exemption, and I don't think we want to put ourselves in the situation where we have to issue exemptions because that's really one of the --

CHAIRMAN ARMIJO: But that would be covered in your test program language?

MR. CLIFFORD: I think we would have to structure the rule so that both Paragraph B(1) and B(2) could be replaced by the optional. I guess today we weren't really considering that.

MR. RULAND: Paul, this is Bill Ruland.

Is this the first time we heard this

notion that 2,200 degrees would also be subject to a test program?

MR. CLIFFORD: Well, we've heard the comment, and we've heard it loudly, and we're considering how to meet the needs of the industry that they could go below 2,200.

CHAIRMAN ARMIJO: Yeah. Never heard above.

MR. CLIFFORD: But going above 2,200 you start getting into --

CHAIRMAN ARMIJO: Lots of luck.

MR. RULAND: So really at this point we understand the comment, and you know, it's not the subject of this meeting, but something we'd have to talk about.

MR. MEYER: Could I make one technical comment about 2,200, which is 1,204 degrees Centigrade for those of us who think in Centigrade, 1,200 degrees Centigrade?

Twelve hundred degrees Centigrade is -- and Mike can correct me on this -- but at 1,200 degrees Centigrade the solubility limit in the beta phase is about .6 weight percent --

MR. BILLONE: Without hydrogen.

MR. MEYER: -- without hydrogen, and this

happens to correspond to if you raise the temperature and you get more oxygen in the beta phase, then the beta phase can go brittle.

And so if you're operating below 1,200 degrees, something close to 17 percent or a little bit less works. If you get above 1,200 degrees, then the oxidation limit changes rapidly and for the worse.

So there is something fundamental about 1,200 degrees. Maybe that's not absolutely controlling, but it's not completely arbitrary.

MEMBER SIEBER: Is 1,200 degrees the real number or is there margin built into that?

MR. BILLONE: Are you talking licensing or data generation?

MEMBER SIEBER: Licensing.

MR. CLIFFORD: Twelve hundred degrees corresponds to the oxidation temperature that the samples were run at, and then the ring compression tests were then performed on.

MR. MEYER: We've been using that limit always.

MEMBER SIEBER: Well, the early FAC hearings, it seemed to me that there was consideration of margin in that.

MR. MEYER: Yes, there was, and in fact,

there was an interim acceptance criterion. I'm old enough to remember this. Twenty-three hundred degrees Fahrenheit was an interim criterion that was used for a while and then it --

MEMBER SIEBER: And then they dropped it.

MR. MEYER: And they dropped it back to 2,200. This was a hotly debated issue in what I believe was the largest hearing the Atomic Energy Commission had ever had.

MEMBER SIEBER: It took months.

MR. MEYER: And we didn't want to touch it.

CHAIRMAN ARMIJO: And I don't blame you.

MEMBER SIEBER: I got that feeling. So 2,200 has some artificiality associated with it right on the good side because it's conservative, and that's why you stuck with it?

Okay. Because it still fits the data you have. Okay.

CHAIRMAN ARMIJO: Paul.

MR. CLIFFORD: The technical basis for the figure that would be put into the rule and the optional test program would be the Argonne post quench ductility test results and a comprehensive test program, which I'll discuss later but we are planning

on.

Now, a new requirement in the rule would capture the observed oxygen diffusion from the fuel bonding layer on the cladding inner diameter. A burn-up threshold would need to be developed to account for specific fuel design and power history effects. The basis of this change, adding this new requirement would be RIL-0801.

CHAIRMAN ARMIJO: In the case here you're talking fuel bonding. You would include just straight zirc oxide formed from the atmosphere inside the fuel rod. That's on the ID, in addition to any fuel that may be firmly attached and is an oxygen source in the case of --

MR. CLIFFORD: Right, fission products.

CHAIRMAN ARMIJO: So then someone could, if you had the data, demonstrate that there was little or no bonding; under certain conditions maybe lower, but they'd have that flexibility in this rule. Is that your thinking or is it going to be mandated that assume it's bonded?

MR. CLIFFORD: Well, right now we're considering words like if a fuel bonding layer is present, then you must do the following, and to show compliance each licensee or vendor would have to for

their specific fuel design show when fuel bonding occurs.

So there may be a different burn-up threshold for different fuel rod designs.

CHAIRMAN ARMIJO: Okay.

MR. MEYER: We're going to talk about this more this afternoon. My personal opinion is that this is a tempest in a teapot. It's just not a big, threatening issue as we'll describe this afternoon.

MR. CLIFFORD: The last change we're considering to the rule is to add a new requirement for breakaway oxidation. This new performance requirement would be related to maintaining cladding ductility for extended small break LOCA scenarios, and right now we're considering a required test to measure the time at which breakaway oxidation occurs for each cladding alloy.

And we're also considering a requirement for periodic testing.

MEMBER SIEBER: That ultimately limits the burn-up of the fuel.

MR. CLIFFORD: The breakaway?

MR. BILLONE: It's more of an early burn-up, low burn-up phenomenon. I mean, for M5 it would be relevant all the way up to the end of life because

it only has about 100 ppm of hydrogen.

MEMBER SIEBER: Okay.

MR. BILLONE: For the other alloys that pick up five or six or 700, high temperature embrittlement would govern the time of breakaway.

MEMBER SIEBER: Okay.

MR. CLIFFORD: We don't see any of the changes affecting or introducing the new limit on the burn-up of fuel. I think the changes we're making since post quench ductility is a function of initial hydrogen, it may affect the hydrogen pickup characteristics of future alloys, but not necessarily the burn-up.

MEMBER SIEBER: So there is a de facto burn-up limit that comes about because you don't have testing at a certain point. Is that true?

MR. CLIFFORD: Well, there may be a de facto limit on how much hydrogen we've tested. In other words, if we've only tested to 725, 800.

MR. BILLONE: Most o four fuel rod was at higher burn-up than the limit. The licensing limit was set before we had all of this data.

MR. CLIFFORD: Right. The licensing limit is 62,000 for most fuel, and there were some fuel rods that tested above that.

MEMBER SIEBER: That stays.

MR. CLIFFORD: Right. That's dictated by other things.

MR. MEYER: Well, our understanding is that the industry has its own limit on absorbed hydrogen.

MEMBER SIEBER: Okay.

MR. MEYER: And at least one manufacturer uses 800. So I think that's compatible with what the industry is doing.

MS. UHLE: I'd like to just add that, in fact, with the breakaway oxidation phenomena it may, in fact, be the limiting parameter that would set reactor power for those plants that are small break LOCA limited because, I mean, right now that's not really considered in a licensing standpoint.

MR. CLIFFORD: Okay. This slide provides further detail on the optional test program. Right now we envision that the regulation, you know, the rule language within 50.54(b)(2) specified general requirements to support the optional test programs. These examples are the criterion for cladding for post quench ductility would be one percent plastic strain as measured using ring compression tests.

And the criterion for determining the time

for breakaway oxygen would be an uptake of 200 ppm of hydrogen. The specifics, the details on how to do the tests would be provided within a reg. guide or another format outside of the rule, and I think it's real important that we emphasize the completeness of this comprehensive test program because we've seen that, you know, different laboratories running the same tests can get different answers.

So it's very important that we have a vetted, validated test program that can be used with confidence by the industry because the worst case scenario would be that a vendor has a new alloy, spends a million dollars running tests, and they come into us and we're not sure what to do with them because it was done in a different manner.

And now we start questioning the validity of the test results. So this is a key component of moving forward.

MEMBER ABDEL-KHALIK: Is there a potential that new breakaway oxidation criterion would make all plants small break LOCA limited?

MR. CLIFFORD: Well, right now we don't see that, but you could ask yourself. You know, we haven't done a break spectrum analysis to try to maximize the time above 800 degrees C. You know, we

haven't determined, well, what if the operator makes this error or what if there's this failure or what if, what if, what if.

But right now we don't see that all plants are going to be small break limited because of this phenomenon, and that will depend on the performance of the alloy.

CHAIRMAN ARMIJO: In your current thinking though with this early version of the rule, would any of the alloys that are currently in use by the industry, M5, ZIRLO, modern Zircaloy-4 and Zirc-2 fail these requirements?

MR. CLIFFORD: Well, I think any time you would put a high burn-up alloy that has a high hydrogen pickup in a region of the core that would be at a higher power at the end of life, then you could challenge the criteria because the post quench ductility is a function of initial hydrogen content and, as Mike showed, there's a slope in that line, and it diminishes from somewhere around 17 percent to somewhere around five percent at 600 ppm.

MR. BILLONE: Were you talking about breakaway oxidation?

CHAIRMAN ARMIJO: Yeah.

MR. CLIFFORD: Oh, I'm sorry.

CHAIRMAN ARMIJO: Yeah, I was thinking breakaway. I see your point there. It would maybe put some constraints on core designers.

MR. CLIFFORD: Right, exactly.

CHAIRMAN ARMIJO: But that's probably okay, but I was talking about breakaway. You know, breakaway oxidation is the new phenomenon that would go into the rule, and my question was how would it impact the existing materials we currently have.

MR. BILLONE: I think Jennifer addressed that. If the answer were 3,000 seconds, for example, for an alloy and an Appendix K calculation was done very conservatively you may exceed 3,000 seconds for that and you wouldn't necessarily be at that same temperature obviously. So you'd have some additional work to do.

So 3,000 seconds and a conservative Appendix K calculation could make it limiting.

MS. UHLE: Right, and I just want to add to that we originally when this was for our research program determined a couple of years ago, we immediately talked to NRR and said, okay, well, here are, you know, based on our understanding of some plants that have low high-head injection capacity, that are using maybe one of the fuels that had the

3,600, you know, seconds. We said, "Okay, well, what are your licensing basis calculations saying?"

And there was a time where there were a few plants that we said, oh, well, that you know, you may be exceeding our understanding of what we thought the limit would be for oxidation, and we then recognized, okay, well, do we take action and shut these plants down, and the answer was, well, no, because this is not realistic. This is an Appendix K calculation.

And then in addition, we also made sure that each of these plants had emergency operating procedures so that if they were exceeding I think it was around 1,200 degrees Fahrenheit, 1,500 degrees Fahrenheit for more than five minutes. They were going to blow down the secondary side, which would then increase the capacity of the high head and would, of course, cool the core.

So at the time we said, well, the current plans are safe, but I do think that if this particular fuel were going to be used for out-years, it may, in fact, drive the vendors to want to develop a best estimate small break LOCA methodology, which I think would not be objectionable to the Committee.

So we feel there's plenty of margin. If

you're using Appendix K, you may question it and look a little deeper, but we felt there was no safety issue.

MR. CLIFFORD: And also, it would give the fuel vendors reason to go back and determine why does this alloy have a shorter breakaway time than the other alloys. Maybe there's something I can slightly tweak in the manufacturing process to give me better performance. could come in with their own proposed test that you'd review and decide whether it was --

MR. CLIFFORD: That's one of the areas we're struggling with. We need to define within the rule something that's enforceable, and so you need to define enough specifics of what you're trying to accomplish within the rule. How you get there can be in a lower tier document.

For instance, that's why you really have to say, well, what is ductility. Well, ductility is a measurement of one percent plastic strain using this type of test apparatus. How you prepare your specimen and all the other things that go into running the tests in a hot cell or glove box, wherever, that can be in a lower tier document, but you have to define something in the rule that's measurable and enforceable.

MS. UHLE: And then in addition, there is also federal law that requires any rulemaking by a federal agency has to have enough detail in the rulemaking package so that a person who is going to be held to this rule will understand what compliance means. Otherwise they say it could be perceived as being arbitrary and capricious.

So OGC is very, very strictly watching us to make sure that we have enough specificity in the rule for the licensee to be able to understand what it means. Otherwise they can't comment on it because they don't know what we would perceive as being acceptable.

CHAIRMAN ARMIJO: thank you.

MR. DUNN: Mr. Chairman, Bert Dunn again. I'm sorry to keep this --

CHAIRMAN ARMIJO: I'd really like to have -- we're running a little bit late.

MR. DUNN: Okay. I'll mention it this afternoon.

CHAIRMAN ARMIJO: -- your opportunity when you speak this afternoon.

MR. DUNN: Okay.

CHAIRMAN ARMIJO: Thank you.

MR. CLIFFORD: Okay. The previous slide

showed a single line representing an allowable ECR versus pre-transient hydrogen content that would be placed in the rule, but it's important to note with this slide that even a single line when converted to burn-up using alloy specific oxidation and hydrogen pickup properties becomes alloy specific, and it is performance based.

Alloy-1 would represent a modern cladding alloy that has lower corrosion and less hydrogen pickup. So you achieve benefits of having that type of cladding versus having an Alloy-3, which would represent an older cladding alloy that has higher corrosion rates.

The next slide, I plan to describe the flexibility of the optional test program. Following approved test protocol and the provisions of the new rule, vendors would be able to run their own test program and realize potential operating margins. In this example, the licensee or the vendor would have the option of testing their specific alloy to try to achieve some flexibility and develop their own line which may be less restrictive than the one that's in the rule. They may want to run cases here which have different transient temperature profiles, one with a quench, one that's slow cooled, and they could apply

those results to different types of LOCA scenarios.

And here --

MEMBER SHACK: Now, presumably you have to do at least enough testing to show the generic rule was applicable to their alloy.

MR. CLIFFORD: Right. There would always be that requirement, and we haven't determined what the subset of testing that would be required to generate that applicability yet, but that's something we need to work on.

And here I've expanded it to show we expect that there will be some benefit realized from running samples oxidized at a lower temperature -- this goes back to your question. Is that 2,200 degrees Fahrenheit? What if you said, "Well, my reactor only gets 1,900 F. So why am I penalizing myself at 2,200 F.?

So here you could run specific tests that would represent a particular reactor design that may have a beef to your ECCS system or may just not realize 2,200 degrees Fahrenheit, and also there's burn-up effects. A high burn-up rod is not going to achieve 2,200 because that's going to be driven by the fresh fuel.

So you could develop plant specific plant

specific, burn-up specific. Implementation can be as simple or as complex as the licensee or vendor chooses, and that will probably be driven by the performance of their alloy and the needs of the licensee.

MEMBER SIEBER: Do you have a minimum set of test requirements in mind that would meet the applicability of the new rule?

And if so, why would you put out the rule before you know what it is you're going to require?

MR. CLIFFORD: It's something we're still working on. I mean, I'm here today to kind of give you an update of where we are at the beginning stages.

MEMBER SIEBER: Okay.

MR. CLIFFORD: We'll be back here again, and we'll have to justify everything we've done and everything we've decided to go forward with.

MR. MEYER: I think it's fair to say that what we've done at the lab already would be likely to be what we would --

MEMBER SIEBER: Yeah, it seems to have the framework, but you don't have it written down, right?

MR. CLIFFORD: Not yet, no.

MEMBER SIEBER: Okay, but you will have it written down by the time you change the rule.

MR. CLIFFORD: Absolutely.

MEMBER SIEBER: Okay. Thank you.

MR. CLIFFORD: So are there any questions on the optional test program?

MEMBER BROWN: Who performs this optional test program?

MR. CLIFFORD: The industry.

MEMBER BROWN: The industry does?

MR. CLIFFORD: Correct.

MEMBER BROWN: So they have to come in and lay it out in accordance with whatever you propose in the rule.

MR. CLIFFORD: Correct, and that really goes back to the importance of the test program. You know, we have to have a test program that we all agree to before they go off and run these tests so that we feel comfortable with the results.

MEMBER BROWN: Now, by optional, that means they're going to deviate from the standard rule of 2,200 degrees or another rule?

MR. CLIFFORD: From the straight line curve? The rule would be written so that you could do either one. You could use the line that's in the rule or you could deviate from it, you know, meeting the requirements of an alternate approach. So no

exemption would be required.

MEMBER SIEBER: But all of these details will not be in the rule.

MR. CLIFFORD: Something has to be in the rule.

MEMBER SIEBER: Well, he already told us what's going to be in the rule.

MEMBER BROWN: I'm not quite sure I understand that.

MR. RULAND: And that's the hard spot, is we have to meet not only the technical requirements, but the legal requirements of the rulemaking, and it's something we've got to work on.

MEMBER BROWN: I'm not a materials guy. I'm just here to learn, but if I had to implement this, it looks like the rule can be anything I choose based on the test program I submit if it demonstrates a certain performance relative to the basic tenets of your overall rulemaking.

MR. CLIFFORD: That is kind of the benefit of a performance based rule. You just define what the requirement is and how they implement it --

MEMBER BROWN: I understand that, but it requires a lot of -- right now it's kind of a no-brainer. The things are there. They're set. Now

there is all of this constant evaluation as to whether is this set of test results valid or suitable or are we going to accept it, and then I think somebody already emphasized the importance of the initial test program that you have to generate in order to demonstrate that.

So you've got a short time frame of test programs versus 30, 40 years of experience and the willingness to accept that, well, we don't know enough about it on a time basis and application basis it seems to me would make it somewhat difficult unless you have some real specificity in your rule in terms of what is required in order to demonstrate acceptance or that they lay it out and it becomes prescriptive or a no-brainer when you see it.

If it requires judgment, the judgment normally defaults to the old way. I'm just an old guy and that's what old guys do. They default to the old if they don't understand the new as well as they think they should.

MR. CLIFFORD: right. I understand.

MEMBER BROWN: Which costs more.

MEMBER SIEBER: That's why we retire.

MEMBER BROWN: Or get retired.

CHAIRMAN ARMIJO: I think we should move

along.

MEMBER BROWN: I'm sorry.

MEMBER SHACK: Well, you know, we don't have 50 years of experience with LOCAs. You know, you have very little limited experience with LOCAs. So I think, you know, the testing program you're requiring here actually is more. You know, you're asking for more than you've really asked in the past.

MEMBER SIEBER: Yes.

MR. CLIFFORD: but we're also providing flexibility.

MEMBER SHACK: You're providing flexibility, but --

MR. CLIFFORD: As opposed to just saying, okay, I'm going to replace the 17 percent with five percent.

MEMBER SHACK: But you're really asking them to demonstrate the performance required in a much more rigorous fashion than we have in the past.

MEMBER SIEBER: Yeah, overall it results in an improvement in the original rules.

CHAIRMAN ARMIJO: You're right. It's tricky.

MEMBER BROWN: You just have the variability of acceptable results, is what you end up

with, with a new underlying basis in each circumstance.

I'm sorry, Sam. I couldn't resist after the last.

CHAIRMAN ARMIJO: All right.

MR. CLIFFORD: Move on?

CHAIRMAN ARMIJO: Yes, sir.

MR. CLIFFORD: Okay. Due to the complexity of the rulemaking, as you'll hear throughout today, the differences between the industry and the staff and the complexity of writing a rule to accomplish all of these objectives, we are considering what is known as the advanced notice of proposed rulemaking. This process is designed to enhance public participation during significant campaigns, which I think everyone would agree that this is a significant campaign.

The key benefit of an ANPR is that it allows us to perform some additional investigations in parallel with developing rule language and in parallel with facilitating stakeholder involvement.

The current process if we were to follow it is in series. We would have to do everything first, make sure we had adequate technical basis that's beyond really reproach, and then move forward

to the bureaucratic aspects of rulemaking. This kind of gives us a parallel path, and we see benefit to it.

The next three slides describe additional research activities that are being considered to supplement the existing technical database. The first activity is the development and validation of a comprehensive performance based test procedure, as we have previously identified. This test procedure provides an acceptable test procedure. In other words, if you follow this to the letter, the staff would accept it. We wouldn't question. We wouldn't say, "Do it a different way." It documents what we find acceptable.

Also, it would insure consistent experimental procedures and protocols.

Finally, we hope it would capture variability, uncertainty, and repeatability in the testing.

An important note here is right now we believe more work needs to be done to validate the prehydrided surrogate which would support the testing with unirradiated specimens.

The second activity being considered is a request for some additional post quench ductility testing in the intermediate hydrogen ranges between

100 and 550. I think this was identified earlier.

And finally, we are considering some additional breakaway oxidation tests to investigate whether or not the timing of breakaway oxidation is sensitive to variations in temperature profile and thermal cycling. Right now all of the tests have been done at isothermal conditions, and we would just like confirmation that variations in temperature don't affect the timing of breakaway.

CHAIRMAN ARMIJO: By that do you mean the rise to temperature or actual cold temperature or what?

MR. CLIFFORD: Well, this is a small break LOCA phenomenon. It's not maybe as clear as a large break where, you know, you go through a certain prescribed load on, reflood, quench process. A small break LOCA, the level can be moving up and down over periods of time. So you could see some sort of thermal cycling. And we will attempt to quantify what those cyclings could be and whether or not it affects it.

MR. MEYER: The breakaway process is rather odd. If you go rapidly on a temperature ramp up to 1,100, 1,200 degrees Centigrade, you won't get breakaway, and you can stay up there, and you won't

get breakaway. You just cook it and diffuse oxygen into the metal.

But if you pause at a temperature somewhere around 975 and the temperature is very critical and you hold it at that temperature, that's where you hit breakaway. It's really strange, and it's real. The big study by Leistikow and Schanz demonstrated that, and we haven't done nearly as big a study as they did, but we can see the same evidence.

MEMBER SIEBER: Why does that happen? That is unusual.

MR. MEYER: I don't know. Maybe Mike can explain why it happens at that temperature, but there are just like two temperatures that are sort of bad news temperatures. If you get to those two temperatures and they're fairly low, if you get there and hold there for a long time, the monoclinic oxide starts forming which will crack.

MEMBER BROWN: Does that mean you hold and then go on up to the higher temperature or does that mean you just hold and stay at the lower temperature?

MR. MEYER: I think that's the question that prompts us to look at the transient measurements because so far all we've done is find those temperatures and go there.

CHAIRMAN ARMIJO: Somewhere along the line, not now, but in the future, maybe we should have a subcommittee meeting just on this issue of breakaway oxidation since it's a new requirement. It's a very complex phenomenon that most of us even in the industry don't understand. It might be a good idea.

But in the meantime, you know, you go ahead.

MEMBER SIEBER: The proposed change to the rule or the testing program really doesn't address that, right?

MR. CLIFFORD: Well, I think this testing would determine whether -- this would determine how you should test it in the future. In other words, if it's sensitive to thermal cycling maybe you need to revise your test protocol. Instead of saying go to this isothermal test that had 975, you know, vary it.

CHAIRMAN ARMIJO: Do a test that shows something.

MEMBER SIEBER: So we should, all industry and NRC, wait for the development.

MR. MEYER: The concept that we have now is if you go to that magic bad temperature and hold it there for 3,600 seconds, it breaks. The oxide breaks up, and so if you're anywhere above some low

temperature like 600 decrees Centigrade where you would begin to have some oxidation, if you're above that temperature for less time than it takes at the critical bad temperature, you're obviously okay.

Now, there is probably some less bounding approach that one can take based on considerations like, well, what if you stay there just half the time and at some other temperature half the time. If the monoclinic oxide starts developing, does it continue or will it revert to a tight tetragonal oxide?

MR. CLIFFORD: And that was difficult to implement because each fuel rod is going to see a different temperature transient. So then each break size is going to introduce different variations in those temperatures.

MEMBER SIEBER: Every rod is going to be in a different condition.

MR. CLIFFORD: Exactly.

MR. MEYER: What we can do right now is to use a bounding approach that will obviously be okay, but it has the potential for being penalizing. So we're going to look at the transient behavior very quickly in the next six to eight weeks and see if we can get further insights that might help us write the rule in a more informed way.

MEMBER SIEBER: Yeah, but you may end up with a lot of fuel failures even though the hot rod is okay.

MEMBER RAY: Well, in reading your text here, again, it seems to me like it's talking about alloys as if they were independent of the manufacturing process. Earlier on it seemed like there was a note taken of the fact that, well, how it's manufactured, the surface finish and all of that is relevant.

Is this testing going to take that into account or, saying it another way, will the testing be clearly associated not just with the alloy but with the manufacturing process as well?

MR. CLIFFORD: Well, I think it would have to be both. Certainly the breakaway would have to consider the manufacturing process.

MEMBER RAY: Well, I just think that that should be explicit because for many of us, we've thought about this as an issue having to do with the alloy alone and not how the tubing was actually made and placed in service.

MR. MEYER: I think you may have missed some of the earlier discussion this morning.

MEMBER RAY: No, I was here the whole

time.

MR. MEYER: You were here the whole time.

MEMBER RAY: Yeah.

MR. BILLONE: We almost need a different language, but I try to call them cladding materials because I can take three variants of Zirc-4. Anomalies and composition and behavior are extremely different. So it's --

MEMBER RAY: Well, that's fine. I'm just reading what's on the page here.

MR. BILLONE: Right, and I'm agreeing.

MEMBER RAY: It just refers to cladding alloys, and to me that doesn't capture the point.

MR. BILLONE: The question is does materials. I don't know what word to use.

CHAIRMAN ARMIJO: I think the intent is the --

MEMBER SHACK: Well, I think they were proposing for the LOCA test -- they were less concerned about manufacturing, and they were only proposing the periodic testing on the breakaways, as I understood.

MR. BILLONE: Right, the breakaways.

MEMBER RAY: That's what I read.

MR. BILLONE: Right.

CHAIRMAN ARMIJO: But it was manufactured including alloy variations and processing and surface treatment and all of that. All of that controls oxidation. The manufacturers are well aware of that for normal productions but have not applied that to breakaway issues.

MEMBER SHACK: I had a question. Were you envisioning the periodic testing to be triggered by the vendor in noting that he was changing his process or you would just impose a periodic test?

MR. CLIFFORD: We're still kicking around that idea of what triggers the test. I mean, exactly how you coined it, you could be part of the change process or it could be a strict every 1,000 tubes. It's something we need to weigh, something we need to decide upon.

I'm sure the less I say the better for your industry.

MEMBER SHACK: A thousand tubes. Yeah, that would get their attention.

CHAIRMAN ARMIJO: It certainly would.

MR. CLIFFORD: The question is if it's just triggered by the change process, then it's a conscious change. You know, they plan on making the change. What we really want to protect against also

is to make sure that an inadvertent change doesn't trigger this.

MEMBER SHACK: That means you could have two triggers, a conscious change trigger and then kind of a backup backstop, you know. No matter what you did, you'd do it.

CHAIRMAN ARMIJO: Well, a lot depends on your qualification of the material. When you go through your initial testing to demonstrate its breakaway corrosion resistance, you would vary your manufacturing parameters as broadly as you think was practical, reasonable in your factory and demonstrate that you still would meet the breakaway time or temperature, whatever the parameter was.

Having done that, then you could have a different criteria for periodic, a very long time or just a conscious change, but just testing every few thousand tubes doesn't seem very practical. Or else you're right on the border.

MR. CLIFFORD: I mean, there's two aspects. I mean, one, we don't want to introduce a burden where they have to run tests that are never going to show anything, but at the same time, we don't want to specify surface roughness. We don't want to specify anything that gets into the details of the

shop.

We hear from both sides of the industry. We hear, "Stay out of our shop," and the other side says, "We don't want to do any testing." So we're trying to come up with a compromise.

CHAIRMAN ARMIJO: Okay. You've got a problem.

MEMBER POWERS: Nothing very surprising.

CHAIRMAN ARMIJO: Okay. Go ahead, Paul.

MR. CLIFFORD: Okay. Here's the last slide. Here's a list of milestones that would need to be achieved during this rulemaking process. Don't need to read through each one, but essentially we need to develop this rule language and really fill in the meant on the skeleton that I've shown you here and show what the final product is going to look like.

And then we feel like ANPR would be very helpful because it would allow the industry the option to comment on an actual structure of a rule and some sample rule language. So it would give them the opportunity to get on the record with not just the technical basis but what the rule is going to mean to them and how it will be implemented.

And also to note on this rulemaking milestone list is that the ACRS meeting down here, you

know, we'll be back once we've worked out all the details. We'll be back before the Subcommittee with what the rule will look like, how it will be implemented, and the future details.

MEMBER POWERS: To pull out, and I may actually be able to do this, the viewgraphs a year ago when this group appeared, it had exactly the same milestones on it. At what point does this ever get enough to go ahead? How much more additional research do you have to do here?

MR. CLIFFORD: Well, we've identified three relatively small activities that we believe will be --

MEMBER POWERS: And when they show up on Item H we'll have three more, relatively small. I mean, these words were identical a year ago.

We have one more test we really want to do. That was exactly what was said a year ago. Now you've got three little activities here. It seems to me that you've kind of got it.

MR. CLIFFORD: We're not saying that we don't. We think we should move, and we will be moving over the course of the next 12 months to get to, you know, Item 10 here on the list. We're not putting this off for a year or two from now.

MEMBER POWERS: What is Item 4 up here?

MR. CLIFFORD: Item 4? Well, this is the idea of an ANPR would allow us to vest through such --

MEMBER POWERS: I understand what they do. When does it get issued?

MR. CLIFFORD: Oh, it will be in the springtime.

MEMBER POWERS: In the springtime.

MR. CLIFFORD: We need to develop the comprehensive test procedures so we can include them in the ANPR so that the lab can review what we're planning on being somewhat as an acceptable test program so that they can review it and determine whether it's something that they can actually perform at their facilities.

So it's important to get comments on that because that's really one of the key aspects to implementing it in the future.

CHAIRMAN ARMIJO: In our last ACRS letter, we recommended that the staff complete its planned test program, and how much of the planned test program remains to be done?

And the emphasis and concern was the big delay in testing the irradiated fuel because of the laboratory problems. Is that part of your plan to get

those things done? Are those tests going to be abandoned? What's going to happen with those?

MR. MEYER: Sure. We have completed the planned program. It was finished in June of this year and documented. There are three activities that -- now we may have different views of this, but I view as enhancements, and one of them is writing down a test procedure in a way that's suitable to put in an ANPR or a regulatory guide.

We haven't written it down yet. The contractor is going to do that by the end of January. All of these things are going to be done by the end of January. We found a couple more samples with intermediate hydride levels that we could handle, and we're going to test those. I don't think we need them. We have a data trend that's clear. We have free hydrided samples that confirm this data trend. I don't think we need anymore.

But we have the samples. There has been a question. We're just going to do it, and it's going to be over with by the time that we can get these other things done.

And then the third thing we're going to do is some scoping tests on transient temperature history for embrittlement in case we can figure out some way

to write a better requirement on the -- I said embrittlement. I meant breakaway -- on breakaway.

I don't know that we'll improve the breakaway situation at all, but at least we'll look and see if we get any bright ideas.

So all of this is designed to be done in a way that will not slow down getting to the end. So far as I know, we have not changed the overall schedule for implementing this rule change.

CHAIRMAN ARMIJO: Okay. I may have been mistaken, but I thought there were some irradiated fuel rods that were -- integral tests.

MR. MEYER: Ah, that's another matter because those don't affect the criteria themselves. Those affect models that would be used to demonstrate compliance with the criteria, and they're not regulated, not in this part of the rule anyway. So those had to do with axial fuel location.

CHAIRMAN ARMIJO: Are those tests going to be done?

MR. MEYER: They're going to be done, but not in the next two months. Hopefully in the next two years. That's a difficult test program and expensive, and we're working very hard to get it placed and started.

CHAIRMAN ARMIJO: And what will those tests address? Not basic material properties abut other things like ballooning, relocation?

MR. MEYER: Yes. They're going to address the ballooning issue, the size of the balloon. Is there a burn-up effect on burst strain? We'll look for that. We will look at the mechanical behavior of a ballooned and oxidized rod to see if we need to do anything else in the balloon other than just accounting for the degradation due to corrosion related hydrogen.

We're going to look at axial fuel relocation to confirm what we think we already know from the German FR-2 tests and some other things, and we're looking to look particularly at the amount of fuel lose through the rupture during the test.

We weren't expecting any before. We saw a little bit, and we just sort of wrote it off as an experimental thing, and then when we saw this Halden test called IFA-650.4 where in an extremely high burn-up fuel rod, 92 gigawatt days per ton, they lost the whole upper section of fuel blown right out the rupture opening.

So maybe at 62 gigawatt days per ton where we're testing the limit that's being used in the U.S.,

maybe we're seeing a little bit of the beginning of that process, and perhaps there is a reason to hold to some burn-up limit. This is all external to embrittlement criteria in 50.46(b), and so that's the future program.

MR. CLIFFORD: Now, from a process perspective, I don't see that issuing an ANPR in '09 is going to slow down the process. I think quite the opposite. I think if we can work out a lot of the details with the industry before we issue a proposed final rule, then I think ultimately that will save time down the road.

MEMBER POWERS: Usually when people appear before us to say we want to issue an ANPR they follow it up immediately with a set of typically three or four specific questions they're going to ask for public comment about. What are your three or four questions that you're going to specifically ask for public comment?

The NPR also typically provides the background information that you have available to you.

MR. CLIFFORD: Well, one specific question would be that single curve that we're proposing or may propose in the rule. I'm concerned that if we draw that line, if we try to be too bounding by drawing

that line that no one will use it and hence it won't be useful. So one of my questions to the industry would be, okay, here's what the line's going to look like. Here's the way the rule is going to be structured. You have two options: Option A, use this line; Option B, run your own test program.

If everybody tells me I can't use that line, then that's going to affect how I write the rule. I might take that out.

That's just an example.

MEMBER POWERS: So you'll have one question?

MR. CLIFFORD: No, I think there's more questions, and I think this afternoon you're going to be hearing from the industry what their concerns are and those concerns are --

MEMBER POWERS: I'm asking what your ANPR is going to say.

MR. CLIFFORD: Well, the ANPR is going to provide the rule language, how the rule will be implemented in the test program, and I think we'll receive comments. You know, for instance, we may receive a lot of comments on the test program.

MEMBER POWERS: Usually when you're issuing an ANPR there are some specific questions that

you need an answer to because you have options. I mean that's why you issue an ANPR, and that you want the flexibility to do some research to change your thing and you have some specific questions. I'm trying to understand what the specific questions are.

MR. CLIFFORD: Well, right now I'd say my biggest question was what I previously said, whether or not --

MEMBER POWERS: Well, it seems to me you also have the question of should we augment this rule, include something on breakaway. I mean, that's a change, and should it be done?

MR. CLIFFORD: Right.

MEMBER POWERS: So maybe you've got two questions. I mean, there's nothing wrong with two questions. I'm just saying that usually when people come in here and say, "We want to issue an ANPR," they have those questions pretty well in mind and they can lay them out pretty explicitly for us.

I'm concerned that you can't do that.

MR. RULAND: Can't do it today.

CHAIRMAN ARMIJO: I expect we will see that ANPR and the associated questions before it goes out or after it goes out. Is that what you're addressing or asking, Dana?

MR. CLIFFORD: I'm not sure how that process works with the ACRS. Does the ACRS review ours?

PARTICIPANTS: No.

MR. CLIFFORD: Do you know, Chris?

PARTICIPANTS: No.

MEMBER POWERS: I mean, typically this is exactly what happens. We have a meeting. People say, "We're going to do this with an ANPR." They say, "Here are the specific questions we're going to ask." They're usually here asking us is this a good idea or not a good idea; are we asking the right questions or not asking the right questions; are there additional questions to ask. That would not be an uncommon thing. In fact, I could think of no contra example to it.

You're coming in much less prepared.

MR. CLIFFORD: Well, I mean, this meeting was a status update, where we were. We didn't come in here and say we're done with our ANPR and we want comments on whether we're doing it right. This date was picked and based upon this date, show us where you are, and I think we made it clear at the beginning that we're early in this process. This is a conceptual rule. This is a proposed or this is a

conceptual milestone list.

How the ANPR -- we haven't written it yet. We haven't even started writing it yet.

MR. RULAND: We understand what your point is, Dr. Powers and we'll give it appropriate consideration. Clearly when we issue the ANPR we have to have a set of questions that we're going to ask. So we understand your point.

Thank you.

CHAIRMAN ARMIJO: Any other comments, questions?

Okay. We're about an hour behind. I'm going to try and make some up. The industry has comments. They were supposed to start 45 minutes ago. So why don't we take lunch now and come back at -- I'm going to cut it less -- 12:45 we'll restart; 12:45 everybody back and we'll restart then.

(Discussion was held off the record.)

CHAIRMAN ARMIJO: I made a mistake and corrected it to 12:30.

(Whereupon, at 11:46 a.m., the meeting was recessed for lunch, to reconvene at 12:30 p.m., the same day.)

AFTERNOON SESSION

(12:31 p.m.)

CHAIRMAN ARMIJO: Let's come back to order.

All right. Mr. Yueh.

MR. YUEH: Okay. Thank you, Mr. Chairman. And I want to thank the Committee for giving the industry an opportunity to present on the subject.

We are going to make five presentations. I will start with the industry position overview; identify some of the gaps we think is in the database; followed by our test plans to fulfill actually some of the gaps.

After that GNF is going to make a presentation in the adequacy of data to support PRA testing, and he also has proposal from control point of view.

And then the industry will make two presentations in the implementation and cost-benefit analysis.

A few words on industry and NRC cooperation. The industry is supportive of NRC's

overall objective with regard to the revision of 10 CFR 50.46. Industry endorses the concept of performance-based approach; expects the new criteria to be technology neutral which will allow for cladding advances without the need for rule exemptions.

The industry supports work that's done so far to, again, a surrogate to irradiation which will allow a quicker acceptability assessment of cladding.

The industry has been involved with ANL program early on through the EPRI Fuel Reliability Program, but was limited input since 2005 I've been told. The industry has been involved in supplying irradiated high burn-up BWR and PWR fuel rods with standard and advanced claddings for LOCA testing, and also provide analytical support for the design and qualification of LOCA and mechanical property tests.

There's a very high level view for industry position. The essential first two points. The first point is due to scope change from the original test plan because of hot cell lab delays and closure, some of the scope changes with less work done on integral tests. There's insufficient data on two-sided oxidation, and you know, we do not have sufficient understanding of breakaway oxidation.

We do not think there sufficient

information provided in NUREG to support the proposed criteria in RIL-0801.

A second point I want to make is, I guess, after Paul's presentation it's less important, that the data generated so far allows a bounding approach and, you know, may have a significant impact on industry, but with no safety benefit. You know, this could be costly. This refers to establishing criteria based on 12 NRC test data only. ANL test data is shown, oxidation at lower temperatures. At the same ECR the ductility is much improved.

And the industry feels data generated so far does not indicate a presence of public safety. The current evaluation methods already takes into account in-service oxide which offset some of the hydrogen uptake which is the main reason, I guess, for the rule revision, because of significant reductions in ductility.

The current approach is also conservative in that it assumes a fixed 1,200 C., Celsius, limit, but the actual LOCA temperature profile is tapered. They only experience that temperature very briefly. So if you integrate the entire temperature profile, it's less detrimental.

CHAIRMAN ARMIJO: The issue of oxidation

already being included, now that's external oxidation being included in the current analysis; that's really a voluntary situation. So you can't really say that everybody is doing that. I don't know that everybody is including the normal oxidation.

And the other problem with that, even if you are, not all alloys have the same hydrogen pick-up for a particular thickness of oxide, and so, yeah, there is some hydrogen being incorporated, but it really isn't being done in any formal way that you could really rely on.

That's my comment on that.

MR. YUEH: Okay. It's in regulation guide.

MR. DUNN: It's in an information notice, and it's not consistently applied.

MR. RODACK: But our experience has been when an applicant will submit a license amendment request for stretch power or some change in operation and a new LOCA analysis is applied as part of the licensing of the model, that is invoked and brought into play.

CHAIRMAN ARMIJO: Staff ask the question and you voluntarily comply.

MR. RODACK: We provide details on how we

comply.

MR. DUNN: The staff has many ways.

CHAIRMAN ARMIJO: All right. Go ahead.

MR. YUEH: Yeah, the other point I didn't state, of course, when the clad has accumulated sufficient hydrogen for embrittlement, it's already usually high burn-up and cannot reach high temperatures.

You know, the data gaps that we have identified is listed here. You know, ANL testing focused on 1,200 Celsius, that's where most of the post quench ductility tests were performed.

There is very little data at 1,100 and 1,000 Celsius. The data collected so far suggests that lower temperature has a lot more benefit in terms of ductility.

Different labs have generated different post quench ductility data. How they perform the test, you know, different heat-up profile and cooling scenarios result in different post quench ductility results.

There's insufficient information to understand what the differences are or what causes the difference.

The critical post quench ductility

transition boundary recommendation is not supported by data at --

MEMBER SHACK: But, I mean, does that refer, for example, to the CEA tests?

MR. YUEH: CEA, yes.

MEMBER SHACK: But why would I consider tests with such a long cool down period in contrast to the ANL tests? Don't the ANL tests seem more prototypical? Is there a good argument for the long -- I mean, the only argument we heard or at least was discussed today happens to be the time constant of furnace.

Is there a better argument?

MR. YUEH: Well, this also are the differences with CEA test. If you slow cool and then you quench, you get different results. You get a difference between the quench temperature.

MEMBER SHACK: But is that slow cool prototypical? I mean, okay, well, who cares?

MR. YUEH: You know, my point, the industry point is there is anomalies in there, things that happen that we don't understand.

CHAIRMAN ARMIJO: No, I think the real issue is if the test is prototypical or close to prototypical of what happens in the reactor, then that

should be the time-temperature transience that you use in your program. If somebody chooses to do it some artificial way that gives you different results, well, what good is that?

MR. YUEH: Well, if you talk prototypic, then ANL test profile are not necessarily prototypic. It just assumes, you know, once you reach temperature the entire duration.

CHAIRMAN ARMIJO: Well, that's what we want to see. We want to see something that's really applicable to the real reactor with margin so that this regulation makes some sense.

MR. YUEH: Well, in terms of CA test and ANL test, obviously we would prefer the ANL test.

CHAIRMAN ARMIJO: Okay. Good to hear.

MR. DUNN: Well, I think the question is that the temperature at which you do the quench, the 800 is pretty high. More typical would be somewhere around 400 to 600 and then for small breaks you could even wind up at 200, and our information is clouded by the cool-down rate in the CEA which the cool-down rate at Argonne is more typical for large breaks probably than small breaks.

MEMBER SHACK: I mean, there is a difficulty that you're not going to have a test that

encompasses everything. The question is whether the degree of conservatism associated with those profiles is undue, excessive. I mean, they are proposing that for a generic result, and you have your option to provide more data, you know.

I can understand your arguments in some detail, but you know, would you accept those as a reasonable proposal for a generic starting point, which again it seems to me the curve should have a generic element.

MR. DUNN: Well, as a starting point, I suppose.

MR. YUEH: The ANL test data, the way the heating and cooling profile and the ANL test used less sensitive, I think to the temperature as compared to the slower cooling rate.

MR. DUNN: Yeah, I mean, clearly it can be. I don't know what the proper time constance is. None of us I don't think do. I don't know whether one degree or a tenth of a degree or ten degrees, where the whatever changes within the clad is marked. There's bene proposals, but I don't think I've ever seen anything definitive on it.

I'm arguing with you. I don't have --

(Laughter.)

CHAIRMAN ARMIJO: Okay. Well, go ahead. Keep going. It's kind of late anyway.

MR. YUEH: I have a slide later on, the critical post quench ductility transition boundary, and then, you know, this limited quenching temperatures we just talked about a little bit and alloy testing. There's no data on irradiated Zircaloy-2.

You know, requirement in RIL-0801 to use two-sided oxidation away from the ballooned region is not supported by the ANL data. Limerick rods in integral test show that limited ID oxygen source. So if NRC want to impose a two-sided oxidation, right now it's not supported by the data, especially the Limerick rod showed very little oxygen state in --

CHAIRMAN ARMIJO: Is somebody going to present that to the Committee? I know it was in some of your earlier presentation material, maybe in the workshops. You actually showed microstructures of the Limerick rod. I think it's important to see it.

That could be a Limerick phenomenon. It could be a Zircaloy-2 phenomenon, Zircaloy-2 minor. I don't know why that was different, but it was different, and I think the Committee needs to see that. There are some issues, real facts here that

have to be addressed.

MR. YUEH: I actually had that slide on here, and then because of time limitation I deleted it.

CHAIRMAN ARMIJO: Big mistake. Go ahead.

MR. YUEH: This is also linked to the Harden test, which I will talk about later.

And then support for periodic testing, the driving force for the breakaway oxidation, i think, is mainly from the E110 material behavior. You know, it is a phenomenon specific so far to E110 which the process is fundamentally different to the process used in the West. The electrolytic process is different from the start, which involves fluorine early on.

This slide basically shows the effect of burn-up on the peak fuel temperature. This is to support, I guess, our hope for optional testing criteria, low temperatures. After first cycle irradiation is achievable peak cladding temperature can be the intended degrees Celsius lower than the fresh fuel, and you know, from this angle we show optional criteria based on peak cladding temperature, and this is to support our view that bounding approach will have a significant negative impact on the industry with little safety benefit.

CHAIRMAN ARMIJO: Now on this curve would you explain? I don't know whose data that is. I guess it's Westinghouse data.

MR. YUEH: Yeah.

CHAIRMAN ARMIJO: When you get to Westinghouse, will you explain that curve? If I read it, your peak temperatures at least calculated for your first cycle fuel were somewhere in the 900 Centigrade; is that right? Am I reading that right?

MR. YUEH: Yes, yes.

CHAIRMAN ARMIJO: And the bounding would be -- would you assume it's 1,200 Centigrade?

MR. YUEH: Yes. But the chart on the left is not a one-to-one comparison with the chart on the right. On the left is three loop, and the right-hand side, it's data from four loop plant. This is just to illustrate the temperature difference between different power levels, 1.66 versus, you know, 1.11.

MR. RODACK: But that top curve is the peak --

CHAIRMAN ARMIJO: Driven by decay heat, right? It's not --

MR. RODACK: But it's from the fresh fuel, the first burn fuel, the hot fuel.

CHAIRMAN ARMIJO: Am I the only guy who

sees this? Your third cycle fuel, .62 peaking factor?

MEMBER ABDEL-KHALIK: This is just the bundle average power --

CHAIRMAN ARMIJO: Yeah, yeah.

MEMBER ABDEL-KHALIK: -- compared to the --

CHAIRMAN ARMIJO: I would like to see the rod, you know, peak rods and those are the ones that fail, not --

MR. YUEH: On a similar train, I do have a slide for you, a back-up slide on that.

CHAIRMAN ARMIJO: But if you're going to make a point on this, we really need to see --

PARTICIPANT: Apples.

CHAIRMAN ARMIJO: Yeah, real details on what these numbers are.

MR. YUEH: This is a 3D peaking factor for entire plant. It is every rod in the plant, which shows a similar trend for the power decrease in conventional burn-up.

CHAIRMAN ARMIJO: Okay.

CHAIRMAN ARMIJO: And the difference translates to about 150 C. difference for this specific plant.

CHAIRMAN ARMIJO: And you think that would

be similar for other plants?

MR. YUEH: Yes.

CHAIRMAN ARMIJO: But it would definitely be lower, but you don't have numbers.

MR. YUEH: Yeah, I do not have the same numbers for the other plants.

CHAIRMAN ARMIJO: Okay.

MEMBER POWERS: Well, is your contention -- I take it your contention is they're two bounding. On the other hand, there is the advantage of simplicity. Write a rule that goes power level by power level, configuration by configuration; a very lengthy rule I would think.

MR. YUEH: Yeah. You know, from the industry's point of view, you know, we're looking at reduction of allowable ductility from 17 percent to potentially five percent, and you know, with allowable ECR tied to different peak cladding temperatures. That's extra sprays that can be, you know, used without compromising safety.

You know, if the entire core, if the 1,200 Celsius criteria works for the core design, people can still choose to do that.

CHAIRMAN ARMIJO: Well, your argument is that there's a compensating effect to the high

hydrogen pickup of high burn-up fuel rods and other things, and that compensating effect is that they can't get very hot. It's hot up to 1,200 C. So maybe those aren't your limiting rods in a LOCA. It could be second cycle fuel or first cycle fuel, which can really get hot even though it doesn't have as much hydrogen.

So somewhere in there that has got to be sorted out, and you have to have a real clear position with numbers to back it up for us to really appreciate what you're saying. I see conceptually what you're saying, but I don't see numbers that support that.

MR. RODACK: Well, clearly from this graph, the graph on the left indicates the third burn fuel, what we call high burn-up fuel, is at a significantly lower power level, and that fuel really by keeping the fresh fuel and the fuel at burn-ups less than 40,000 megawatt days per ton, if I can read that correctly. Keeping that fuel limited to the 2,200 degree temperature limit assures that the third burn fuel is going to be at a significantly lower temperature.

And when we're talking about the effects of high burn-up on clad performance, the high burn-up fuel just isn't going to get to be a problem. There

may be an issue in the range 25,000 to 40,000, and that's probably where we'll need to focus with this new rule, but high burn-up fuel just isn't an issue.

CHAIRMAN ARMIJO: As long as the new rule would permit you to take credit for the fact that it's limited by temperature. If the new rule would say, no, it's everything has to be evaluated as if it went to 1,200 Centigrade, then that would be a big problem.

MR. RODACK: Well, there's excess conservatism, yeah, requiring that.

MR. YUEH: This shows the ANL test database. The dashed line is the same one as in RIL-0801. Our concern is at the elevated hydrogen levels the line extrapolates to zero. You know, the reason for that is samples reach five percent ECR before reach 12,000, and we do not believe that the line realistically physically should be at zero at 800 ppm.

And we are going to talk about it a little bit later, have plans trying to produce some samples that reach in 1,200 Celsius before reaching the five percent ECR.

There's a lot of issues with two-sided oxidation, and we don't believe there's sufficient data to support full two-sided oxidation away from ballooned region. We think, you know, early on in the

day we talk about an ID oxide as an oxygen sources, and the RIL-0801 referenced Halden IFA-650.5 test as a justification for double-sided oxidation requirement throughout the rod.

Basically the test results showed the presence of similar inner and outer surface oxygen stabilized alpha phase away from the balloon region. The issues are the layer is only around 21 micrometer on both sides. At five micron pre-LOCA ID oxide has enough oxygen to generate that kind of oxygen stabilized alpha. You know, the Halden test, therefore, is not sufficient evidence that there's limited oxygen source at the cladding surface.

Now, the effect of ID oxide is going to contribute to the oxygen in the prior beta phase. The difference being inside and outside is there's no longer the same oxygen level gradient across because most of it is dissolved. The question is does it still have the same impact as the outside. And we don't have the answer to that.

And we are thinking of conducting tests in this year to evaluate what the impact is. And once again, the Limerick integral test also does not support unlimited oxygen source on the inside of the filter away from the balloon region.

CHAIRMAN ARMIJO: Is somebody going to talk about that test? These are just words, but is there any numbers that you can provide, burn-up of the fuel rod, the kind of test that went to the ID alpha layer thickness, if any, compared to the OD?

And is this a phenomenon, again, that's just limited to Zircaloy 2 of Limerick fuel as opposed to, you know, staff showed us lots of pictures of very thick alpha layers, ID and OD, and that's pretty persuasive. So what's different about Limerick and why is that more general than what the staff showed?

MR. YUEH: The very thick oxygen stabilized alpha phase we saw earlier from a lab test where, you know, we had gone through a LOCA site with high temperature, 1,200 Celsius. The Halden test, I think, only reached 1,050 Celsius. I have a slide on that a little bit later. So the oxygen diffusion is slow. So that's why you see the thin -- well, you still see the oxygen state itself there. It's a thin layer because there's limited time for that layer to build up and there's a limited oxygen source inside the segment.

CHAIRMAN ARMIJO: Does the Limerick integral test go to 1,200?

MR. YUEH: I think so.

CHAIRMAN ARMIJO: Is that high enough and long enough to be a severe test?

MR. YUEH: I think it was 57 burn-up --

MR. LIN: Yeah.

MR. YUEH: -- Celsius for several hundred.

MR. LIN: The rate is 57. The average is about 52, something like that, and the bonded layer, I believe what we're seeing, there were APACHE bonded layer, but it's not uniform. It's not everywhere. The post integral test according to the NUREG, there was just one area that's identified as potentially showing some oxygen stabilized alpha layer, but our picture, as Mike will tell you, is not very clear with region nodes.

But the majority of the cladding that they sort they did not see any outside layer on the ID. They did not see any significant oxygen stabilized layer.

CHAIRMAN ARMIJO: Yeah, but what's unique about that particular cladding, and that's what I'm trying to get at, is that has a line coming down the ID compared to the rest, but it's not general. It's not a standard Zircaloy-4 or --

MR. LIN: I think all we can say is we don't really know because that's the only test that's

been conducted. So it is general and remains to be seen. You have to see the other one.

CHAIRMAN ARMIJO: Okay.

MR. YUEH: It's controlled by oxygen diffusion. So I think the metrics materials, you know, if it's Zirc-2, our line of material, it's still zirconium. I don't think the diffusion coefficient is going to change very much.

But we are going to run a test on a monoclad with an ID oxide and take it through a LOCA cycle and see the evolution of the oxygen stabilized alpha and oxygen profile into the metal.

CHAIRMAN ARMIJO: Okay.

MR. YUEH: This is a plot of various tests conducted on ANL showing the embrittlement, F cap (phonetic) power ECR versus the hydrogen level. The black symbols are non-irradiated hydrogen pre-charge samples, and the red are irradiated samples. This shows the critical ductile-to-brittle transition ECR.

And you know, the point that I want to make here is that between the irradiated and hydrogen pre-charge, they fit pretty well on a single trail line, and this would support, you know, that offering the prehydriding can be a good sample for irradiation.

And also, you know, the samples came from

different manufacturers and different alloys. They all fit on the same trail line pretty much.

CHAIRMAN ARMIJO: Except those initial data points are funny..

MR. YUEH: Yeah, on the left-hand side. Some of the earlier vintage --

MEMBER SHACK: What you touch them they scatter.

CHAIRMAN ARMIJO: That's what I'm saying.

MEMBER SHACK: You like the polynomial fit better than the straight line, too, don't you?

MR. YUEH: That's right. We don't think it goes to zero, and we are going to make an effort trying to bring some samples that actually experience that.

A summary of the technical concerns with RIL-0801, the test conducted ANL verified previous tests and provided new insights into the embrittlement phenomenon, but many questions still are unanswered and will require additional data to resolve. We still have the two-sided oxidation, inner surface oxygen uptake and supply question. You know, we're still waiting for the integral LOCA test hopefully can shed some light on this, and we also are conducting our own tests.

Breakaway oxidation, which my colleague here is going to talk about later, I think, you know, we need to determine if impurity effects really exist. That's one of the things out there that we don't really know what is causing the breakaway oxidation in E110, and we are targeting to work with ANL, maybe trying to do further investigation on this.

The industry is also planning to conduct post quench ductility testing in the lower temperature range, 1,000 to 1,150 Celsius just to develop data, post quench utility data. ANL test has only post quench ductility data at 135 Celsius for 12 engine oxidation. So we want to try to get the data at the low oxidation temperatures.

There is no data on Zircaloy-2 post quench ductility, both irradiated and non-irradiated conditions.

CHAIRMAN ARMIJO: Now, do you propose to generate that data or do you think the staff should generate that?

MR. YUEH: We haven't decided whether we're going to generate the data for Zircaloy-2. It's possible. Irradiated, you know, at this point is probably not likely.

MEMBER POWERS: Suppose those who

understood everything that there is to know about E100 and concluded that whatever sensitivity E110 has is extraneous to every other known form of cladding. Would that preclude concerns over breakaway oxidation?

MR. YUEH: Well, we're hoping if we can develop an understanding why we have breakaway oxidation as E110, then you know, we support the industry position on, you know, methods to control. So that would sort of obviously preclude PRA testing.

So right now we do not know what is causing breakaway oxidation.

MEMBER POWERS: And how would that change if you understood E110?

MR. YUEH: Well, if we know what is causing it, then in the manufacturing process we can try to monitor or detect whatever the factor is at the start of the manufacturing.

MEMBER POWERS: Yeah, but that presumes that the only way to trigger breakaway oxidation prematurely is whatever occurred in E110. How would you assure that?

MR. YUEH: We cannot --

MEMBER POWERS: The contention made when the staff spoke was that they wanted to make sure that some inadvertent and presumably unrecognized change in

the fuel cladding fabrication process led to a sensitivity to breakaway oxidation. Okay? At no time did they say, "We want a periodic testing brochure that whatever caused breakaway oxidation in E110 doesn't arise."

Something unknown. I'm trying to understand how understanding E110 gets me away from that seemingly legitimate concern. Have I characterized what you've said properly?

MR. CLIFFORD: Yes.

MR. YUEH: Yes. Maybe I can deal with that a little bit later on during my presentation or can talk about it right now. The way it is that for us to understand what would drive into this unknown regime, in essence I would have to go in and play around and mess out my process in order to generate that condition, but I have right now an E110 that's already showing this condition, and that's a condition I don't want to get to.

MEMBER POWERS: I can't understand why you'd be interested in E110.

CHAIRMAN ARMIJO: I don't know either.

MEMBER POWERS: But what I don't see is how that addresses the question raised by the staff about unknown, unanticipated changes in the

manufacturing process leading to a sensitivity to breakaway oxidation. I mean, I think the staff operates from the belief that, gee, a very subtle change in E110 produced a big sensitivity.

I'll bet there are other subtleties that I don't even recognize that could also produce that sensitivity, and I just don't want it to happen.

MR. YUEH: E110, I think it's not a subtle change from material extractions. It's fundamentally different, and you know, the test data gathered so far, you have materials fabricated from different vendors using different equipment and processed differently, and the result come out very similar.

CHAIRMAN ARMIJO: For breakaway as well as the others. That's your point.

MR. YUEH: Yeah, yeah.

CHAIRMAN ARMIJO: You have huge variability among these different alloys, except for E110, and they have acceptable --

MEMBER POWERS: It appears that what they're saying is that the only way to get a sensitivity to breakaway oxidation is to do whatever they did in E110. I find that remarkable, but I'm willing to listen.

CHAIRMAN ARMIJO: The real issue, I think,

is is E110 really a hypersensitive material, and there are such things, and the question --

MEMBER POWERS: Quite frankly, I don't give a damn about E110.

CHAIRMAN ARMIJO: I don't either. If it's driving the work and regulations on materials that aren't likely E110, aren't hypersensitive to this phenomenon, then we should just put that aside and demonstrate that the manufacturing process over a wide range within each supplier --

MEMBER POWERS: I think that's the question.

CHAIRMAN ARMIJO: -- is capable of providing consistent performance.

MEMBER POWERS: I think that's the question, Sam. What is a wide range? How much variation can you tolerate?

And especially when they stand up and tell me that, gee, this breakaway is very sensitive to surface, three times surface composition, the phase of the moon, the particular inclination of the Saturn rings, whatever it is, and they just don't want it to happen.

CHAIRMAN ARMIJO: I think what they should show you, talk to you about is how they qualified

their manufacturing process for cladding and how they, you know, evaluate a normal process and how robust their process is, and that kind of philosophy could be applied to breakaway oxidation testing to show that there's a lot of variability both in chemistry and surface preparation and heat treatment that will still provide acceptable breakaway oxidation.

If they can do that, you've qualified the process. If you go beyond that you have to --

MEMBER POWERS: You can come in here and tell me everything about any process. I don't care how simple it is. I'll bet I can ask more questions than you can answer.

CHAIRMAN ARMIJO: I know that.

MEMBER POWERS: Okay. The staff has found a way to cut through all of that, which is performance based. Did it work or didn't it work? And I don't get to ask my incredible litany of questions. I don't see anything wrong with that offhand.

CHAIRMAN ARMIJO: Well, it depends on whether it's a practical thing to do and whether it's --

MEMBER POWERS: Well, I presume the test is fairly easy to do.

MEMBER SHACK: We seem to see a variation

for ZIRLO that's as simple as which solvent you use to wipe the thing off.

CHAIRMAN ARMIJO: But that's been known for years.

MEMBER SHACK: And you know, so if your process ever came down to the fact that you used a different -- an OSHA requirement came down that said get rid of this solvent and use that solvent, you know, would it trigger a problem?

Well, a performance test would seem a reasonable thing to do.

MR. RODACK: At the time we made the change, we would need to do that, yeah.

MEMBER SHACK: Okay. So your question about periodic then is you would prefer it to be triggered by the process change rather than a time or a rod change.

MR. RODACK: Yeah.

MEMBER SHACK: Okay.

MR. YUEH: That's in essence what we're proposing.

MEMBER SHACK: Okay. There's where you're at. Well, again, you know, the problem with that is what qualifies as a process change.

MEMBER RAY: Well, I mean, I think the

question was raised earlier as to whether you recognize when change has occurred. Jack was talking about changes in the equipment --

MEMBER POWERS: That was the true durations.

MEMBER RAY: -- would result in something be affected. It seems like the discussion here is between do we need to find out what the phenomena causes are so we can make sure we don't infringe on them or is it sufficient just to establish that we're okay with the process that we think we're using and not have to answer.

I mean that even goes to this E110 question. Do we know why it does what it does?

CHAIRMAN ARMIJO: It would be nice to know because if you found the magic bullet then you would avoid it.

MEMBER SHACK: I mean the difference seems to me even smaller. They're willing to tolerate the notion of doing the test when they change the process. The question is do you have a periodic back-up of any sort, a backstop. So it's a smaller difference than one might expect.

CHAIRMAN ARMIJO: Okay. I think we should --

MEMBER BROWN: Is E110 the only material that has had the breakaway oxidation phenomenon?

MEMBER POWERS: Everything is breakaway oxidation.

CHAIRMAN ARMIJO: They all do it, but this one is particularly sensitive.

MEMBER BROWN: I mean just being uninitiated I was just listening to the interchange here and trying to figure out which that as.

MEMBER SHACK: Now, apparently ZIRLO wiped with the wrong solvent will exhibit --

CHAIRMAN ARMIJO: If you wipe anything with a fluoride --

MEMBER SHACK: Right. Well, this wasn't a fluoride though. I mean, it would seem like a fairly innocuous solvent, but it seemed to make a difference.

MEMBER POWERS: There are no innocuous solvents.

MR. YUEH: Yeah, test variations, even if you --

MEMBER SHACK: Yes, that's another possibility, right.

MR. YUEH: You get the same variations.

CHAIRMAN ARMIJO: Okay.

MR. YUEH: This last slide on the industry

position, this is on current approach in rulemaking.

Maintaining post quench ductility has been the historical approach to insure fuel rod integrity. You know, opinion is that this approach is not adequate to bound the ballooned area and is unnecessarily conservative the way that it's implemented.

We have questions. Will the industry be asked to license a second requirement for the ballooned area in the future?

The cost estimates to implement changes to methodology for the post quench ductility change is asking to be in the order of several hundred million dollars.

Other approaches, such as quench survivability used by JAEA are better suited at demonstrating that the entire fuel rod integrity, you know, is assured.

If the rulemaking is to proceed based on post quench ductility, it really should be performance based and allow the industry flexibility in demonstrating compliance, which I think Paul this morning agreed.

CHAIRMAN ARMIJO: Any questions, comments?

MEMBER POWERS: Suppose that the advanced

notice of public rulemaking asked the question of the industry: you can do this new rule if you go to a new clad or you can stay with your old clad and stay with the old rule. How would that affect compliance cost?

MR. YUEH: This is a question of licensing.

MR. DUNN: Now, one of the compliance costs is the potential need to analyze the complete burn-up spectrum for the plant, and a fair number of the current evaluation models operate with justification on just the first cycle of operation. So it is a matter of redoing that for all of the plants and what have you.

That probably wouldn't be necessary with an introduction of a new alloy. It might. It will depend upon the characteristics of the new alloy or the new design. So that would be one difference in the importation.

But you are right. With a new alloy, you will have to do a substantial amount of LOCA testing, and I would think it very unlikely we would not have to have qualified and approved evaluation of the new alloy in LOCA tests, LOCA evaluations.

MEMBER POWERS: I hence raised this issue of cost compliance. I've looked far enough ahead in

the viewgraphs to know what the argument is, and staff is coming forward with an ANPR and they're struggling with questions to ask. Should not one of the questions be can we make this rule one of the voluntary rules which says don't change anything? You can live with the old rule if you want to. If you do change something, then you have to go to this new rule.

I mean, is that a question that you'd want to contemplate in this ANPR?

MR. CLIFFORD: I guess my initial reaction would be that it's almost a disincentive to develop a new cladding alloy because if they go a new alloy now they have to meet all--

MEMBER POWERS: Oh, yeah.

MR. CLIFFORD: -- requirements and that's the opposite of where you would want to go.

MEMBER POWERS: Yeah, but their disincentive is up there in their millions of dollars of compliance.

CHAIRMAN ARMIJO: It may not be true, Paul, you know. If people can figure out how to make very low hydrogen pickup cladding, that could be a huge commercial incentive for a number of reasons.

MR. CLIFFORD: I agree, but applying the

same criteria to all alloys --

CHAIRMAN ARMIJO: To discourage willy-nilly changes, that's what it would do for sure.

MR. CLIFFORD: But applying the same hydrogen based criteria to all alloys would weed out the bad alloys. It would give incentive to go to a better alloy.

CHAIRMAN ARMIJO: It would focus your R&D to get low hydrogen pickup.

MR. CLIFFORD: But if you said, okay, if you stay with Zirc-4 you don't have to do anything, then a lot of licensees might say, "Okay. I'm not going to do anything."

MEMBER POWERS: Yeah. I mean, and the plants are safe enough as they are right now. We haven't lost anything.

MR. CLIFFORD: There aren't a whole lot of plants operating --

MEMBER POWERS: And you get rid of this question of how much of the compliance costs.

CHAIRMAN ARMIJO: As we talked, I think Tom made the point, you know, the plants have converted. They're using M5. They're using ZIRLO. They're using -- well, Zirc-2 hasn't changed all that much. So for those particular alloys, something like

old alloys, old rule, and if you want new alloys or significant changes in your alloys, a new rule is what you've got to follow. It's going to be tough. It's not going to be easy.

With the old alloys at least you've got not LOCA experience, but you've got a lot of experience with.

MEMBER ABDEL-KHALIK: Back to the issue of periodic testing, fuel failures do occur, and oftentimes or sometimes these failures are attributed to manufacturing problems. If that is the case, doesn't that imply that there is enough variability in current manufacturing processes so that periodic testing must be done or would be necessary?

MR. YUEH: Fuel failure due to manufacturing of the cladding, that has not been an issue. At least I can only talk about the BWR side of the business. That has not been an issue for a long number of years.

MEMBER ABDEL-KHALIK: Maybe on the PWR side. There are no fuel failures attributed to manufacturing issues?

MR. RODACK: To the best of my knowledge I'm not aware of any at least in the past five years that have been addressed. I'm more familiar with the

more recent experience, and I'm not aware of any cladding issues.

There have been issues with welding the end caps to the clad.

CHAIRMAN ARMIJO: Quality.

MR. RODACK: There have been issues with what's called end cap piping where there's a capillary effect of an end cap or have a passive whereby a coolant can gain entry into the rod. Most of the manufacturing attributed failures have to do with hydrogen contamination of the pellets, you know, or somehow getting extra hydrogen into the rod.

CHAIRMAN ARMIJO: My experience has been I've never seen any fuel failures caused by cladding corrosion unless there was a heavy CRUD deposit that blocked heat transfer. So cladding, it can look variable. You know, we used to have bid variability in cladding corrosion behavior with nominally the same manufacturing process, but those days are far behind, and so cladding processing is pretty well controlled, and it seems to me that if you were going to qualify a new outlet, you'd nail down your process and you'd study its susceptibility to breakaway corrosion by just going off normal to the extent that's feasible and demonstrate that you still had a good material

that would meet the requirements, and that would be one of the requirements of a new alloy qualification.

MR. YUEH: If I may just comment on that, I think what the industry is proposing is that we let the vendor quality assurance program do its work. The 50.46 was suggesting does not need to go into details of mandating periodic testing and so on. The vendor qualification assurance program is already doing that. As you mentioned, the cladding processing process, we have various controls in place, and that may include or certainly includes periodic testing of certain features, but that's all under the umbrella of the qualification assurance program.

CHAIRMAN ARMIJO: Okay. Well, that's something that you guys and the staff --

MR. YUEH: I have a comment on fuel failures. You know, for various reasons I think the operations of the process, you know, if the process is bottled without much deviations owning to the procedures, you wouldn't necessarily see failures that are attributed to manufacturing defects.

If it's an operation, process monitoring is not going to necessarily catch it.

MEMBER SHACK: Just coming back to this cost estimate of several hundred million dollars, now,

that's a second level bullet in your viewgraph, but I would assume that would, in fact, apply to, you know, any time. If you changed the rule, even to the rule that you guys want, you're going to have the same cost of compliance things. You're going to be changing codes, you know. If you're going to be doing this thing on a pin-by-pin basis practically where a different criteria for each pin, you're certainly going to have different evaluation models than you have now.

So I would assume that we're talking the same cost estimate for any change in the rule unless we make it a voluntary change; is that correct?

It's just that you figure you get more for your money out of your version.

MR. RODACK: I think that's essentially correct. I would believe you get more for your money out of that, but I mean, yeah, the huge expense is in redoing the analyses of record for each of the operating plants and resubmitting them.

MEMBER SHACK: That's going to be the same for any change.

MR. RODACK: Now, this voluntary aspect, another huge impact of implementing the rule is timing. If you implement it and it's effective, it's

going to drain critical -- not every engineer can go and do a LOCA analysis. Not every NRC reviewer can review an LOCA analysis. It's going to require a phased approach to do the analysis, get it submitted and reviewed.

If you were to apply the rule on a voluntary basis, that would sort of implicitly address the timing issue. So you want to be faced with the same challenge.

MR. DUNN: Yeah, no one would take up on it.

MR. RODACK: Unless you had a really good ally and you get a lot more power out of it.

MR. DUNN: There are ways to make the job a little bit easier. One of them is the temperature difference. You can construct a normalization curve, for example, that justifies that you could not approach the criteria for the third burn or the second burn fuel, keep your evaluation model as it is, and you wouldn't have to do anything then with the NRC other than justify that, and then you would have to say that applies to these first plants.

So I would say there's really a fair amount of variation in the --

MEMBER SHACK: The rule could affect you.

MR. DUNN: -- thing. Part of it comes down into how the plant is operated and how it's monitored. If you're monitoring just for cycle and assuming the rest of it is shown to be proper because of calculations on the fuel, you have one set of rules for that computer that's in the plant, and a lot of us are doing that today.

Most of my plants are actually monitoring each one of the burn-up steps because we took a little bit of a different approach 25, 30 years ago than the rest of industry to the LOCA control. I should say half of my plants are like that.

So there's variation around there. So it will change.

MEMBER SHACK: Okay, but it doesn't really belong on the post quench ductility versus another measure. I mean you can have a rule that maintains post quench ductility as the ultimate criteria and still meet your -- by having the temperature variability.

MR. DUNN: Well, that was just one example.

MEMBER SHACK: Yeah.

MR. DUNN: We have to see exactly what's happening.

MEMBER SHACK: You keep hammering on post quench ductility, and I guess you can keep going on it, right?

CHAIRMAN ARMIJO: Now, there's a comment here. You guys are okay with it, Rob?

MR. MONTGOMERY: Yeah. I'd just like to make one comment, Dr. Shack, to your question. It was brought up by Dr. Meyer earlier that we did discuss the difference between, say, going to a post quench ductility versus a strength based approach, and it's very possible that going to a strength based approach, it may make it much less burn-up sensitive because the data shows that strength is less sensitive to the hydrogen content.

So there are other alternatives out there that could make the development of the criteria more difficult, but may demonstrate compliance maybe easier. So I just wanted to make that comment.

CHAIRMAN ARMIJO: Let's move on to --

MEMBER POWERS: Well, I think that's an interesting question to consider, is is there a change. When one looks at the proposed rulemaking, is there a way to ease the cost of compliance without changing the requirements, or is there a way of casting the requirements that makes compliance and

consequently -- I mean it's not just the cost of compliance. It's the costs of reviewing the compliance that have to be considered. I mean, is that a question to pose when you're preparing an advanced notice of rulemaking?

It's an interesting thought. Thank you.

MR. YUEH: Moving on to industry LOCA oxidation test plans, we have two types of test plans. One is oxidation at lower temperatures, evaluate more hydrogen pre-charging.

And the second test for the plant to conduct is ID oxidation and potential reaction with fuel pellets with any rate end state.

The motivation for LOCA oxidation test is preliminary annual data showed the ductility at the same ECR with different oxidation temperatures very much different, and this is showing this table, which shows oxidation temperatures, 1,000, 1,100 and 1,200, comparable ECR and measured weight gains. Yet the room temperature of the strain is very different, and you can see that at 1,100, it's still very much ductile even at room temperature compared to the 1,200 oxidation temperature.

CHAIRMAN ARMIJO: And these are ANL data?

MR. YUEH: This is ANL data.

And our point is since high burn-up fuel rods with hydrogen cannot reach 1,200 Celsius, we proposed earlier at the earlier workshop for peak cladding temperature tied to fuel, peak cladding temperature.

And we will also make an attempt to demonstrate post quench ductility is not reduced to zero at elevated hydrogen levels at 1,200 Celsius. The difficulty was the five percent ECR is reached before the sample reaches 1,200 Celsius.

The test equipment that we have in mind is different. We're hopeful that we can reach 1,200 Celsius before the five percent ECR.

I think you talked a little bit earlier about the different labs with the different outcomes, the different heat-up and cooling rates and quench temperatures. I'm just going to skip this since we're short on time.

LOCA oxidation test scores are to develop a mechanistic understanding of embrittlement mechanisms. All plans are to evaluate an entire range of relevant oxidation temperatures from 800 to 1,200 Celsius, but we will focus on 1,100 and 1,200 Celsius; hydrogen levels from as-built to 800 ppm.

We would fully characterize the sample in

addition to the ring compression test. We would try on select samples to measure oxygen profile, you know, re-verify the hydrogen level, measure the micro hardness, prior beta, oxide/oxygen stabilized alpha phase thickness.

We would generate sufficient data to support an alternative post quench ductility criteria at lower temperatures, and once again, to resolve if the ductility is reduced to zero at 1,200 Celsius at elevated hydrogen levels

CHAIRMAN ARMIJO: By zero you mean the one percent strain or the two percent --

CHAIRMAN ARMIJO: The one percent essentially goes to one percent plastic.

CHAIRMAN ARMIJO: Okay. So you're saying it may never go?

MR. YUEH: It may stay at five percent.

MEMBER ABDEL-KHALIK: Back to the previous slide, no, the previous one. This data, albeit limited, can this data be used to support the argument that one can exclude free accident oxidation from the 17 percent limit?

MR. YUEH: The test data does not show the dependence of the pre accident oxidation. I think there's a minimum requirement for prior beta

thickness.

MEMBER ABDEL-KHALIK: I'm looking at this limited data in and of itself. Oxidation that's accumulated at relatively low temperature has limited impact on ductility.

MR. YUEH: Oh, yeah, yeah.

MEMBER ABDEL-KHALIK: Can that be an argument in support of excluding?

MR. MEYER: Maybe I can answer this question. The information notice that introduced the idea of making a corrosion subtraction from 17 percent has been replaced by a correlation that depends directly on hydrogen.

Now, hear the way it went. The hydrogen comes from the corrosion process. So there has got to be corrosion in order for there to be hydrogen. So previously we were trying to key off of the corrosion thickness because it was easy to measure, but then we find that the percentage of hydrogen that's absorbed isn't constant from one material to another.

So it's better to go directly to hydrogen and simply eliminate the corrosion subtraction. So you do not use the corrosion thickness at all in the method that's being proposed.

CHAIRMAN ARMIJO: In these particular

tests, what was the hydrogen content of these samples?

MR. YUEH: I believe these were as we see it.

CHAIRMAN ARMIJO: Well, these had essentially no hydrogen.

MR. YUEH: Yes.

CHAIRMAN ARMIJO: And would you expect the same results if you had 200, 400, or 600 ppm, the same relative performance?

MR. YUEH: I believe we will get something similar, but not necessarily in the same proportion in terms of improvement in ductility because the ductility is controlled by oxygen diffusion, but our test preliminary result, you know, support other observations that hydrogen enhances oxygen diffusion. So at this point we're not sure whether the proportion is going to be the same, but I think they will be different.

CHAIRMAN ARMIJO: So these are tests that are committed by industry, and you're going to be doing these in the near future?

MR. YUEH: Yes.

CHAIRMAN ARMIJO: Okay.

MR. YUEH: Our test approach is divided into basically three different sections: evaluate

oxygen diffusion coefficients. This will be done testing different temperatures with different hydrogen levels at different ECRs; evaluating the cooling effect. We will try to cool the sample at different temperatures and different quench temperatures.

And the third phase, just evaluate the condition for critical embrittlement whether it's a single oxygen value or a distribution effect. You know, the CEA data and ANL data put together suggest there's a difference, and the micro structure may make a difference in the post quench ductility.

These tests, right now it's scheduled to be completed by the end of 2009, this year.

So those are to generate efficient data to determine if it's feasible to develop an embrittlement model. If a model is successfully developed that can be correlated with observations, then you would allow us to integrate the entire temperature profile and the heating and cooling effect, the differences would be eliminated, and it would also allow the industry to take credit for the low temperatures.

Two potential parts raised for us: allowable ECR depending on both hydrogen concentration and peak cladding temperature, which Paul discussed earlier. One approach is if the model is successfully

developed, then the criteria can be just maintain ductility based on predictions.

If not, a workable model cannot be developed, then we would develop a family of curves tied to different cladding temperatures as shown here.

Moving on to ID oxidation, RIL-0801 justification for two-sided oxidation is quoted in the Halden IFA-650.5 test. The peak test temperature reached was 1,050 Celsius. The exposure was relatively short, and the temperatures were relatively low. That's why you still see the oxygen stabilized alpha there, why the same; cannot be said for the Limerick test. It was a higher temperature, probably longer and the oxygen contained in the oxygen stabilized alpha had the opportunity to diffuse away from the edge.

So the other point is the in-service oxide, a few microns of it can generate the oxygen stabilized alpha phase as seen in the Halden staff. Our challenge is to characterize the sample. If we're able to replicate similar conditions in the sample, we would try to characterize the sample, measure the oxygen profile across the sample to see if it's the same as outside.

The other portion of the ID oxidation is

to verify some of the Hoffmann's earlier work on pellet/clad reaction. In the earlier work it was conducted between either this no contact pressure or ten to 100 bars, and the conclusion from that test was if there's no contact, there's no oxygen transfer between the pellet and the clad.

And also, a thin oxide can prevent, you know, direct interaction below 1,100 Celsius, and we want to conduct further tests at around 1,100 Celsius just to characterize the behavior.

CHAIRMAN ARMIJO: Now, the industry has been collecting metallographic data on fuel for decades, and you have available microstructural information on how much fuel clad bonding there is as a function of burn-up, clad designs, and everything else.

Is EPRI going to accumulate that data to really put this thing in perspective or is there anything like that planned? Because all we hear about is that there's a lot of fuel bonded to the cladding and others saying, well, maybe not too much. You know, what's the facts?

MR. YUEH: Yeah, we have attempted to compile a database as you suggest, and we do have limited data because a lot of the PIEs and other work

is not necessarily zoned into these areas. So we do have a limited database.

CHAIRMAN ARMIJO: Is that available to the staff and the Committee?

MR. YUEH: I do not believe so.

CHAIRMAN ARMIJO: Well, it would be a good idea if you could because, you know, one of the things that you will see is that fuel is actually bonded to the cladding under some conditions, particularly at high burn-up, and it's not bonded by just O_2 stuck to CrO_2. It's intermediate phase, cesium rich, intermediate phase. It is a bonding agent, and you can literally see fuel particles pulled away from the fuel pellet. So it's really there, but it's sporadic, and I don't think there's been a systematic study of that, but that's something if you have that data you should --

MR. YUEH: But the database is limited, and for example, I have a very small picture. This is, I think, what you're looking for. It's kind of small, but this shows an ID oxide plus the fueling.

CHAIRMAN ARMIJO: If you go off the presentation you can blow that up.

MR. YUEH: Yeah, I can try to enlarge it.

CHAIRMAN ARMIJO: Okay. That's the

bonding phase there.

MR. YUEH: Yeah, yeah.

CHAIRMAN ARMIJO: If you had really good metallography, you'll see that's a cesium rich, cesium combing (phonetic) compound bonded to the UO_2.

MR. YUEH: Yeah. We tried to compile database. As I said, in a lot of hot sales, this is not what they're looking for, and we don't always find this kind of data.

CHAIRMAN ARMIJO: Okay.

MR. YUEH: But you know, we should have a question whether after the oxide is consumed, you know, if this oxide is consumed, will the fuel stay out here to the clad? It may not.

CHAIRMAN ARMIJO: Good question.

MR. YUEH: So there's a lot of question and answer. Unfortunately, we cannot replicate our reactor.

So for ID oxidation test scores to determine if oxygen containing thin film can generate an oxygen stabilized alpha layer similar to the Halden test, and if successful, we will evaluate the impact from such an oxide.

The other goal is to determine if pellet/clad reaction takes place at temperatures

around 1,100 Celsius, and if so, to what extent can it be an oxygen source with any rated pellet, okay, with or without pre-oxidation and with and without contact pressure. In a LOCA scenario there will be no contact pressure.

CHAIRMAN ARMIJO: Except what's already bonded.

MR. YUEH: Yeah, assuming that it still sticks to it.

CHAIRMAN ARMIJO: Yeah. There's lots of pictures will little bits of fuel stuck to the cladding.

MR. YUEH: Yeah, and with this test hopefully we can answer whether the fuel itself can be an oxygen source at the lower temperatures because earlier study shows it's probably not at the lower temperatures.

At higher temperatures it can be an oxygen source.

To summarize test plans, where conducted ANL has advanced our understanding of high temperature oxidation, but significant relevant gaps still remain, and we talked about where these gaps are.

The industry is conducting a series of complementary LOCA oxidation tests to fill some of the

gaps. Both of these test are schedule to be completed the end of this year.

During the test, our scope may change, and we may add things to it. You know, if that's the case, it may be, you know, extended.

Our goal is to study the effect of oxidation temperatures on post quench ductility over entire range of relevant hydrogen concentrations which support an alternative criteria not tied to 1,200 Celsius, and hopefully generate data at 1,200 C. and elevated hydrogen levels at approximately five percent ECR.

Develop a mechanistic understanding of the embrittlement phenomenon, and develop a better understanding of ID oxidation, the in-service oxide effect, and potential pellet/clad reaction at around 1,100 Celsius.

And we are also planning to work with ANL to investigate breakaway oxidation causes specifically linked to the E110.

That's it for me.

CHAIRMAN ARMIJO: Questions from the Committee?

MEMBER POWERS: The staff in their presentation said that they felt it essential to have

a feasible, doable, whatever, test methodology. Now, recognizing that you may not like the existence of the test, are you planning to help staff in the development of that methodology, which apparently they want to have done by the end of January?

MR. YUEH: We will like to participate in the development of the test methodology.

MEMBER POWERS: And what is your general thinking about their current methodology?

MR. YUEH: We think the radiant heat is difficult to control. Variations, and we would prefer a simpler heating method like the one used by CEA. The test fixture we're working on now, the LOCA oxidation temperature we're working on now is performance like that, except our samples will not be cooled just by turning off the power. Our plan is to remove the sample in a quartz tube away from the mass and let it cool, and we should achieve similar cooling rate as ANL.

CHAIRMAN ARMIJO: Yeah, to the extent possible, since you're going to be generating data relatively near term, to the extent possible, I urge you to do as much similarity in your test as the ANL test so that we aren't later confounded. Well, you got this result because he tested this way.

You know, there ought to be some things that are --

MEMBER POWERS: Is that what you want to do, Sam? It seems to me that you'd go in the opposite direction. You'd say, "Hey, do things just as differently as you possibly can," because we get the same result then that you --

CHAIRMAN ARMIJO: If you got the same result, but if you get different results, then some people are saying, "Oh, gee, they got -- with that goofy way they tested, no wonder everything passed." You know, you've got to do it a legitimate effort to get at the truth, and the question is ANL has done an awful lot of work, and unless you see some real flaws in it, I would urge you to kind of do it the same way so that you minimize the differences that could cause confusion.

MR. YUEH: Well, it is our goal to benchmark, you know, the new test fixture and compare to annotate.

MEMBER POWERS: I think that's the critical thing, is to benchmark maybe not just of one, but at two or three different points, but then I think there's advantages.

CHAIRMAN ARMIJO: No, I agree.

MEMBER POWERS: Because, I mean, one of the questions that you have is how much of this is actually replicatable.

MR. YUEH: We're going to try to replicate similar conditions, and it is benchmark and verify. Hopefully we get a similar results.

MEMBER POWERS: Suppose you don't. Suppose you don't.

MR. DUNN: Maybe the answer to that is what has happened between a CEA program and the Argonne program, and that is that we early on, I guess, five years ago or so, AREVA facilitated the joining, so to speak, of the two experts in there to try to discovery --

MEMBER POWERS: Who's doing the CEA experiments?

MR. DUNN: It's Brachert at Sacley.

PARTICIPANT: (Speaking from an unmiked location.)

MR. DUNN: No, Jean Paul is an AREVA person that is a liaison. He's highly qualified as a metallurgist and stuff like that, but he doesn't actually conduct the experiments. The experiments are done -- well, the primary investigator is Jean Cristophe Brachet, and then following along with him,

we have work also at Granoble and one or two other facilities.DUNN: Okay. I've got to follow up on one point with you. AREVA is an international company. We have developed these same techniques or addressed -- excuse me -- the same questions in the European arena, and I am a little concerned about wanting to come up with specific test procedures and plans and recommendations of specific tests by January. I don't know that -- I think we will argue that may be we should take a cut above that for the NUREG. I don't know.

CHAIRMAN ARMIJO: Well, do the best you can. You don't have to do it. I'm just --

MR. DUNN: No, Ken spoke for the industry, and I've got some --

CHAIRMAN ARMIJO: -- downstream confusion where, you know, different test methods should be discrete.

MEMBER SHACK: Well, there's a reg. guide level of detail that you need, and then there's the detail that needs to go into the rule, and they're different.

MR. DUNN: Absolutely. I just wasn't sure where we're cutting it, and that's where we cut it, is what's going to be important to that.

CHAIRMAN ARMIJO: Okay. We're now about -- no, no, we didn't count lunch.

MEMBER POWERS: Boy, there's some serious questions about the Subcommittee.

CHAIRMAN ARMIJO: Okay. Dr. Lin, Mr. Lin.

MEMBER POWERS: I think some Subcommittee chairman training is called for here.

CHAIRMAN ARMIJO: I'm going to be removed.

MR. LIN: Good afternoon. I'm Yang-Pi Lin from Global Nuclear Fuel, Hitachi. I'm here to talk to you a little bit about the periodic testing or, more appropriately, a preferred alternative to periodic testing. I'm really talking about the qualification and control and that's with respect to breakaway oxidation behavior.

Now, given the discussion we've had so far, I'm hoping that this will be a quick presentation. Most of the points have already been made.

CHAIRMAN ARMIJO: Tell us what's already been covered and move on.

MR. LIN: So just going back a little bit to September, there was the public workshop, and I just summarize a few points from that presentation, and that's based on the NUREG/CR-6967, and the need

for periodic testing as described in RIL-0801 appears to be based on the two rationales here.

One is for post quench ductility, variability in the as-fabricated material, and that's only suggesting a manufacturing variability, and there is also the breakaway oxidation concern, and as we've been talking about today, it has been dominated by performance of the Russian alloy E110.

Back then our conclusion was that the technical basis for the justification for periodic testing was rather weak based on the data that was presented, and certainly both the data in NUREG and the wording in another NUREG -- that's the NUREG containing a lot of the Russian work, and I emphasize "wording" because early on in September there was certainly confusion about what the result here meant, but I think a lot of it has to do with how they calculate or they ascribe an ECR. They do it based on measured weight gain as opposed to a calculated value.

Certainly those reports do not lead you at face value to what I would call a trace element effect in the bulk. We'll get into a little bit more of that a little bit later, and we're certainly wanting to work with ANL to get to the bottom of that, and in talking with Mike I know that there are some more data

that's ANO that's to be published, and that may shed some more light, but we haven't seen the data on that yet.

So back then the recommendation was to go to an alternative approach where we identified the key parameters that affect post quench ductility or break away oxidation or control those parameters through the manufacturing qualification assurance program.

So the key take-away from the September meeting was that the NRC staff was certainly amenable to consider this alternative approach, and industry was asked to clarify some of the details of this approach, and that the focus would be on breakaway oxidation and not on post quench ductility, and that has already been mentioned earlier today.

So I just want to throw up here the industry position on this alternative approach to periodic testing. We're still feeling that periodic testing is not justified by the published ANL data, and just on semantics, by periodic testing, I'm really thinking a testing to be conducted per so many rods manufactured, you know, 1,000, 10,000, whatever, that type approach. That's different than the qualification, and that's my theme, is to go to this qualification approach.

And the periodic testing for breakaway oxidation is not practically workable for the vendors, and I'll explain that in the next slide or so, and the preferred approach is one which the quality assurance program is leveraged. All few (phonetic) vendors operate under appropriate qualification assurance program for regulation.

But the key to this is that we will control the important process steps. So as an example, if we recognize that surface roughness is an issue, we will qualify and control the surface roughness, and there will be some high temperature breakaway oxidation tests done as part of that qualification process.

But a lot of the routine monitoring would be on the surface roughness, but not necessarily on the high temperature oxidation.

So in essence, the main point here is that if we proceed with revised ruling, then we certainly would prefer to see that the rule would be an enabling type of ruling where the breakaway oxidation behavior is left to the qualification and quality assurance of the vendors.

MEMBER ABDEL-KHALIK: But doesn't that imply that you really understand all of the parameters

that affect this break away oxidation so that, you know, any and all parameters that you actually measure as a part of your QA program which you plan to control include all the parameters that affect breakaway oxidation?

MR. LIN: To the extent that we can identify them, it may very well come down to that. We have this black box here that we just don't know what part of that box is the controlling one, and then you have to address it at that level. It will be some --

MEMBER ABDEL-KHALIK: But wouldn't that make your argument sort of defunct?

MR. LIN: The example I want to get to is on this trace elements. We talked about this already. So if it's okay I'll jump around a little bit.

We talked about the difference between the Western alloys produced by the Kroll process assisting from the E110, the Russian electrolytic process. The main difference is in some as yet unidentified trace elements. We don't know what it is, but the trace elements are very different.

Now, what would happen is we certainly understand NRC's concern that you don't want the Kroll process because you're not controlling the right element, and let's say it's calcium just for the sake

of argument, and we have a particular specification for calcium. But because you don't know what level it is, right now we'd say a maximum of so much, but it's some range that you don't want to be in, but because you're not controlling that, gradually you could drift into some other regime like the E110.

Now, what would we do? We don't know what it is. So the task, the quality assurance program, what I would do most likely will be that we will be testing something very early in the process, at the sponge level or at the ingot making level so that you don't inadvertently process all of the cladding all the way down to the final end and then find out you have a problem.

MEMBER ABDEL-KHALIK: I think you missed the question I was trying to raise. The point is you're checking for certain sort of performance indicators as part of your QA program, and what assurance do you have that these performance indicators have anything to do with this breakaway oxidation?

MR. LIN: I think is it not covered under the qualification process? I mean, the whole idea --

MEMBER ABDEL-KHALIK: If you don't know the mechanism, if you don't know the control

parameters, you know, you're sort of assuming.

CHAIRMAN ARMIJO: It's a corrosion problem, and you have a lot of experience, and you know what surface treatments do to normal corrosion behaviors in Zircaloys. You know what heat treatments do. You've buried them from belt polishing, pick lead, acid edge, a variety of things, and so you could test within that broad scope to show that your material is insensitive to those treatments.

You also have various heat treatments that people do, and you could test within a certain range and say, "Hey, within that broad range this material is insensitive to that phenomenon."

The Russian alloy, I think, is very, very different. The electrolytic, if it is like the old iodide process, is super pure compared to chrome material as a starting alloy. So it could be the absence of trace elements --

MR. LIN: Absolutely.

CHAIRMAN ARMIJO: -- that's the cause of the E110 problem, not the presence of impurities.

And so I think you guys are going to get bogged down in a big mess trying to understand E110 when it's not really relevant. You might want to make Zircaloy-2 with E110 starting material and find out

that it screws it up, but you know, keep it simple.

I think these materials aren't that delicate that they fall apart for some tiny, subtle change. It's pretty significant changes that have caused big changes in corrosion behavior, and I think if the industry focuses on that, you know, with the staff, I think you could probably resolve this problem.

But more direct testing, more analysis of E110 I think is just a loser.

MR. LIN: I certainly would vote for taking a look at in electrolytics there are two. I mean, I would love to see how that works.

CHAIRMAN ARMIJO: It may not be.

MR. LIN: But getting back to this issue of periodic testing versus the qualification, periodic testing would at best detect an issue, and a qualification and quality control is aimed at preventing. That's the difference.

MEMBER SHACK: Well, I can certainly understand that you want a QA process that doesn't require you to throw away a bunch of tubing at the end, the cladding at the end. That's fine. That's your risk.

The NRC's risk is that cladding. In a

direct test on that cladding, I would assume that you would go through all of these QA steps just so that when you get to the end and do that performance test it passes. I mean, it's like every performance test that you do when you measure a yield strength. There's always that possibility that your process doesn't come up with the right yield strength, but you sure as heck don't depend on the process control. You run the test to find out what the yield strength is.

You know, it's a performance based test, and all of the QA in the world only changes your odds of passing the performance test --

CHAIRMAN ARMIJO: But the issue is a regulatory --

MEMBER SHACK: But you still passed the performance test.

CHAIRMAN ARMIJO: Whether it's a regulatory requirement or a manufacturing process control, that's really the issue.

MR. LIN: That's my point. You know, it's up to the QA managers. You know, they're going to define what frequency of testing, what kind of testing would be necessary to insure the proper performance. It's not in the regulations.

MEMBER SHACK: Well, to me that's all

within your purview. The question though is whether you still need a performance test at the end of that. And your argument is no, and I'm not sure.

MR. LIN: And I think it depends. If we truly don't understand the process, then we probably have no choice. You have to do that because you're not controlling. You don't know what you're controlling, and I would agree with that, and hence the desire to try and understand to the extent possible.

MEMBER SHACK: Yeah, I mean, it does come down to the fact that whether there will be enough unknown unknowns that you have a reasonable chance of not meeting the performance criteria. To me it seems easier to do the performance test than it is to run a research program to assure myself that I understand this well enough.

But that's your call, not mine.

MR. DUNN: I was out for our last phone call. So one of the things you haven't mentioned this morning yet was the fact that you don't believe the Kurchatov program accurately identified the trace elements or lack of trace elements as part of the cause of the difference in performance between the two.

MR. LIN: And that's summarized on this chart here that I haven't really talked about, but it's a summary type of level.

MR. DUNN: Let me just say one sentence and then I'll get back to you. I think we have a feeling in industry that we're being asked to do something for which there isn't an established cause. We have no objection to doing things for which we have a recognized cause, but it's like we're picking on one thing and we don't have this idea that these trace elements are actually important, that the testing done at Kurchatov was flawed in some way.

And if you don't have a cause or a suspicion that's credible, we don't test for those things. We're not testing the welds at the end of the fuel rod for corrosion in the middle of the fuel rod, at least exterior corrosion. Maybe for interior corrosion it would be a relationship.

So that's kind of the objection we've got here in part, I guess.

MEMBER POWERS: But I think what the NRC has is an observation. They observe that a clad, compositionally similar, was sensitive, and they say, "Well, if things are distanced, might they not be sensitive to things that we don't know about?"

CHAIRMAN ARMIJO: But you know, that's a good question. Why not us? Why is it just the Russian stuff, but you know, they also had other observations in the material that you handed out for our review earlier that staff gave us. On that Russian material somebody had done a test -- I think Argonne did it. They removed by grinding or polishing some of the material, and it behaved much better.

MR. BILLONE: Yes.

CHAIRMAN ARMIJO: And we control now that say pay. The fundamental materials are the same. It hasn't changed, but the surface has changed. So maybe we got a surface contamination problem with the Russian thing.

You know, there are a lot of things, but all of those are things that this industry, you guys do all the time.

MR. BILLONE: Yes.

CHAIRMAN ARMIJO: We study for surface contamination, heat treatment, alloy chemistry, most of the industry has tighter specs on their alloys than in the ASTM specification. So there's an awful lot of stuff. So it's not such a chaotic or elegant process. It's pretty robust, and so to me doing a check, a process check, a test, an integral test every once in

a while would be okay, but whether it's a regulatory requirement to me is the big issue. Is that justified? And that's really what the staff has got to determine. Is there really enough justification to make periodic testing a regulatory requirement and reporting and everything else that goes with it? Or whether approving a quality assurance plan would be sufficient.

MR. BILLONE: Can I ask a question? You guys require a corrosion test from your recruiting vendor how often? Is it every lot of tubing even though you have confidence in the process? The ASTM type corrosion test, is that done every lot?

MR. DUNN: I don't know the answer, Mike. I don't know whether you know it.

MR. DUNN: I don't either.

MR. LIN: For the BWR there are two types of corrosion test that's of interest. One is the ASTM, the standard G2. We practically don't do that because it never fails, and so that's done at the moment that it's done at the qualification stage, i.e., when you have a new cladding type, and we have our way of defining what type means, and that's when you run some tests.

And the other test is the nodular

corrosion test which we think is more relevant to interact with BWR performance, but that's a GEH, GNF type of test, you know, the exact condition. We do it our way.

MR. BILLONE: The reason I'm asking the question is because I'm wondering how much of a burden it is to add one more test, which is a breakaway oxidation test about the same frequency that you do corrosion tests.

MR. DUNN: Well, to answer the question on nodular corrosion, we do that, but on the PWR cladding where we do it, it takes several days, a month or something like that to complete that test.

MR. BILLONE: That's a long test.

MR. DUNN: That is a long test, and so that wouldn't be conducive to -- well, I just meant we're not already doing something.

MR. BILLONE: I'm just thinking about when you would choose the corrosion tests and would that trigger maybe a time frame to do breakaway oxidation tests. It's a question, not an answer.

MR. LIN: For that it would depend on what kind of breakaway test. Back in September we were certainly talking about a fixed time and temperature, and almost the originals that you see any white or --

but now this morning I'm hearing 200 ppm hydrogen. That is more work. I mean, it's cutting things out, doing evaluation and so on.

I mean, everything is doable to some extent.

CHAIRMAN ARMIJO: Ken, I think we had better move along here.

MR. RODACK: May I also just before we do? Another concern with the breakaway oxidation testing and this issue we're trying to work out between Westinghouse and Argonne is the different results we're getting in the different facilities.

I mean if we're going to require periodic testing as a regulatory requirement, we have to have a repeatable test.

MR. LIN: I think on this slide I would just make one point that I have not really explicitly said, is that one important issue from the manufacturing point of view certainly is a trace element effect, a bulk trace element effect versus a process, a surface effect that we introduced during cladding process. So it impacts how we would do things.

Now, just a little bit more on this alternative approach. So we had already said this is

going to be a quality assurance program. It will come under the umbrella of quality assurance program, and the key to it is to identify key parameters, as many as we can identify, and there may be some that we cannot, and then we will qualify control limits.

I will use surface roughness as an example, and we would qualify a certain range of roughness, but you would in practice control to a tighter limit than that. And most likely that kind of program would involve monitoring of the key parameters, in this case the surface finish.

And then you would qualify, and if there is a process change that takes you outside of the qualified range, and we think this is a better way to address the NRC concern that we would slowly drift into some condition that we don't know about.

Now, let's go back to what parameters are the key parameters. Right now there are four, or at least I list four. One is a surface impurity, like fluorine.

CHAIRMAN ARMIJO: I don't think you'll have time to go into those details because we know the approach you propose.

MR. LIN: The approach is that right now we already control the first two.

CHAIRMAN ARMIJO: Right. I understand.

MR. LIN: The next two, depending on what -- it just affects on how we would go about trying to address those concerns..

CHAIRMAN ARMIJO: Yeah. You know, we can read that material, and we really are behind on schedule. So I'd ask you to pick it up.

MR. LIN: Okay. So this is pretty much the final slide. We really want to have a better understanding of this trace element versus a surface condition, and that would help us to move forward. So I've already -- this is where we're at at the moment.

CHAIRMAN ARMIJO: Next is questions from Committee members.

Next would be Westinghouse.

MR. RODACK: Good afternoon. I'm Tom Rodack with Westinghouse, and I'll be talking about the implication is of implementing a new rule, and particularly the cost.

And here's a brief outline. Up to now you've been seeing fairly technical presentations with a lot of detail. These slides are simple bullet slides, no complicated concepts. I'll first talk about the implications of proposed changes; then provide some assumptions, going through the steps

required that will lead to the basis for the costs, and the cost-benefit assessment.

All right. The implications of the proposed changes. As you've heard, the proposed rule will likely require some form of ID oxidation treatment and will require that we track rods from the beginning of life through end of life and have an explicit methodology for doing that. So each vendor will likely need to change their evaluation models to take these into account, and we'll also likely need to do additional testing, ring compression testing with hydrogen charged specimens, breakaway oxidation testing, expanded hot cell campaigns to develop corrosion-hydrogen relationships, and we've also been talking about periodic testing.

Now, I haven't factored periodic testing into the costs that we came up with here. That would be an additional increment.

Okay. Some of the assumptions associated with full scope implementation. First, all operating reactors will need to demonstrate compliance. This will likely require that most perform new small and large break LOCA analysis. Most or all vendors will need to revise their LOCA evaluation models to demonstrate compliance, and then the tech spec

administrative controls section will need to be revised to reference the new evaluation model or whatever other basis there is for demonstrating compliance with the new rule.

All right. Now, the series of sort of the chronology of how the rule would be implemented, first, the vendors would update their evaluation models and submit those to NRC and as I said, it would be to show a treatment of ID oxidation and explicit burn-up methodology.

NRC would then need to review and approve those. It's likely that each vendor would have a different method. So it wouldn't be a one size fits all type review.

And then each licensee would need to obtain new analysis from their vendor. The licensee would then prepare and submit a license amendment request to revise the amendment in their tech specs to the evaluation model, and this may necessitate burn-up dependent peaking limits for the plant.

NRC would then review and approve that license amendment request. The licensee would implement the results in their revised tech specs and update their safety analysis report. And the licensee and the vendor would monitor compliance with the

limits on a cycle-by-cycle basis.

All right. Now, here is an estimate of the costs associated with that. First of all, for the vendor for each alloy there would likely be hydrogen charged ring compression tests to develop a database on the order of a million dollar expense; an expanded hot cell database to develop the hydrogen data on the order of $10 million; and then there's the additional cost of periodic testing that we don't know.

The biggest cost is with the licensee specific implementation simply because of the large number of plants, and the cost to the vendors and licensees to re-license the evaluation model, reanalyze most plants, and update the licensing bases, et cetera would be several hundred million dollars, probably on the order of maybe between a half million and two million per plant, depending on the vendor and just where they are with LOCA margin and so forth.

Then another aspect of this is the cost to the NRC in terms of resource requirements. I'm not in a great position to estimate this, but it seems that it has got to be draining at least ten to 15 man-years worth of effort to review all of this for the entire U.S. fleet.

MEMBER RAY: Before you go on.

MR. RODACK: Yes.

MEMBER RAY: I looked ahead and I know your next slide is conclusions. You haven't listed any benefits at all. The next slide said there is little benefit, but that's all it says.

MR. RODACK: Well, there was a previous discussion.

MEMBER RAY: Is Westinghouse's position that a performance based rule is not worth doing?

MR. RODACK: Our position is that there's little benefit, public health and safety to change the role. We feel that the current role with the information notice in 9829, which requires that you take into account the pre-LOCA oxidation captures most of what's captured in the new rule and also the existing criterion of maintaining post LOCA ductility is in itself a very conservative limit.

And, yes, we will be regaining a little bit of margin, perhaps in the 25 to 40,000 megawatt days per kilogram -- get the units right -- but in the 25 to 40 burn-up range, beginning with the margin, but we don't believe there's a significant benefit there.

MEMBER RAY: Well, that's a good, honest answer, but I think it's to the point, which is if there's no benefit, then not stating any benefit is

appropriate, but I just question whether or not it's true that there isn't any benefit.

MEMBER SHACK: What's the cost of an exemption for a new cladding?

MEMBER SIEBER: If you want a new cladding.

MEMBER SHACK: If you want a new cladding.

MR. RODACK: Well, hold it. The fact of the matter is we're living with that right now. I mean, we have submitted exemption requests for optimized ZIRLO cladding, and we haven't had -- I don't think it's been that significant a cost. I think it has been less than the cost of reanalyzing the LOCA per plant.

MEMBER POWERS: It seems to me that how you react to your slides depends a little bit on what you think the rule is trying to accomplish. On the one hand you can say, "Well, we're going to put this rule in because we want to make it easier both on the industry and the staff to introduce new cladding." That was one view.

The other view would be, no, we're introducing this rule or proposing this rule because we want to assure there is adequate protection of the public health and safety as we use clads up to high

burn-up and in light of a discovery of the synergism between hydrogen and oxygen on the embrittlement of cladding.

MEMBER RAY: Well, Dana, that's exactly right. I mean, I would have done what you just did, which is to list those, and I would assume the staff would step forward and say approximately what you've said, which is there is a benefit to public health and safety. There is also a benefit to margin which has some economic value presumably down the road.

But I think to say that the cost-benefit doesn't work out without ever stating the benefits in any respect isn't --

MEMBER POWERS: Well, you know, I think he's going down a path here that if I were in his place, I would take it, too, which says --

MEMBER RAY: I wouldn't accept it then either.

(Laughter.)

MEMBER POWERS: Yeah. I have introduced new claddings here. I have data on the costs or can acquire data on the cost of getting the exemption for those, and so if the rule is only there to facilitate things, then it's impracticable because I do it the other way and it didn't cost me hundreds of millions

of dollars. It cost me a few million dollars. Okay?

But that may not be the issue that's at hand here.

MEMBER RAY: I agree.

MEMBER POWERS: We may, in fact, have new phenomenology not recognized by the old rule, but recognizable now. And if that's the case, then you and I have to plug our ears when he brings up cost-benefit because it's a public health and safety issue.

MEMBER RAY: Yeah, there were a couple of references made earlier today about, well, but if we do this, it might have a negative effect on current design basis. But given what you said, well, that's just the outcome of this new information, right?

MEMBER POWERS: It's new information. That's right.

MEMBER RAY: So if you adopt the point of view you just described, then I think the argument that's being made here about cost benefit doesn't hold water.

On the other hand, if you take the point of view that, no, this is just about facilitating new cladding material introduction and maybe getting some additional margin that I can put value on later, then at least you ought to say that I would think on the

benefits side, but to just list the costs and then argue that there's little public health and safety benefit I don't think is very -- it's disingenuous, if I can say that.

MEMBER POWERS: That's the argument he made, that with the information notice he's got adequate margin.

MEMBER RAY: I know, but you haven't shown that what Dr. Powers said isn't true, that there is a public health and safety benefit, number one, and number two, I think that the issue of the value of the margin that you would obtain needs a little more explanation or discussion because it is omitted here entirely.

All you referred to is the benefits of public health and safety and say it's little.

MEMBER SIEBER: If that.

MEMBER RAY: But, you know, in fact, presumably the margin has some value. It may not be value that would be sufficient to go to a performance based rule because you can obtain it through exemptions and so why not?

MEMBER SIEBER: Well, facilitating the use of additional alloys under a new regimen of testing and development is a commercial decision and it is not

ours to make. The only decision that we need to make is if we identify a decrease in public health and safety then we have to evaluate whether the cost to implement a rule to cure that is less than the benefit to the public health and safety.

Now, if additional features of a new rule, for example, implementation over new alloy groups or so forth are not part of that discussion as I see it.

On the other hand, we have the phenomenon to break away oxidation which somehow has come up. It's not clear in my mind exactly what causes it. Is it restricted to E110 or would that phenomenon be relevant to other alloy types?

And I think that question has to be answered, but you don't have to revise the rule to do it. Basically the way I see it --

MEMBER RAY: The argument being made here that I was commenting on was a cost-benefit argument. I think if the industry says there is a benefit that warrants the cost or the benefit is whatever it is. I just was objecting to the argument that the costs weren't justified by the little public health and safety benefit, period.

MEMBER SIEBER: I took Westinghouse's presentation as being these are the costs.

MEMBER RAY: Well, then don't say cost-benefits. Just say it's --

CHAIRMAN ARMIJO: No, there's no benefit specified in here anyway.

MEMBER SIEBER: Well, somebody else will have to come up with a benefit.

MEMBER RAY: I just object to the omission of the benefits.

CHAIRMAN ARMIJO: If Westinghouse sees no benefit and says they see no benefit, that's their position.

MEMBER SIEBER: Well, they said they --

MEMBER RAY: We may not agree with it.

MEMBER SHACK: Well, I want to know where Ken's third slide comes and says the industry is supportive of this since we've got Westinghouse objecting to it and we've got AREVA objecting to it. I guess that leaves GE.

(Laughter.)

CHAIRMAN ARMIJO: Is AREVA objecting?

MEMBER SHACK: I'm just looking at your slide here.

MR. DUNN: What was the margin you were talking about?

MEMBER RAY: Well, I was just using his

word, which is it gives us a little margin. I said, okay, margin has value.

MR. DUNN: All right.

MEMBER SIEBER: It has a commercial value, but if you do the same thing tomorrow that you're doing today, the claim, analytical margin, you haven't changed the public health better.

MEMBER RAY: That was not my point. My point was simply the words cost-benefit --

CHAIRMAN ARMIJO: I think we've got to move on.

MEMBER RAY: -- used here -- onward.

MR. RODACK: I do want to cover some of the sub-bullets. This will require significant expert resources to implement both on the part of industry and the NRC, and this is a critical stage in the time line for nuclear. We simply don't have resources to waste at this point.

Okay. The second --

PARTICIPANT: "Waste" is a bad word.

MR. RODACK: I realize that. I'm sorry. Let me retract that, and I'll not substitute another.

(Laughter.)

MR. RODACK: We need to be very careful how we use our scarce resources.

The other point that I wanted to make was that this will require significant effort. There are limited resources, and if a new rule were to be promulgated, then we would really need to consider a phased implementation of the rule to make it practical.

MEMBER POWERS: Let me be clear. I appreciate you raising the issue of cost of implementation issue here because I think you raised the issue of why we're doing this rule here because if it is just to facilitate the introduction of new clads with within the licensee and the staff, it's quite different than if we're putting this rule in because we have now discovered new phenomenology.

And so it's a legitimate concern. If we go back to accommodate new cladding, and if I see this is voluntary, you only have to do it if you introduce new cladding, will I get rid of your problem?

MR. RODACK: I'm tempted to say yes, but I hate to answer a question like that in haste.

MEMBER POWERS: I understand that. I think you may have answered it enough here because I think the real critical question is the one that you've crystallized by your presentation, which is why are we doing it. We have discovered new

phenomenology. Breakaway oxidation is not the new phenomenology. I t's phenomenology that was not recognized at the time that the rule was put in. It is really the synergism in embrittlement that comes from hydrogen and oxygen together.

And if that's why it's here, I think it puts it into the adequate protection rule, and we can't consider cost-benefit analysis. But I don't know that that's the case.

CHAIRMAN ARMIJO: Yeah, it's like a new generic issue.

MEMBER BROWN: Yeah, but you can still look at a consequence analysis aspect. I mean, if they wanted to argue to look at the consequences of the breakaway oxidation, what does it cause? What's the fallout? What's the waterfall, the cascade of events that have to occur in order for that to be a problem?

Is it just simply some rods that fail and you get some fuel contamination in the water, the coolant? Is it a matter that you have a cascading failure because one or two of them fail because of this, because of localized heating? Is it an accident associated type phenomena that it only becomes a problem or not?

And then somewhere if somebody wants to argue if this breakaway oxidation -- I'm just sitting here on the side and trying to figure out how do you deal with something --

MEMBER POWERS: I do not see breakaway oxidation as the principal issue.

MEMBER BROWN: Well, that's what I'm gathering out of all this discussion, being somewhat of a -- not a neophyte relative to this. In other words, how big of a problem is it?

And why would you go to a -- I may sound like I'm taking their side, but unless you can identify, unless somebody can identify a significant, even a small public impact.

MEMBER POWERS: We've got one. It's very clear that hydrogen uptake is --

MEMBER BROWN: Now, that's a technical issue relative to the oxidation elements themselves. It's a consequence of --

MEMBER POWERS: It is absolutely crucial.

MEMBER BROWN: Okay.

MEMBER POWERS: If you quench that core and it busts on you, you are dead in the --

MEMBER BROWN: Are they all going to bust?

MEMBER POWERS: Yes.

MEMBER BROWN: No. You overstated it again. Okay?

CHAIRMAN ARMIJO: Okay. I think we've got to move on. We've got one more presentation from industry.

MR. DUNN: I would hope that I could go very fast.

MEMBER POWERS: One slide. We'll see how long we can make it last.

MEMBER SIEBER: We already read your slide. So. It's a very good slide.

MR. RULAND: Can I? This is Bill Ruland.

The staff has some responses to this discussion, and in the interest of time, we're going to hold off and Paul is going to talk.

CHAIRMAN ARMIJO: Confine it in your --

MR. RULAND: Yes.

CHAIRMAN ARMIJO: I appreciate that.

MR. RULAND: Because there are a number of things that have been said here that we don't agree with, but we'll have an opportunity to speak.

CHAIRMAN ARMIJO: Absolutely.

MR. DUNN: Okay. I want to apologize for interrupting this morning. At the time I thought the staff was presenting a position, not just a status,

and I can make some of those comments directly to Paul and Ralph, and they don't need to come before this.

With the exception of breakaway oxidation, I think the existing rule as implemented under 98-29 is adequate. I didn't say we were against changing the rule because if we go to a hydrogen based implementation on transient development, that's clearly a more scientifically founded position to be in. The caveat I would personally have with that is that -- I'm just going to try and say it rather than bring it up in the slides -- is that I do not believe at this stage the interior alpha layer development or migration of oxygen into the beta lab is sufficiently well established, and that would violate the 98-29 being adequate. Okay? Because 98-29 will account for the hydrogen by and large, but it will not account for doubling the oxidation away from the ruptured area.

To get back to the main point on this thing, I think that breakaway oxidation should be included in the regulatory package. It does not have to be included in a 50.46 change. I think it could be implemented in other means.

The reason I say that is that the typical performance time for a small break loss of coolant accident is on the order of a half hour. That's true

for me in Europe. That's true for the plants I serve in the United States.

However, there are a certain class of accidents that mitigate or interrupt portions of the emergency core cooling system for which utilities cannot take or may not be taking aggressive action to resolve. You can envision here an HPI line break where the operator has to go in and re-manipulate the distribution of the high pressure injection system perhaps to achieve quality penetration into the reactor vessel and into the core.

Some utilities haven't perhaps preached that as well as they should have because they've been limited to a 17 percent, and so they can sit there for, you know, a day at the temperature that a small break loss of coolant accident gets to and they won't hit the 17 percent. We should do something about that. Okay? It's not very many utilities. I only -- well, I'm not going to. There. I won't identify.

I think AREVA also supports Dr. Powers' idea of maybe even two years ago now -- I'm not sure when it was first put out -- of an enabling rule where the details are expressed in NUREGs and reg. guides because there is deviations amongst the alloys, and we're all coming with new alloys, and in some of the

new alloys there may be differences that you'd want to take account of.

This will show you one of the reasons why you would want to do this. This is a plot of corrosion of M5 versus Zirc-4. The Zirc-4 is the red line in both cases. On the left-hand side, I hope you can read it. I can't read it here. They're both versus burn-up and we have corrosion on the left and then we have hydrogen pickup on the right, and I think Dr. Meyer alluded to this earlier, that you can't simply change the Zirc-4 hydrogen by the amount of corrosion that exists and come up with the M5 hydrogen content.e bit in the same boat; at least they have U.S. headquarters.

One of the things is that we should determine what a new alloy is. We should talk about a test spectrum for the new alloy, and we should set, you know, certain screening tests for the variation of current alloy. If I change an alloy a little bit, do I have to do the whole thing over again, you know?

Hydrogen is a particular problem that way. One of the things that we would like is to be able to use extrapolation hydrogen through test assembly and burn-up and stuff like that so that we can gradually work the hydrogen into the equation for the evaluation

model because that would speed up the implementation of a new alloy by several years.

And I would say at present not do the periodic testing, and there you've got my concerns. You can read them.

Now, two things that did come up this morning, well, I did just talk about the potential EOP changes on the breakaway oxidation and that was I didn't think very clear in what was said this morning.

The only other thing is I would ask the Committee or maybe Ralph, is that if we are going to implement interior oxygen migration or interior alpha region development and migration of oxygen into the beta region, that we expand that database. And the integral tests that are upcoming, that are a y ear away, nine months away, a year and a half away right now, is an excellent opportunity to do that. They will be highly exposed material. They will be on new alloys, and I think also we are going to do another couple of H.B. Robinsons, I think.

And then you can have six, seven, eight, ten points to demonstrate that is a fact, and at least for me I will be much less concerned about implementing it than I am today.

If you take a full credit for the cooling

mechanisms that occurred during loss of coolant accident, the current location at which we do double-sided oxidation will not bound the rest of the fuel rod. In a full implementation you would account for a lot of effects at the rupture area that actually will benefit the cooling at that location, and that location, unless I take extremely conservative approaches to fuel relocation, will even with fuel relocation operate 100 to 150 degrees cooler for the most part than the region of the fuel pin below it or the region well above it.

And so we will be herding. We'll have a substantial impact on the oxidation that some people will report to you in terms of doubling the amount of oxidation that they have to live with or doubling the amount they report against the metric of local oxidation.

All right. I'm done.

MEMBER POWERS: At the very beginning of the day, I think maybe it was Mike made the point that the transport oxygen into the metal is being hidden in a metric on the amount of oxide that's formed on the outside.

MR. DUNN: That's true.

MEMBER POWERS: So are you telling us that

you would prefer to see the oxygen transport in the metal to be explicit rather than hidden in this correlation?

MR. DUNN: I don't think it would do a lot of good or make much of a change. So would I prefer it? Probably not from my Joe Public role.

From the standpoint of a vendor, I don't think I'd care too much which way we did that. It's just a correlation that you would write into the Fortran, but you would have to wind up getting it approved and --

MEMBER POWERS: It's just that I said --

MR. DUNN: -- I would think maybe the Cathcart-Pawel alpha layer correlations might be a better way. They're already established. We're already using Cathcart-Pawel for this application on the outside.

MEMBER POWERS: It's just that I saw in the industry plans explicitly let's go measure the oxygen diffusion coefficient, and then you gave your presentation, and I was just adding two and two together and saying, "Ah, maybe they want to go explicit on diffusion in the metal rather than hiding it in the correlation." That's what prompted the question.

MR. DUNN: Well, we are considering the development of such a correlation, and that would be a step forward if we talk about actually bringing the oxygen layer in there, and then you have to though also include the effect that a certain amount of oxygen has on a particular alloy because that varies a little bit, too.

MEMBER POWERS: True, sure. I mean, you would have to do both.

MR. DUNN: Yeah.

MEMBER POWERS: Interesting.

CHAIRMAN ARMIJO: Okay. Other questions?

Well, we can take a ten-minute break and back at three.

(Whereupon, the foregoing matter went off the record at 2:49 p.m. and went back on the record at 3:00 p.m.)

CHAIRMAN ARMIJO: Okay. Let's get back.

All right. Here's Ralph.

MR. MEYER: Okay. So we've heard many of these comments before, and several times we hear the same comment from different organizations. So what we've chosen to do is to assemble them in a frequently asked question format so that it doesn't become personal.

(Laughter.)

MR. MEYER: There was one comment that came up that I hadn't seen before or if I did I didn't pay attention. It was at the top of EPRI's slide list, and it said that NRC's research program was reduced in scope because of the closure of the alpha-gamma hot cell at Argonne, and that is simply not true.

We experienced a major delay and have branched out to two other laboratories to pick up the testing that cannot be done at Argonne any longer, but we're doing exactly the same amount. I mean, there are always some tactical changes that you make along the way, but we haven't eliminated any significant portion of the program, and we will get them all done eventually.

MEMBER SHACK: Ralph, one thing you haven't addressed is whether you think with the information notice that you have a problem with adequate protection or public safety with the current rule without a new rule change. Could this be made voluntary?

MR. BILLONE: He's ready for you.

MR. MEYER: Oh, okay. I have to double click.

Okay. I'm going to get to that very quickly.

MR. CLIFFORD: Excuse me. Paul Clifford, NRR.

We can address that now. We don't believe that this rule should be voluntary. I mean, there's enough evidence from the Argonne test program to show that the current rule is inadequate, and that the constant 17 percent ECR does not insure post quench ductility, and that that should be addressed.

In addition, we also favor, strongly favor, introduction of new requirements for breakaway oxidation.

MEMBER SHACK: Even though the alloys that are currently in use seem to have adequate breakaway oxidation behavior. I mean, I can understand for every new alloy that came up, and this would be voluntary or at least conceptually could be voluntary.

You know, the question is: could it be voluntary for the alloys you've already approved and which seem to have adequate breakaway oxidation?

MS. UHLE: Can I try that one?

I was involved on the thermal hydraulics side with the LOCA analyses when we first found out about the breakaway oxidation and the fact that some

of the cladding alloys were, you know, 3,600 seconds, on that order, and then others were higher. I mean, the issue is the way the plans are currently operating, the way that their licensing basis calculations restrict them to operate, we feel that insures plant safety as well as the emergency operating procedures that are in place for those plants we were particularly concerned about.

However, there is no I would say requirement in any regulation that talks about breakaway. So licensees are free, as you know, to change the way they're operating and to have different pin powers and different loading characteristics, and then one can question are you still going to be okay with the breakaway phenomena.

And so without having that requirement in the regulation, we would always be having to double check, and it would always be somewhat voluntary, and we just don't feel, the staff does not feel and OGC does not feel -- that's our General Counsel -- that that's an appropriate way to regulate.

Well, just to follow up, if that's the case and you wanted to make sure that that was a regulated practice for those particular plants, would you accept the already generated data from Argonne on

what the times are for these, you know, existing alloys, the Zirc-4s and the M5s and ZIRLOs, or would the licensees have to generate more information?

MR. CLIFFORD: The data that was generated at Argonne is open and available to the licensees to credit in their analyses.

CHAIRMAN ARMIJO: Right, but that would be acceptable to you, or would you require even more data?

MS. UHLE: I think, Paul, the question is we have a certain data set about the breakaway times for the alloys that are allowed in the plants that have been reviewed and approved, and I think you're questioning would the licensees be able to when this rule gets adopted, if it gets adopted, with the breakaway would they be able to point to that and say, "Here is my breakaway time"?

And the answer --

CHAIRMAN ARMIJO: Or would you say, "That's not enough. We know you've got to do more"?

MR. MEYER: Well, right now we believe that would be sufficient.

MS. UHLE: However, if a new alloy were introduced --

CHAIRMAN ARMIJO: Oh, yeah, new alloys are

totally different. I agree.

MS. UHLE: And then also we have and in your question haven't addressed the repetitive testing issue that I obviously don't want to bring up again.

MEMBER RAY: Well, Paul, I realize this was a historical recitation you gave, but I think the answer to Bill's question ought to appear in here somewhere other than just as a response to a query. In other words, there's a motivation or a need other than this what originated as an NEI petition to eliminate the need for exemptions.

CHAIRMAN ARMIJO: Well, you know, I've got to take issue with one of Paul's statements though. The existing regulations don't assure post quench ductility for some alloys, but your test data show that it does, in fact, provide protection for many of the alloys.

MR. CLIFFORD: Well, certainly for I believe the ones --

CHAIRMAN ARMIJO: I'm just talking about the ones that are actually out there now, not the old Zircaloy-4s. Modern Zircaloy-4s, M5s, ZIRLOs, Zircaloy-2. I thought your post quench test data were acceptable. cover you.

You know, it's not the best way to do it.

It's not scientifically, but is it adequate? That's the question.

MR. MEYER: Can you wait one slide?

MEMBER SHACK: Yep.

MR. MEYER: Just one.

MR. RULAND: One other just comment. Sorry, Ralph. Our regulations are the sum total of what is necessary and sufficient to assure safety, and in this particular case, we don't believe that the current rule demonstrates that adequate protection may or may not exist, and as a result, we're going forward with the rulemaking, and that is our judgment based on the information we've gotten from the Argonne laboratory.

MEMBER POWERS: You're going to go with the advanced notice of proposed rulemaking.

MR. RULAND: Because we want -- we are an open agency.

MS. UHLE: I do want to point out though that we do not feel that this is an imminent safety issue or the plants are coming down, but if you were to read the regulations as written, there would be certain phenomena that are not considered that we feel are important to consider, and the sum total of those phenomena would allow the licensee then to figure out

their core loading and their peak power and what have you in a way that would be completely flexible.

Right now we are where we feel we're safe because of the regulation as written, but also because we know currently how they're operating, and the issue is it's not just what the cladding is or what the burn-up is. It's also what their core loading is and what their peak power is and how their system responds to the LOCA.

So that degree of flexibility there is what we're trying to I would say curtail.

CHAIRMAN ARMIJO: Your first slide, Ralph.

MR. MEYER: Are you ready?

(Laughter.)

MR. MEYER: Okay. I'm going to start with an historical fact. This work did not initiate from an NEI petition to write something convenient in the rule.

In 1993, when we learned about the effect of hydrogen on a different accident, the reactivity initiated accident from test program in Japan, we thought that there is likely to be an effect of that hydrogen one way or another on the LOCA embrittlement criteria, and that was the reason that this program was initiated.

After the petition in 2000 from NEI, we added on a secondary goal of trying to eliminate the restriction to two specific alloys in the rule, and the first two slides that I have in here were simply put in to try and emphasize that we're not talking about a technicality or a regulatory nitpick. This is an important criterion that is designed to protect against loss of integrity of fuel assemblies in a loss of coolant accident, and if we have a realistic limit and comply with it, we will not get the kind of behavior that was seen in this cleaning accident at the Hungarian plant where you had basically oxygen related embrittlement at relatively low temperature for a long period of time. It was way beyond the limits that we're trying to set, but this is what we're protecting against.

MEMBER SIEBER: Before you switch that, Pax is VVER reactor?

MR. MEYER: Yes.

MR. BILLONE: An E110.

MR. MEYER: An E110. It had a susceptible cladding, and it cooked for a long time, but it never went above 1,300 degrees Centigrade.

MEMBER SIEBER: But that's the one that's susceptible to breakaway.

MR. MEYER: That's right. That's right. It was way over the hill.

MEMBER SIEBER: Right. The rule says don't use E110.

(Laughter.)

MR. MEYER: Okay. Bill, you asked about would the --

MEMBER SHACK: Having looked ahead I --

MR. MEYER: -- corrosion subtraction have accommodated the effect, and here is just an example, and here we have a North Anna fuel rod with 70 gigawatt days for ton. Is that local or is that rod average?

MEMBER SIEBER: Average, rod average.

MR. MEYER: Rod average. So this was from a lead test assembly that was going a little beyond the 62 gigawatt day per ton rod average. So it has had a little higher duty than a regular fuel rod would have, but it had a corrosion layer of 40 microns, and if you took the corrosion layer and subtracted it from 17 percent, you would be here, and yet it had about 550 parts per million hydrogen and actually had a threshold transition from ductile to brittle behavior at about five percent DCR.

So the interim criteria or the information

notice, even if it were applied, would not accommodate the --

CHAIRMAN ARMIJO: Ralph, would you just happen to remember what the hydrogen pickup fraction is? I'm just trying to calibrate myself.

MR. BILLONE: It varies all on the length of the rod. It varies with burn-up, but for that example it's about 20 percent.

CHAIRMAN ARMIJO: Twenty percent of the corrosion generated --

MR. BILLONE: Of the hydrogen generated ends up --

CHAIRMAN ARMIJO: -- hydrogen into the cladding.

MR. BILLONE: Right, but it's not constant along --

CHAIRMAN ARMIJO: I understand.

MR. BILLONE: At one point in the rod, in one rod.

MR. MEYER: There's margin.

MR. BILLONE: One rod.

MR. MEYER: And so I don't want to reach a final conclusion from a slide like this because at 70 gigawatt days per ton it was probably operating at a relatively low power, and so you wouldn't get up to

the temperature that it was taken up to in this test, and that's worth a few percent in oxidation.

MEMBER SIEBER: And it is beyond your current burn-up limit, right?

MR. MEYER: Say again?

MEMBER SIEBER: It's beyond your current burn-up limit of 62?

PARTICIPANT: Right.

MR. BILLONE: It doesn't really matter though. He says it's beyond the current burn-up limit.

MR. MEYER: Yes. Yes, it is. Yes, it is.

Okay. So we know that there's something different going on in the balloon with this hydrogen absorption that we talked about this morning, and so one of the questions has to do with understanding the balloon, and do we have to understand it better before we can go forward.

What we have targeted to do in the research program was to address the non-conservatisms that you just saw from the corrosion related hydrogen in the regulation. We are doing additional work on the balloon to see if anything else is needed, but the planned changes for the rulemaking at the present time

would keep the methodology that's described in 50.46(b)(2), which basically says account for the wall thinning in doing the oxidation calculation, and couple that with the reduced oxidation limit based on the amount of pre-accident hydrogen that is in the material.

So that's all I plan to say on this subject. It's a big subject, but if you have any questions on this, let me have them or I'm going to go on to other subjects.

MR. MONTGOMERY: Mr. Chairman, may I ask a question real quick on that?

CHAIRMAN ARMIJO: Sure.

MR. MONTGOMERY: It will just be a quick question.

Ralph, you mentioned --

CHAIRMAN ARMIJO: Identification, please.

MR. MONTGOMERY: Oh, I'm sorry. Robert Montgomery. I'm with EPRI, ANATECH.

You bring up this point about the balloon region and considering the pre-accident hydrogen content in the balloon area. Mike showed a plot this morning -- I think it was in your presentation -- where you showed the hydrogen as a function of axial position in the ECR, and in the burst opening

location, it was about 2,000 ppm, and I know the tests --

MR. BILLONE: The NUREG. I didn't show it, but it was in the NUREG.

MR. MONTGOMERY: It was in one of the slides that I had here that I picked up today.

But anyway, that 2,000 ppm is well above the pre-accident corrosion hydrogen. So how does that work exactly?

MR. MEYER: Okay. Now, I mentioned this this morning, and I'll do it quickly so that I don't take up too much time, but if you look at the test results for fresh material, and I presume this might also be applicable to low burn-up, maybe even medium burn-up, you find that the hydrogen concentration at the ruptured mid-plane is very low. It's essentially zero. It's only when you look at test results for high burn-up cladding that's gone through this kind of ballooning and rupture scenario where you get a different answer, and the results are mixed at this time.

We have one and only one measurement, and we have a couple of pieces of material that were sampled and indicated a fairly high hydrogen concentration at the ruptured mid-plane, not as high

as the two bands, but higher than the pre-accident concentration.

The Japanese have done several tests, and they have mixed results also. They have one test with a high hydrogen concentration, but there's some funny things about that test. They have others with very low hydrogen concentrations in the mid-plane area.

So it is not clear that this absorbed hydrogen from ID oxidation is going to have a major effect on the mechanical behavior in the rupture node. We'll find out. That's part of our future test mode.

MR. MONTGOMERY: That's future evaluation.

Just a follow-on comment about this point about dealing with the corrosion hydrogen in the balloon area. I looked in the RIL and I didn't find any comment on that. Is that a shift in --

MR. MEYER: No.

MR. MONTGOMERY: I didn't find anything in the RIL that relates to treating the balloon region as having preexisting hydrogen and calculating the ECR based on that effect.

MR. MEYER: If you could read it otherwise then, it was my mistake for not making it more clear. It has always been our intention.

MR. MONTGOMERY: Because now this is going

to become extremely limiting.

MR. MEYER: I don't think I said otherwise.

MR. MONTGOMERY: Yeah.

MR. MEYER: You'll have to show me the part that you're talking about that maybe what I wrote was ambiguous.

MR. MONTGOMERY: Well, the reason why I raise this question is because if you look at the balloon region where you have, you know, about a 50 percent average wall thickness reduction in the balloon, if you have 600 ppm of hydrogen, you're at five percent ECR without any wall thinning effect, that's something on the order of maybe what, 30 seconds? What's five percent ECR, 100 seconds, maybe less?

Now, if you half that, you're down in the ten or 15, 20 second range because of the wall thickness effect. So it's going to be extremely limited. We've just got to think about that.

MR. MEYER: I didn't mean to be sarcastic. It's just reality.

MS. UHLE: Well, can I interrupt?

MR. MEYER: There's nothing we're doing that's intending to be penalizing here.

MS. UHLE: Just with regard to the balloon issue, we internal to NRC have not yet come to consensus. So, I mean, the concept is we are doing further research, and maybe it's appropriate if we talk about it off line because I think we are behind already, and I don't think you were objecting to anything that was on the slide there.

CHAIRMAN ARMIJO: No, he was just asking.

MR. MONTGOMERY: Just for clarification.

MR. MEYER: Okay. One of the next most frequent questions asked is did we make these measurements at too high a temperature, and Westinghouse has said that the high burn-up fuel can't get to 1,200 degrees in a LOCA and had the testing been done at 11 or 1,000 degrees, the threshold would be lower.

CHAIRMAN ARMIJO: Do you mean higher?

MR. BILLONE: Higher.

MR. MEYER: The threshold would be higher. Sorry.

CHAIRMAN ARMIJO: I think that was my question.

MR. MEYER: Both statements are true for high burn-up fuel that's in low power locations. I'll come to that. Let me just comment on the origin of

the increase in the threshold. It has to do with the solubility limit in the beta phase.

As you reduce the temperature from 1,200 to 1,100 to 1,000, you reduce the solubility. So it simply won't absorb enough oxygen to become brittle. So the beta phase itself has more and more ductility. It's a very slowly changing effect until you get above 1,200, at which point it kicks up, which is the effect that I was trying to explain this morning.

CHAIRMAN ARMIJO: But it should have a big effect on diffusivity.

MR. MEYER: Huh?

CHAIRMAN ARMIJO: The temperature difference, you'd have a big effect on oxygen diffusion rates.

MR. MEYER: On oxygen diffusivity, is that what you said?

MR. BILLONE: Both, both the diffusion rates.

MR. MEYER: Of course.

CHAIRMAN ARMIJO: Yeah.

MR. MEYER: But when you do the calculation, you're going to be doing the calculation at a lower temperature anyway. So that's kind of a wash. That part, if you're operating at a lower

temperature for a given period of time, you're going to calculate a lower ECR depending on what cladding you had.

Okay. So the figure that we see showing first cycle fuel, second cycle fuel, and third cycle fuel of a typical Westinghouse core shows a greatly depressed power level in the third cycle high burn-up fuel, which presumably is the fuel that's way out in that hydrogen plot. So it's the fuel that's got maybe four, 500 ppm hydrogen in it.

That's really not the fuel that we're concerned about because I believe that you could probably do some generic analysis to show that it didn't even rupture. It didn't get above, you know, 800, 900 degrees, in which case the amount of oxidation during the transient is trivial and you could just sort of set it aside.

So the thing that we're really focusing on is that the corrosion level that we tested, 40 microns, is really typical or at least reasonable for some of the higher corrosion levels in second cycle fuel, which does operate at fairly high power levels. The five percent number that we have is already somewhat tempered by a lower temperature because we never made it to 1,200 in the test. So it's a little

more realistic than a true value at 1,200 degree.

Some core designs have burnable poison concentrations such that they may not reach their peak power until the second cycle. And third cycle fuel is sometimes put inside the core.

So what you have to worry about is fuel that has some significant burn-up, therefore, some significant corrosion and significant hydrogen that is running in a high powered location, and so that's where the --

MEMBER SIEBER: And has enough fissile material left to do it.

CHAIRMAN ARMIJO: Well, you can drive it by loading.

MEMBER SIEBER: Yeah, but that's a sinkhole compared to it --

CHAIRMAN ARMIJO: It's not necessarily economical either.

MR. MEYER: Okay. But in addition to that, we have been working on rule language that would permit a licensee or a supplier to do tests at a lower temperature and arrive at a higher limit and use that instead of the default value that is put in the rule.

So the rule per se would not force the licensee to use an unnecessary penalty, but it could

cause you to do some extra work to justify a tailored criterion instead of using the default one.

Now, the next favorite subject to criticize is the double-sided oxygen pickup. It's true bonding seems to be necessary to get the pickup. You don't have bonding in low burn-up or even medium burn-up fuel, and we don't at the present time know where this transition takes place.

Now, it's possible as you suggested that one could go through and look at a historical collection of micrographs and make some reasonable estimate of when this kicks in. It's going to kick in at a different burn-up for BWRs and PWRs because the pressure difference in the operating conditions closes the gap a lot closer in a PWR than in a BWR.

So these comments about the Argonne data not showing a full alpha layer, well, the only example of that that we're able to look at was a BWR rod which is one that would develop the bonding later, and the Halden rod that we looked at was a PWR rod. So its cladding would have collapsed down on the fuel rod a lot earlier.

MEMBER SIEBER: You're talking about creep down rates.

MR. MEYER: Yes, creep down.

Also just a practical note. The guys in the lab noticed a big difference in the difficulty of defueling the Robinson rod compared with the Limerick rock. So I mean, you know, that the bonding is a lot stronger, a given burn-up in the PWR rod. So there is a difference between the Bs and the Ps.

There was also a comment made about the Halden result, that the alpha layer thickness was only 21 microns so that there was not an unlimited supply of oxygen on the ID. Well, you don't need an unlimited supply of oxygen because it only takes .6 of a weight percent of oxygen in the beta phase to embrittle it. I don't have a good, reliable number, but something on the order of ten microns or 15 microns of an oxide layer on the surface is enough to give all of the oxygen that you need to embrittle the beta phase.

So you can have unequal --

CHAIRMAN ARMIJO: But you don't really need bonded fuel as a source of oxygen.

MR. MEYER: On the inside you do.

MEMBER SIEBER: It helps.

MR. MEYER: But not on the outside.

MEMBER SIEBER: Right.

MR. MEYER: On the outside you've got the

steam outside. You've got an excess of oxygen on the outside. You don't need all of that. So you don't have to have the same amount.

MEMBER SIEBER: They're not oxygen free on the inside because you assemble the rod in air, close it, weld it, and then pressurize it with nitrogen. So the original oxygen is still there.

CHAIRMAN ARMIJO: No, it's evacuated and refilled.

MEMBER SIEBER: That must be lighter then than I remember.

MR. MEYER: Okay. So we all know the principle here. Let me just go on.

So is taking double-sided oxygen pickup at all burn-ups an overly penalizing assumption? It would certainly be simpler than introducing some burn-up dependent transition from one-sided to two-sided, and I'm not convinced that there's a penalty for doing that.

First of all, rupture in a rod exposed to LOCA conditions happens at a fairly low temperature, somewhere around 800 degrees Centigrade, and so every fuel rod in which you're going to have an oxidation issue is already going to have a rupture. So you're already doing two-sided oxygen pickup in the ruptured

node.

Now, it's true the ruptured node is running a little cooler than the adjacent nodes because you have an expanded surface area, but it's also true that the cladding is thinner, and so since we are working on a percent of the cladding thickness that increases the calculated oxidation in the balloon region.

We don't have a lot of information on this. We in Research have only been able to find two cases where we can make a comparison, and in the two cases where we could make the comparison, the oxidation in the rupture node was higher than two-sided oxygen pickup in the peak cladding note would have been.

So I don't know whether the peak cladding temperature node is ever going to produce the limiting oxidation value or not. Bert seems to think it will, and I haven't seen any results that show that.

MR. DUNN: I'll send you the reference, a reference, as an example.

MR. MEYER: Okay.

MR. DUNN: It's about three times.

MR. MEYER: And if it does become limiting, it's not going to be by some huge factor of

two difference. It's going to be just because it exceeds the two-sided amount you're already calculating in the balloon.

So I'm not convinced this is a huge practical issue. In any event, under the rule language that we're considering, a licensee or supplier could come in and argue for a kick-in time for the two-sided oxygen pickup away from the balloon, and this kick-in time could be different for PWRs and BWRs.

CHAIRMAN ARMIJO: Which kick-in time?

MR. MEYER: Okay. The burn-up at which bonding takes place.

CHAIRMAN ARMIJO: Oh, okay.

MR. MEYER: And how does it develop from no bonding to full bonding? I mean, you've got to make some transition from one-sided to two-sided, and I don't know how to do it, but you could conceivably make some algorithm for accounting for that that would be reasonable, and that would be allowed under the rule construction that we're talking about.

So from time to time we also talk about changing the whole basis for this, and it just wasn't something that we set out to do in this research program. The Commission addressed this in the hearing and came to this conclusion, that the strength and

flexibility tests were reassuring, but they weren't convincing because they didn't know what the loads were during a LOCA.

And as I read it, I read it they didn't think you could know what the loads would be in a LOCA. I mean, you could have some seismic loads. You could have some pump tripping or something like that, and so they settled on ductility, and we simply tried to stay with that, to not be innovative here, but to simply look at what the effect of burn-up was on the ductility based criteria.

We have done only a few strength measurements and we'll do a few more, but we haven't done anything to try and investigate the challenges that the rods would have. So we wouldn't know what strength was strong enough.

CHAIRMAN ARMIJO: Ralph, do you think there's a sense of timing with the original Commission decision on strength versus ductility, that we know a lot more about what the loads are?

You know, the Japanese must have some basis for doing their testing in this different way using this almost like a tensile test.

MR. MEYER: Well, see, that doesn't get you anywhere toward what the loads are. That just

tells you a little bit about the strength.

CHAIRMAN ARMIJO: It tells you about the strength, but they must have some reason.

MR. BILLONE: Yeah, they do.

CHAIRMAN ARMIJO: This is more prototypic of the loading you would get in --

MR. BILLONE: The difference of contraction between the control rods --

CHAIRMAN ARMIJO: Right. Something bonds up, hangs up --

MR. BILLONE: Right.

CHAIRMAN ARMIJO: -- and it stretches it, and it's like a tensile test.

MR. BILLONE: That's one mechanism.

MR. MEYER: That's one load you can postulate.

MR. BILLONE: There's bending and impact and other loads that may be relevant.

MS. UHLE: There's a hydrodynamic load switch. It could be anything depending on where the break was, the size of the break.

CHAIRMAN ARMIJO: We're still at the same point as far as state of knowledge of the loads definition.

MS. UHLE: I think the structure, I mean,

we don't have any structural people here to help answer the question, I mean, unless there's someone from the audience.

MR. MEYER: We have a structural person here.

MR. MONTGOMERY: Robert Montgomery again. I'm a nuclear engineer. I'm not really a structural engineer, but I work for one, and he would say that, yeah, we can quantify those loads.

(Laughter.)

MR. BILLONE: Joe.

MR. MONTGOMERY: Everybody knows Joe.

MS. UHLE: Excuse me. During a LOCA thought --

MR. MONTGOMERY: During and after.

MS. UHLE: Well, let's say the agency position is we haven't reviewed and approved it yet.

MEMBER SHACK: Well, the structural engineer, to give him the pressure loads, can probably compute that, but the thermal hydraulic guy might have a hard time.

MR. RODACK: Mr. Chairman, if I may.

CHAIRMAN ARMIJO: Well, this is kind of like a good discussion. So go ahead.

MR. RODACK: Tom Rodack from Westinghouse.

I'd just like to point out in the response to request for public comment, Humihassa Negassi (phonetic) from the Japan Atomic Energy Agency provided a letter that stated because of this progress loading conditions during and after a LOCA can be calculated today.

So someone at the Japan Atomic Energy Agency feels that we can calculate loads then.

MS. UHLE: The Office of Research actually has through cooperative program with OECD and the Committee for the Safety of Nuclear Installations, or CSNI, there is a proposal that is being considered by the committee to take a look at various modeling and, you know, fairly criteria for LOCA and compare what the other countries are doing. So we may learn something from that.

So we are not I would say ignoring what other people are doing. We're staying abreast of that, but at this time we're not where we need to be for the rulemaking as far as changing to something like load.

MR. MEYER: Does axial fuel relocation need to be addressed in the revised rule? What we're talking about here is fragmented fuel particles moving under gravity or some pressure down into the expanded

volume of the ballooned region. So this increases the mass of heat generating material in that node and would increase the temperature in that node.

The bottom line is we don't specify in the regulation how to do the calculation, nor would it affect the criteria that we're talking about because they are based on materials properties. It would affect the analysis and valuation models that are used to show compliance with the criteria.

We are going to do a little more work in this area, but I would say right now that there's ample information on this subject in earlier tests, particularly the German FR-2 tests which were done a long time ago, well instrumented, and I think Westinghouse, in fact, already uses the model for axial fuel relocation.

So it's something that can be done in the evaluation models and does not have an impact on the criteria that we're trying to revise.

MEMBER POWERS: Well, it seems to me that years ago, several years ago we had some gentlemen in here from Catarash (phonetic) who were advocating doing tests in the Phoebus reactor to look specifically at this issue. I can't remember what the basis for their argument that we're in desperate need

of experiments in this area, but I know that they essentially said we desperately needed experiments in this area, and I note that they have subsequently not done those. So it must have not been too desperately needed, but do you recall why they --

MR. MEYER: Let me take a cut at that, and then, Mike, you can fill in if I miss something.

IRSN is interested most of all in bundle effects. So in the Phoebus reactor they can look at the ballooning behavior of multiple rods in a bundle. We did this with UNERI and rod simulators back in the '70s and early '80s. We had multi-rod burst tests, and from those multi-rod burst tests we reached a conclusion that the balloons occurred at random axial locations and, therefore, one did not have to assume that they were all coplaner because if they were co-planer, the ballooning strain is is big enough that it would plug the whole thing up.

Based on actual tests, we concluded that they occurred at random axial locations largely because of small, random changes in temperature distribution which set off this instability.

IRSN's concern is that in high burn-up fuel you may have less temperature variation once you collapse the cladding and fill up all of the cracks

with goo, and that maybe you might get different behavior than we saw in our unirradiated, multi-rod burst test.

Also, some of the ballooning strains, just the individual rod strains and the flow blockage, which is a bundled rendition of those, that are customarily used are based on an old NUREG report, NUREG-0630, which was written before all of the testing was completed during this active period of research in the late '70s and early '80s, and so those ballooning strains in IRSN's opinion that we're using are a little too small.

So we're going to be looking at individual rod effects in our integral test, but not bundle effects. We don't have the capability of doing the bundle test, and the international community so far has not embraced the IRSN proposals sufficiently to provide the money to do it.

MR. BILLONE: That was a perfect answer.

MR. MEYER: Cooling rate effects. Okay. So we talked about quenching versus slow cooling, and here is the data slide. This is now the post test hydrogen concentration, which is a little better representation than the others that we use, and it shows this difference in cooling rate of, oh, about

four or five percent ECR when you're way out here, going to zero at low hydrogen.

So we have some data, and those data are available to the industry. The rule that we're talking about would use, well, not exactly that line, but a line based on the quench data, which is bounding for all heating rates, all cooling rates, but the way that we're trying to construct the rule would allow a licensee or a supplier to use other data for slower cooling rates, including using the data that we've already generated.

CHAIRMAN ARMIJO: Ralph, in your linear fit there, that's all from 800 Centigrade.

MR. BILLONE: Right.

CHAIRMAN ARMIJO: Now, would you expect less embrittlement quench from 700 or from 600?

MR. BILLONE: We did do those tests.

CHAIRMAN ARMIJO: You did do those tests.

MR. BILLONE: With prehydrided materials, and we did not get any benefit with our cooling rate.

CHAIRMAN ARMIJO: You did do that test.

MR. MEYER: That's a different story.

MR. BILLONE: We did 800, 700, 600, and then cooling without quench. We did a whole series for the same hydrogen content.

CHAIRMAN ARMIJO: And you found the same --

MR. BILLONE: And it was brittle for 800, 700, 600, and was ductile for the slow cooling with no quench. So at those rates that we're talking about, which is on the order of 100 to 300 seconds, to go from 1,200 to 800 or to go from 1,200 to 600 we didn't see it.

Now, our French colleagues with the thousands of seconds of cooling did see a benefit, but we just stopped testing that because we didn't see a benefit. I can't ask for below 600. I think Bert mentioned 400.

MR. DUNN: I did. One question. Have you repeated these tests now so that you've got more than one or is it still just one test?

MR. BILLONE: There were one series of tests.

MR. DUNN: One series of tests.

MR. BILLONE: Yeah. We have two actually, two series, but that was the better one.

MR. MEYER: And I think this is the last question which is about ballooning dimensions and flow blockage, and the answer here is, no, we don't need to do this before rulemaking because the amount of

ballooning and flow blockage is not hard wired into the rule itself. It's in the evaluation models, and those can be handled separately.

(Pause in proceeding.)

MR. BILLONE: All right. Who is the computer genius that can help me get out of this?

All right. This is part 2.

CHAIRMAN ARMIJO: We ask questions.

MR. BILLONE: Probably. Okay. This is Part 2 of the response to frequently asked questions, and one of the questions near and dear to my heart is were results from other laboratories considered and are they consistent with ANL's results. A lot of these answers are going to be a qualified yes.

Yes in response to both questions, but some perspective is needed on the term "consistent," namely, consistence doesn't necessarily mean the same answer, and the reason for that is consistency within data set scatter is anticipated if the same materials, same sample preparation techniques, same temperature histories for oxidation and quench, similar post quench ductility tests, meaning you're doing ring tests like we're doing them, and you're stopping those tests after the first significant load drop so you can measure permanent strain, something nobody in the

world does, and if you're running our tests at our temperatures, which is 135 degrees C., most of the world data is room temperature ring compression tests.

The exception is CEA and limited amount in the Russian program.

If you don't have these similarities, you would not expect to see consistency results or they're consistent, but you understand the differences.

So, again, let me reemphasize some things that we do. We settle on the 135 degree C., particularly for the 1,200 degrees C. test, and we rely on permanent strain change in diameter, measured change in diameter. To get a permanent strain, you can't crush the ring into four pieces and be like, you know, the old days where they tried to fit them together.

And I have to admit this idea of stopping at the first load drop came from a conversation I had with Rob Montgomery when he asked me could I fit the two or three pieces together, and I refused to do that, but I would be willing to try to stop the test.

And so for maybe 90 to 95 percent of our test samples we were successful in getting a single crack through that first load drop.

CHAIRMAN ARMIJO: Now you can answer my

question. Is a crack the full length of your specimens?

MR. BILLONE: Full length. We call failure the full length of the specimen all the way through the wall.

CHAIRMAN ARMIJO: Again, I still have this concern of initiating it at ends rather than -- because whether that would happen in a full length fuel rod segment.

MR. BILLONE: Again, really it's a matter of forget the full length fuel rod for a moment. We're doing a ductility screening test, and we're trying to do it in a consistent manner for all different materials and different hydrogen levels and oxidation levels. That's more important than the issue of a full length fuel rod. You wouldn't expect to have that kind of compression loading.

CHAIRMAN ARMIJO: I think it's a conservative test. I think what you're doing is a conservative test. I would expect --

MR. BILLONE: It's one of my -- you're going to have to wait.

CHAIRMAN ARMIJO: Okay.

MR. BILLONE: I'll have to pull something outside of my pocket.

CHAIRMAN ARMIJO: Okay.

MR. BILLONE: Okay. I want to speed up. So comparing data it's very difficult because nobody stops the tests to measure the permanent strain. You can try to compare offset strains, but it's better really to ask the question: is there consistency within the ANL data set?

Because we use the same furnace and we use the same temperature profiles, and everything else is the same except the material is different. So if you just look at, for example, Zircaloy-4 and our ductility values, which I'll show you in the next curve at 13 percent oxidation level or ECR, you get a range of five to 40 percent offset strain for different types of Zirc-4 within the ductile range. Yet the embrittlement threshold is very narrow for the modern materials. It's between 17 and 19 percent.

So if you just compare the Argonne results, and this is from the NUREG report except I've added this red line here, this is 15 by 15, modern Zirc-4. This is 17 by 17, modern Zirc-4. That happens to be Zirc-2, but you get a difference of about five to about 40 percent there.

However, they tend to come to the same value. So that's comparing things within the ductile

range, and you have to be cautious any time you see a bunch of ductility plots and it looks like a shotgun plot. You really don't expect to see consistent results with the same oxidation level for different materials, different vendor type Zirc-4s.

The other thing you have to be careful about is interpretation of what is embrittlement. Way back in the early '90s, Bamer (phonetic) has a famous paper on E110 and Zirc-4. He used ten percent total displacement as a measure of embrittlement. That's elastic plus plastic.

But what's more extreme is our Russian colleagues. If our Russian colleagues were looking at this same Argonne data, they would do the following. If we take the open circles, as I said, 15 by 15 Zirc-4, by the Argonne approach you get 19 percent ECR. The Russians take what they call a fracture mechanics approach, which maybe makes sense to Bill Shack, but not me. They will take this nosedive in the curve and come up with about 14 percent for the same data set.

So here you have the same data set and different methods for analyzing the data. Also, be very cautious if you ever read any of the Russian results. It's okay for Zirc-4, but they report everything in terms of measured ECR. They measure the

amount of zirconium consumed, and for E110 that is just the wrong metric completely to use.

So all of the results are about eight percent ECR for 1,200 degrees C., 1,100, 1,000 degrees.

MEMBER SHACK: Very consistent then.

MR. BILLONE: Very consistent results, but one test at 5,000 seconds to get to eight percent, and the other one will take 300 seconds, but they don't care. It's the same point. So just be very cautious.

There's some very good data in that report.

This is the variation between more of the modern, prehydrided Zirc-4 and the older type Zirc-4. I don't have a data point here, but you can use your imagination, and you would go from about five to 35 percent in that. In comparing it in the ductile regime, however, they both embrittle at about 375 weight parts per million. So there's a more narrow range.

So within the Argonne data set you can compare different materials in terms of were they embrittled, but within the ductile range it doesn't make sense to do that.

And then finally, again, we talked about

the high burn-up ZIRLO. These are two rings that were oxidized at 6.3 percent ECR, cool without quench, and we measured ten and 30 percent offset strains. We also were able to get a permanent strain from both of these rings because they had single cracks, one there and one there. These rings are right next to each other in the oxidized sample, and we got curious. Why would you get 30 percent for one and ten percent for the other?

So we mapped out the hydrogen profile and the loading. This is the loading direction. This ring failed on the side with about 640 weight parts per million hydrogen. Right next to it you've got a ring with a region up around 700 ppm, and the failure is at the bottom.

So this is the lower offset strain and the higher local hydrogen content. Are these results consistent? Well, they make sense. Let me just answer it that way. If you probe deeply enough into what's going on, mechanistically it makes sense that this would show higher offset strain.

Okay. It leads me into this plot. I'll go backwards and explain it. I think you saw it as part of the EPRI presentation, and it's comparing CEA data for slow cooling, slow cooling with quench and

direct quench to ANL data, but actually it's ANL data that's all from high burn-up fuel that was slow cooled, the H.P. Robinson.

I think they should really check these points here because they should be at about 6.2 percent ECR. So I think these points are shifted, but again, we're comparing things within the ductile regime. Let's go back and see what's going on.

The CEA tests are one-sided tests, outer surface oxidation, not a big deal. They're 17 by 17 AREVA Zirc-4. the ramp is really eight seconds to go from 1,000 to 1,200 degrees C. That's about 25 degrees C. per second. So essentially you're doing an isothermal test.

They hold at 1,200. They quench at 1,200, which is very, very severe, or they quench at eight. They cool the furnace slowly in about 1,000 seconds to about 800 degrees C. or about 2,200 seconds to 600 degrees C. or a very, very longtime to cool without quench.

So that's their heating and cooling scenario. As you know, our tests are basically two-sided. We use both 15 by 15 and 17 by 17 Zirc-4. Our ramps from 1,000 to 1,200 or more in the range of one to three degrees C. per second, and please note that

with these materials, you're accumulating five to six percent ECR at temperatures less than 1,200 degrees C. during the ramp. And then we're cooling much faster prior to quench than the CEA tests.

Also, the plot I'm showing you, the data are not really comparable with respect to ECR because you'll see plots of about three percent ECR from the Argonne data. That sample only reached 1,110 degrees C., whereas the CEA samples were all at 1,200. And the next data point only reached 1,060 degrees C.

So let's look at this and see if it makes sense to compare data. This would be, again, the high burn-up 15 by 15 Zirc-4 temperature history, and again, this is about three percent here. The CEA one-sided test, they get to about four percent after about 50 seconds at 1,200 degrees C., and either they're cooling like this, which is direct quench, or they're cooling very, very slowly and going off scale.

So I don't know why one would expect consistency within the ductile range of these points. It's like an apples and oranges comparison.

As far as consideration of data from other labs, let me make this quick because I think you probably should know this. We hosted a major LOCA topical meeting at Argonne in 2004; had presentations

from all the reputable people doing LOCA testing. Almost everyone, including us at the time, presented room temperature ring compression data.

We had also very close collaboration with Kurchatov Institute, RC and RAIAR -- sorry -- on the E110 work, and CEA, and I'd like to thank Bert for facilitating a big change on Zirc-4 and M5, and of course JAEA which was to be JARI (phonetic). We participate in their program review meetings. They participate in our program review meetings, and we have a lot of exchange.

What I do want to show you is just this last one. We did not generate any data for prehydrided M5 at Argonne. So we went into our last set of tests, which was high burn-up, ring holes, M5 cladding, with no clue on our own data as to what test temperatures and oxidation levels to shoot for.

But we did have access to the CEA data, and I'll show that in the next plot. Well, the temperature histories are not finished. We made that point.

Okay. We ran a series -- well, I'm sorry. The CEA data was published at 11 percent Cathcart-Pawel ECR. In other words, and in the previous slide it shows you your temperature history. I think it was

about 450 seconds at 1,200 degrees C., and they got I would call that low ductility, but definitely ductile, six to seven percent offset strain, and they don't measure permanent strain because they don't stop the tests. It's completely crushed afterwards.

And at 18 percent they got nil. I mean, it was completely brittle. So we used their data to know that we wanted to work within this range, and while I have that, so you could say these data are consistent. They don't overlap, and this is prehydrided, and this is high burn-up quench.

We ran into a problem with our last three tests and gave Ralph a little bit of a headache. We had been using the criterion of two percent offset strain as ductile, but we really have relied on permanent strain, and for each one of these without quench we got at least one value of permanent strain. Then we ran out of luck with these. We go fairly low ductilities, but all basically above two percent, and each one of these cracked into two pieces, and we never got a permanent strain measurement.

So when we look back at these values and compared, oh, this is 3.8 percent offset strain; it's 1.1 percent permanent strain, and we looked at the difference between the two, and you had to get really

above 3.5 percent offset strain to have confidence that you had ductility in the M5. And that's why I gave a range of 13 to 15 percent. I'm very comfortable in excluding that data point and saying that it's ductile at 13 percent.

You reading the report are free to interpret that data any way you want. It is all above two percent. We don't have any permanent strain measurements. I'm just not comfortable calling all of that ductile, and what we're looking for is some increase more dramatic than that. But the point really was we used the CEA data to set it.

Further testing need for zirconium-based alloys, yes, for embrittlement due to breakaway oxidation. I believe that's true. Maybe no for high temperature embrittlement. Maybe the vendor would want to do these tests on fresh cladding for new alloys, but it seems like the low zirconium alloy material, we don't see much scatter in all of the materials we've tested so far. So it's not clear whether new materials would be very much different than the 17 to 20 percent than we're measuring. So it's a maybe no for the high temperature embrittlement.

There's further testing. You know, this

is more embrittlement. These are all of the reasons why one would want to do embrittlement tests, and I guess I should point out that we talk about different processes for making E110 ingots from the ore versus the Western alloys.

MR. MEYER: Excuse me. The record should show doing breakaway tests, not just embrittlement tests; isn't that correct?

I don't think you mentioned the word "breakaway" in your previous -- it's okay. You're talking about breakaway.

MR. BILLONE: Yes, yes. Sorry.

MR. MEYER: I just wanted those words to be in the record.

MR. BILLONE: Yeah. There's reasons why you would want to do testing of future alloys with breakaway. We've already discussed them. There are just two points I want to make: that there are certain trace elements that may be beneficial, and they tend to be trace elements like calcium, magnesium, and aluminum, and I'll show that in an upcoming graph which have valances or charges less than plus four, which is zirconium. Things with greater than plus four like niobium and certainly fluorine, fluorine definitely is a killer as far as

growing stable oxide layer, and we'll talk about where that fluorine comes from in a second in the E110.

So given the variability and the difficulty of measuring fluorine, any possible changes to the manufacturing processes, I would say that's a yes. I don't have time to go through all of the answers.

Yeah, I do want to remind you of just the evolution. Obviously, our vendors are getting much, much better because as I showed before, in terms of breakaway, minimum breakaway time, we went from about 1,800 seconds to 5,000 seconds just by improving the normal performance corrosion behavior of the material, and basically avoiding pickling as a final step and making sure our surfaces are not rough, that they're polished.

I didn't present anything on the E110, but basically the breakaway time, looking at these times, the breakaway time is less than 300 seconds based on outer surface appearance, and about 600 seconds based on picking up 200 ppm of hydrogen. That's quite extreme compared to over 6,000 seconds for a comparable alloy, which is M5.

All right. You know the answer to this. Is extrapolation of the data to zero oxidation at 800

weight parts per million appropriate? No, it's not accurate, but if we had continued our testing, and this is for the ZIRLO in particular, for the hydrogen content we had, it's about five percent ECR, which means you had to transition, and that's 540 ppm of hydrogen.

If you go to higher hydrogen levels, you're just going to go down this curve, and this is about ten, 20 degrees C. So you will find some oxidation level at 700 ppm and 800 ppm, which are still ductile. It won't be zero, but it will be at a significantly lower temperature, and it just didn't seem meaningful to do these tests. It might be meaningful to do a test up to 1,000 degrees C. and hold just to see how you do and then try to show that that's a bounding temperature for that type of fuel.

So the extrapolation is zero; at 800 ppm hydrogen is not reasonable, and that's why if we had continued our testing -- I show this curve this morning -- it's more likely that we would curve because as you go to higher hydrogen contents, you're going lower on the temperature ramp. You're going to lower temperatures. It's very simple to understand.

Okay, and it looks like in a previous graph an interpolation of the embrittlement data seems

-- well, is it reasonable between 105, 50 weight parts per million? Of course, we'll be generating data at intermediate hydrogen level for high burn-up fuel, but when you throw in the prehydrided material, it looks like the interpolation is reasonable.

What we're doing is we had previously used 40 to 45 micron corrosion layer of ZIRLO where we had two segments at 25 to 30 microns. We don't know the hydrogen content yet, but it had better be lower or this whole hydrogen pickup fraction is all out the window if it's higher.

So interpolation is good. I think we had to do a little bit more work on this prehydrided under rated cladding to be used in LOCA embrittlement testing as a surrogate for rated cladding. Can it be probably I think definitely yes, but we don't have enough data yet to have confidence in one-to-one equivalence, and again, the issue for me is the circumferential variation of hydrogen.

Basically I could skip all of this and go to just one picture that I --

CHAIRMAN ARMIJO: Wouldn't you expect that the prehydriding in a laboratory situation would give you more uniform hydrogen?

MR. BILLONE: Well, those that do it well,

it's uniform and that's all proprietary. The ones that do it for EPRI, the ones that do it for JARI in Japan, the ones that do it for CEA where CEA does it. We're not so good at it. So we're good at generating radiance in a circumferential direction.

CHAIRMAN ARMIJO: That's your skill.

MR. BILLONE: Which has taught us a lot about how immobile hydrogen is.

Yeah, here's the point. This ring is -- I think I showed it earlier -- is a ductility of ten percent. They cracked in two places, but the hydrogen varied from 300 to about 600 ppm. Average is about 400. So if you want to know is prehydriding a good surrogate and you're going to use uniform hydrogen, you might want to do 400, 500 and 600. The 600 is probably too pessimistic. The 400 I'm pretty sure is a little too optimistic, uniform, and the 500 might be just about right.

So when I say a good surrogate, yes, but I'd like this, you know, as the floor. This is what you're going to compare it to.

Are you going to go with the average and the uniformly prehydride? that's okay if you cool without quench, as we found out, but if you're quenching and freezing that hydrogen in, you'll get a

difference in this versus a uniformly prehydrided.

I'm going to duck this one because the industry knows more than I do. Do manufacturing variables in trace elements have a significant .... behavior? Yes for breakaway oxidation. We have a lot of data on that, and I want to get to a bottom line on E110, which is partly -- we already know from Argonne's experience. See, these alloys come to us, but whatever is done to these alloys, these cladding materials is vendor proprietary. So we don't really know the details. We can measure surface roughness. We can send out to the lab to get certain chemical composition, not everything. We can do certain hydrogen and oxygen measurements at Argonne, plus diameter measurements and all of that kind of stuff.

But if you talk about E110, we know that when we pickle it with a recommended acid formula for Zircaloy-2, which is really the wrong thing to do because Zircaloy and niobium alloys are very sensitive. So we're sort of over etching the material. It looks like hell -- excuse me if this is being recorded -- after about 300 seconds. So you've got a completely white oxide layer.

So we know it has got surface contamination basically from our studies of fluorine.

If you look at how hafnium is reduced, there's a very high hafnium content in the ore, and by the time you get to the ingot you want low hafnium content. You can use fluorides, and the differences in these two solubilities to reduce the hafnium.

But notice that using fluorine you're introducing that as an impurity at a step between the ore and ingot. So my opinion about E110 is it could be multiple factors, but definitely fluorine would be the worst actor, the most mobile, and the most destructive for the growth of the oxide layer. It should be in the bulk of this, and it should be on the surfaces and the pickling that they use.

Let's skip that, skip that.

This is a Hee Chung, colleague of mine, conceptual idea of fluorine atoms and their migration essentially to the surface between the metal and the oxide and some of the ways they make the oxide unstable. The fluorine atoms are even more mobile than oxygen atoms. They definitely can move. They're more likely to end up at the surface than deeply in the oxide, but they can go in the oxide as well.

And we know from what we do to the outside of the material. So if you want to control something, and again, this is not my field of expertise. I'm not

a manufacturer of tubing. I don't even get the information from the vendors, but you definitely want to control fluorides, impurities, surface substrates, and bulk.

Okay. This is what you asked me about rings impression. So I've got to pull my other toy out. Okay. We'll go back to the earlier discussion.

Okay. Are they nonprototypical? Well, we don't know what prototypical is. So the question is not meaningful. We don't know what a prototypical LOCA load is, and are they overly conservative? That's really the question we should talk about.

So I don't think they're overly conservative, and again, nonprototypical is not relevant. These tests are standard screening tests for ductility. I already talked about why, the economy of size. I won't go into that again. But basically keep in mind that the loading leads to hoop bending stresses that go from positive and negative to the walls of the material. That's not a severe loading as an axial tensile loading or a ring expansion loading. It's a bending type loading.

The most comparable type of other testing that you could do, which probably is relevant to a loading mode and it's what we do with our big LOCA

interim specimens is axial bending tests because they are bending, inducing stress in a different direction, in the axial direction, but they'll go from positive to negative as you go through the material.

So in this case you're looking for a failure all the way across the material for brittle. In this case you're looking for a line across the material that's scaled to the wall. Just difference in directions.

And as I mentioned before, those that have done the comparisons, and CEA has done extensive comparisons between the bend tests and the ring tests, they find very good correlation at the oxidation level and hydrogen content or embrittlement from both testing methods. CEA prefers the bend test. They give a much cleaner load displacement signal from it.

CHAIRMAN ARMIJO: What's the nature of their crack? Is it an axial crack when they do a bend test or do they have circumferential cracking?

MR. BILLONE: It goes straight across.

CHAIRMAN ARMIJO: So it's a circumferential crack versus an axial crack?

MR. BILLONE: Yeah. I mean, you get the axial crack when you have a hoop stress in the ring.

CHAIRMAN ARMIJO: Right. And the bend

test, you're going to get a circumferential?

MR. BILLONE: You're going to get a -- well, however you want to describe it, but it's going to start on the tensile side and rip right through the material.

CHAIRMAN ARMIJO: Yeah, yeah.

MR. BILLONE: So you end up with two pieces.

CHAIRMAN ARMIJO: But the strains are about the same or are the same.

MR. BILLONE: No. The embrittlement, were they embrittled? You wouldn't expect the strains --

CHAIRMAN ARMIJO: I think we're saying this. I mean the same thing you are saying.

MR. BILLONE: Okay.

CHAIRMAN ARMIJO: It embrittles at the same level --

MR. BILLONE: Of oxidation and hydrogen content.

CHAIRMAN ARMIJO: Right.

MR. BILLONE: And so if it's brittle, it breaks and you have two straight pieces with no permanent deformation. If it's ductile, it breaks in two pieces, and the straight piece is broken.

That's my comment on the ring compression

test, and I'm almost done. I don't know if you want to cover this one, but --

CHAIRMAN ARMIJO: You had better.

MR. BILLONE: Okay.

CHAIRMAN ARMIJO: Somebody is going to already ask.

MR. BILLONE: Should CRUD be included in LOCA analysis? Yes, obviously for thermal hydraulics. No, for high temperature embrittlement. I can't say anything about what's in the CRUD chemically that would make it into the metal that would affect the metal's ductility.

MEMBER ABDEL-KHALIK: Even for plants that had zinc?

MR. BILLONE: Pardon?

MEMBER ABDEL-KHALIK: For plants that add zinc.

MR. BILLONE: Yeah?

MEMBER ABDEL-KHALIK: Does that change the nature of the oxide layer?

MR. BILLONE: The zinc, as I remember, is about midway. The zinc gets into the oxide layer, yeah. It does.

MEMBER ABDEL-KHALIK: So you think that would have no effect?

MR. BILLONE: No effect on high temperature embrittlement of the metal underneath the oxide layer, and it doesn't seem destabilize the oxide layer under in-reactor conditions.

The question is when you take this up to high temperature and during breakaway is there an effect of the CRUD, and that's what I want to reduce this question down to. I don't think it's going to affect. If you test at 1,200 degrees C., for example, to find out the oxidation level at which you embrittle, I don't think it matters whether you have tenacious CRUD and it's only the tenacious CRUD which would communicate with the oxide layer. It's on the oxide -- it's just not the corrosion layer outer surface as I'll show later.

CHAIRMAN ARMIJO: When you did your test of irradiated fuel, unless you removed the tenacious CRUD --

MR. BILLONE: No, we left it.

CHAIRMAN ARMIJO: It's already in your test result.

MR. BILLONE: Right. And we just have to do some metallography because this is the material we tested. This is the Limerick Zirc-4. I don't know if the contrast is good enough for you to see it. Very

thin corrosion layer. This is the cladding metal, and the lighter gray is the CRUD. And basically as you go around the circumference, that corrosion layer varied from like three microns to 18 microns, and you know, most spaces in which the tenacious CRUD was thick, the oxide layer was very thin. This is about three microns, and this is close to 18 microns, and you can't see any CRUD.

But that's the material we tested. These are the function of time. This is the unirradiated and this is the high burn-up. It's all tested, in cell. This is the 3,600 seconds for Zirc-2. This is 6,000. There may be some breakaway that you would expect to occur between these two.

So basically we just want to retrieve this sample and this sample, look at the metallography of the oxide layer on the outer surface, and verify that breakaway didn't occur. If it didn't occur, then tenacious CRUD in the BWR is irrelevant.

So at least we did the tests back in 2001, which is a matter of retrieving the samples, and then this is just a comparison of the weight gain. And I have to mention these are one-sided oxidation tests with some steam leakage over time. This increase could have been more inner surface oxidation. So

metallography is the answer for that one.

And I think that was my last question. Okay. Thank you for your patience.

CHAIRMAN ARMIJO: Okay. Question from the panel?

Okay. Mr. Clifford.

MR. CLIFFORD: First off, I'd like to emphasize something that was on one of Mike's slides based on some discussions I heard earlier. The point is whether or not you intend to behave differently than current domestic alloys, and I think the point I want to stress is all zirconium alloys will experience breakaway oxidation.

MR. BILLONE: Yes.

MR. CLIFFORD: It's not something inherent to E110. It's just the timing at which that phenomenon occurs. That's all I wanted to understand.

CHAIRMAN ARMIJO: I can do that.

MR. CLIFFORD: Okay. Well, I heard some questions back and forth and it sounded like there was some confusion.

CHAIRMAN ARMIJO: No, it's this unusually short time.

MR. CLIFFORD: Right, right.

MEMBER BROWN: What's the difference

between short and long?

MR. CLIFFORD: Three hundred seconds versus 3,000 seconds.

MEMBER BROWN: Oh, okay.

MEMBER SIEBER: There you go.

MR. BILLONE: Or 6,000.

MR. CLIFFORD: Or 6,000.

Okay. Moving forward with the rulemaking, as you've heard from the debate today, there are some challenges ahead of us both tactically and from a regulatory perspective. First of all, we need to craft a rule that meets all of the objectives with respect to replacing prescriptive criteria with performance based criteria, adding the flexibility of an optional test program, but also satisfies the legal requirements that are demanded by our Office of General Counsel.

So this will be a difficult task moving forward, and it will probably take us some time, a month or six weeks or eight weeks or so to really nail down how that language needs to appear to satisfy that criteria.

And another thing that's important, our goal here, as I described before, is to really provide top level requirements in the rule itself and try to

get down away from the rule when you get into the test protocols and the procedures and everything else, and that's what we aim to do, and let's just hope, cross our fingers that that's what we're able to do.

The regulations define a process for implementing changes to not only regulations but also regulatory positions to a given licensed power plant, and these are defined in 10 CFR 50.109. It's going to be a lengthy process once we draft this rule in determining what the effect of implementing this rule is, and then weighing this against the requirements of 50.109.

And as this paragraph says, there's two exceptions that kick you out. One is compliance. The other one is adequate protection. If you deem that these changes are either of those two exceptions, then it kicks you out of a cost-benefit assessment, and Dr. Powers was 100 percent correct when he characterized his position a couple of hours ago, and we have not yet begun our backfit determination, but this is something we're going to have to undertake in the near future.

Any questions on that?

MEMBER SIEBER: Yeah, I do have a question.

MR. CLIFFORD: Yeah.

MEMBER SIEBER: You can write a simple rule that addresses a specific safety issue and claim adequate protection or you can identify a specific safety position and write a comprehensive rule that covers a whole variety of things. In your cost-benefit analysis, you make that distinction and say, "I'm going to write a rule and enforce those portions of the rule that have safety implications and make the rest optional as long as the original analysis is bounding."

MR. CLIFFORD: I'm not sure that's been done before, but I agree in concept you could do that. For instance, if you were to show at the end of the day that 17 percent was valid for all alloys, but you were just expanding the applicability. That's something you could do more readily than by changing the criteria. You can get into more questions.

MEMBER SIEBER: Well, if you had a situation where breakaway oxidation was an issue that undermines the current rule, that otherwise the current rule is adequate for maintaining adequate protection, would you write a whole new rule that changed the procedure or would you deal with the subject of oxidation?

MR. CLIFFORD: Are you asking whether you can break up these findings into different pieces and do a different backfit analysis for each? Is that what you're asking?

MEMBER SIEBER: I'm asking if you would impose a broad scope rule as opposed to addressing a specific subject.

MEMBER SHACK: He just wants to add essentially the breakaway to the current 50.46.

MR. DUDLEY: I'm Richard Dudley. I'm the rulemaking project manager.

In this case the Commission has directed us to go forward with a performance based rule. It's not our decision at this point, and so your fix, which is just to do something to fix the breakaway oxidation, we are not actively --

MEMBER SIEBER: If the rest of the rule were adequate.

MR. DUDLEY: Yeah, right, if the rest of the rule were adequate.

MEMBER SIEBER: And that's the Commission's decision to make.

MR. DUDLEY: And the Commission has made that decision in the 2003 SRM, right.

MEMBER RAY: Well, in that regard, you say

you haven't yet made this determination. Supposing in making the determination you conclude that it's not required for adequate protection and it's not cost justified to do. Then what happens?

MR. DUDLEY: We would not go forward with that.

MEMBER SIEBER: Yeah, you'd go do something else.

MEMBER RAY: Notwithstanding the Commission's direction?

MR. DUDLEY: We would tell the Commission in a SECY paper why we could not implement their direction based on our existing regulations and processes and procedures.

MS. UHLE: Or the results of the option of doing a forward fit rule, which would mean impose particular requirements on those licensees that have, you know, started operation past a certain date or whatever. So that's called forward fitting, and then you don't have to pass the backfit rule.

MEMBER RAY: Well, you can make changes without them being a backfit. They can be optional. We've talked about it here many times today.

MS. UHLE: That's true, but that's not --

MEMBER RAY: I'm really asking the

question would you then not do it as an optional of performance based --

MEMBER SIEBER: Yeah, either/or.

MR. DUDLEY: Well, you mean if we determined it wasn't adequate protection?

MEMBER RAY: If you can't pass the backfit test, does that mean you don't do anything or could you implement a rule that was an option?

MR. DUDLEY: Oh, okay. Yes, we could still implement a performance based rule. That's correct.

MEMBER RAY: Okay. Well, that was the question I was asking.

MR. DUDLEY: Right, okay. I must have misunderstood.

MEMBER SIEBER: You can do it like the fire protection rule where you have two alternatives. One of them is deterministic. The other one is --

MEMBER RAY: Yeah.

MEMBER SIEBER: -- 05 which is a performance measure.

MR. DUDLEY: Okay, yeah.

MEMBER SIEBER: And give the licensee a choice.

MS. UHLE: Or the forward fit option.

MEMBER SIEBER: Okay. That helps my understanding of the law.

MR. CLIFFORD: I'm not going to spend any time on this slide. This just reiterates that the industry has provided us with some expectations of what the cost of implementation would be and their significance. This is a summary of what they've provided.

That's essentially all I have for this. Trying to get us back on time.

(Laughter.)

CHAIRMAN ARMIJO: Congratulations, Paul. That's terrific. Very good.

Now, any comments from --

MEMBER SHACK: I just have a question that's irrelevant to this, but it was Said's question on the zinc additions. You know, was there any qualification of the fuel in terms of its 50.46 behavior done for zinc additions? I mean, I wouldn't expect a big deal, but you know, it's not completely obvious to me that it doesn't change transport through the oxide.

MS. UHLE: But I think the question is have we tested to the effect of water chemistry on the primary side.

MEMBER SHACK: Yeah, when you were accepting zinc additions.

MS. UHLE: Oh, oh. That's a different question.

MEMBER SHACK: That is different, yeah. You know, you've accepted zinc additions, and you've checked some things, but did you check their behavior?

MEMBER POWERS: I cannot understand how you would incorporate zinc into the outside without introducing vacancies. And vacancies is the key to moving oxygen through the oxide layer.

CHAIRMAN ARMIJO: Well, the zinc --

MEMBER SHACK: Well, I'm not asking for a -- all I want to know is did we do any tests.

MR. SCOTT: This is Harold Scott from Research.

The Halden reactor project in Norway ran a series of tests, I think, sponsored by the project to see what would happen if they had zinc in the coolant on cladding. I don't --

MEMBER POWERS: During the LOCA or just normal operations?

MR. SCOTT: Just normal, normal, sorry, normal operations.

MEMBER POWERS: Okay.

CHAIRMAN ARMIJO: But in a LOCA, the zinc if it's there could be some sort of a zinc oxide, and it will be reduced just like the zirc oxide is reduced and dissolved into the metal. But it's a small amount compared to the iron oxide which is the bulk of the tenacious CRUD.

And if it has already been in your irradiated fuel samples and you didn't grind it off, it has already had its effect, whatever it is, in your data.

MR. BILLONE: I have to look. We did detailed analysis of the CRUD in terms of what was in there. I remember some of them, but I --

MEMBER ABDEL-KHALIK: But you probably got your stuff from plants long before zinc addition.

CHAIRMAN ARMIJO: Oh, yeah. It was long before zinc, but zinc is trivial. It's mostly iron oxide.

MR. BILLONE: Limerick came out of the reactor in '99 or something like that.

CHAIRMAN ARMIJO: From which plant? Robinson?

MR. BILLONE: No, the Limerick.

PARTICIPANT: You didn't add zinc in Limerick.

MR. BILLONE: Okay.

MR. LIN: This is Yang-Pi Lin.

I think the Limerick most probably had zinc. There were two plants. One of them had noble metal without exposure and one of them did not. I'm not quite sure which one it came from.

CHAIRMAN ARMIJO: We could find out.

MR. BILLONE: Anyway, we did measure it. I just can't remember.

PARTICIPANT: I'd say more PWRs.

CHAIRMAN ARMIJO: Right. That's pretty recent.

MEMBER RAY: Maybe I ought to ask this question of Jack since he read it. I didn't. Was the Commission's decision based on the expectation that they would pass the backfit rule or was it based on a general belief that a performance based rule would be a better rule and more supported by the industry or more beneficial from the industry viewpoint?

What was their motivation?

MEMBER SIEBER: I wasn't there at the time, and I read the part where they told the staff what to do. Perhaps the staff can.

MR. DUDLEY: My understanding was that it was to implement a performance based rule, to make it

easier for vendors and licensees to use new cladding materials that weren't specified in the existing 50.46.

It seems like independent from perhaps the initiation of the rule the fuel research program that was going on that had been initiated earlier developed information that is affecting our ability to do a performance based rule.

MEMBER RAY: Okay, but inherent in the initial Commission decision, it seems to me, is the optionality notion. Like Jack said, every other example I can think of it's an option because you can't pass the backfit rule when you implement a performance based alternative to an existing deterministic rule.

MR. DUDLEY: Okay, yes. Right.

MEMBER RAY: So I don't see that the Commission's direction has really anything to do with the backfit analysis. It either passes or it doesn't, but you still have the Commission decision.

MEMBER SIEBER: Well, the interesting thing to consider is the Westinghouse analysis that all reloads would have to be done in accordance with the new rule at the cost of hundreds of millions of dollars and so forth, which to me I think has to be

justified by some increase in safety someplace along the line, if in fact that's true.

MEMBER RAY: I reject that.

MEMBER SHACK: On the other hand, I think all of this research has been a worthwhile endeavor, and I think an alternative performance based rule is a good idea, and I also think a new phenomenon has maybe not been identified, but brought to the forefront with these further investigations.

So there are good outcomes here.

MEMBER RAY: Yeah, yeah. I agree entirely, but this threshold question of backfit or not backfit I think is an important element of this whole process that I'm just trying to focus on.

MS. UHLE: Well, Jennifer Uhle from Research.

I mean the history here was originally there was a petition for rulemaking that came in and said that industry was interested in having performance based rules so that they didn't have to do exemptions. That was started. Previously there was a research program underway identified really and driven by Dr. Meyer concerned about the effects of high burn-up. That work was going on.

So when the Commission has looked at this,

they were focused on two different things. However, it was wrapped together in the same rulemaking.

Now, recently there has been an issue of the priority of this rulemaking, and it was rated as a high priority rulemaking in part because of the safety issue because typically if it's a burden reduction type issue with, you know, getting away from having to do exemptions, that would not be typically rated as a high priority rulemaking.

So the Commission is aware of the safety question and whether or not it passes that is obviously something that we have to consider.

MEMBER SIEBER: Well, was there anything about the existing rule that is non-conservative to the point where a new rule from a technical standpoint is needed?

MR. BILLONE: Seventeen percent.

MEMBER SIEBER: Explain that please for the record.

MR. BILLONE: It says below 2,200 F. and below 17 percent.

MEMBER SIEBER: Right.

MR. BILLONE: Less than or equal to 17 percent emission. That is not conservative, and particularly at the lower temperatures where you get

breakaway oxidation on one side of the process.

MEMBER SIEBER: Okay. During breakaway oxidation is separate from --

MR. BILLONE: It's non-conservative.

MEMBER SIEBER: Seventeen percent is still not a valid measure?

MR. BILLONE: Well, present year (phonetic) alloy doesn't look too bad for M5. For alloys that pick up greater than PK of hydrogen, it's non-conservative.

MEMBER SIEBER: So is that justification for an adequate protection finding?

MR. BILLONE: I can't answer. Someone else has to answer.

MEMBER SIEBER: It could be.

MS. UHLE: Yes.

MR. DUDLEY: Yes, yes. I mean, I can't make that decision, but you know, that's certainly an argument we would likely make.

MEMBER SIEBER: Well, but that sort of fleshes out the argument as to what path to take, we take, as to whether there are adequate protection issues buried in all of the discovery that came out of the research that's been done.

CHAIRMAN ARMIJO: Well, I still want to

get back to a real clear answer. I've heard it from Mike. Is the 17 percent non-conservative ignoring breakaway, ignoring breakaway; is it non-conservative for the modern alloys in use in power plants today?

MS. UHLE: The answer to that is yes.

CHAIRMAN ARMIJO: Okay.

MEMBER SIEBER: That helps the court reporter rather than the shaking of the head.

MS. UHLE: And I would say I would modify that. Yes, under certain circumstances. It depends on how long the fuel has been in there and it depends on the maximum temperature that the particular plant is going to see during a LOCA. So it's a complicated yes, but, yes, there certainly --

CHAIRMAN ARMIJO: If you go through the complicated analysis, the question is is it really non-conservative. You haven't done them.

MS. UHLE: We have done those, and yes, it is non-conservative, but again, it's not always non-conservative, depending on how the plant is operated and how long the fuel has been there.

MEMBER SIEBER: So that's the point upon which your argument should be built. The research leads us to these conclusions: breakaway analysis, non-conservatisms, in some cases for the 17 percent

oxidation, and so forth, and I think that helps you case.

We listen to a lot of analysis and data to reach that conclusion, you know, pretty much by listening to the facts you had as opposed to the arguments, and that's okay, you know. But it is better to bring the argument out first and then say here are the facts that prove it.

CHAIRMAN ARMIJO: Go ahead, please.

MEMBER BROWN: That's non-conservative for all existing?

PARTICIPANTS: No.

MEMBER BROWN: Non-conservative for what then? We've got a bunch of existing plants in which you hit the refuel. You have to do a whole bunch of things. Are those plants conservative or non-conservative today as they're operating with reloads, their existing design fuel?

MR. CLIFFORD: We have completed an operability assessment to conclude that there's no current safety issue, but that doesn't conclude that the rule as written can be applied in the future because the rule as written says that you could have up to 17 percent anywhere for any fuel under any condition, and you would maintain post quench

ductility. That part of the rule is incorrect.

That's a different question than --

MEMBER BROWN: I'm just looking at Ralph's curve or the thing his, straight line for all hydrogen concentrations or pickups, and the way I read that based on his conversation was that that line is not good.

MR. CLIFFORD: The single line is not good.

MEMBER BROWN: The single line is not good. I'm a real dummy, okay? And I'm playing the part of dummy here that's listening to this conversation, and all I've heard you say is that that means existing plants today.

Well, it could be, could be. There's a consideration of something that happens where how it is operated in the plant, where the plants are non-conservative, and we tend not to like that. That tends to be bad from a public safety standpoint. If you have an accident or whatever, you could have a fairly catastrophic event.

So I'm sitting here trying to put that in context, again of being the local dummy, of why doesn't that require some type of action, why you're not going to shut down everybody. On a go-forward

basis, you would have some type of action that would put you into a curve or at least a type of cladding that doesn't have this problem of its hydrogen, you know, whatever the pickup that it can see.

MEMBER RAY: It does require action, and they are taking it.

MEMBER BROWN: Yeah, well, that means this rule is not -- it seems to me the rule is not optional per se. That's why I don't get the backfit --

MEMBER RAY: Well, because different people have to do the backfit decision. It's a process issue.

MEMBER SIEBER: I think that's what the staff has told us.

MEMBER BROWN: I understand that, but if it's not good, then why --

MR. DUDLEY: If we make the adequate protection decision, I don't know that we even have to go through the backfit analysis. I mean, we don't.

MEMBER SIEBER: No, you don't, but you have to make the decision.

MR. DUDLEY: Right.

MEMBER POWERS: But you nearly always go through the backfit analysis just to put it into the state of consideration.

MR. DUDLEY: In addition to that, we do a regulatory analysis of every rule, and we have to make sure the rule on itself is cost beneficial overall, not just, you know, over the backfit part.

MEMBER SIEBER: Okay. Let's move on.

CHAIRMAN ARMIJO: Any other comments?

MEMBER BONACA: No, except, I mean, the point is that nobody is arguing that the rule change should not take place. I believe the industry argument is that there should be more research about some of their concerns. So I don't see that there is a disagreement on the rule change. It's a question of the timing and the kind of reporting information.

I believe that there is enough information that comes out that something has to be done, and you can't just put it off continuously.

So no further comments.

CHAIRMAN ARMIJO: Dana?

MEMBER POWERS: Well, we've written twice to the staff saying move this important research forward into the regulatory process, and commented twice that don't get hung up on looking at reg. guide issues before you break the rule.

It looks like the staff is going to propose an advanced notice of proposed rulemaking. I

don't fault them there. It's as good a strategy as any, especially when you've got open questions. I'm disappointed that they haven't thought out their open questions on this better.

And okay. It takes time people are saying and it will get done.

What I'm concerned about, it keeps coming in that there's always a little more research to do and a little more research to do. There will always be a little more research to do. I think they've got a good understanding, adequate understanding to write the rule. I'll bet there is research they have to do after their advanced notice of rulemaking when they get the comment, but we've got to get to that quickly because there's so much research that could be done in connection with this issue, and you just don't have the money to do it all. You've got to focus in on the things that really need to be resolved.

One of the bio ears that you had before you that you've gold us is a testing protocol, and I would move aggressively to get all of the help you can in drafting that, and the industry seems to have some ideas in that area. I would hope them not to be in the dark on developing that protocol for the advanced notice of rulemaking just because that's strictly

mechanics.

And, again, you can get tied up into reg. guide level of issues on that testing protocol versus regulation level of issues, and I would kind of avoid that. You can't separate them completely, but I'd get on with it. It's time to move this thing forward, and I just can't say that enough because we've written on this thing for now four years saying move this forward, and so I'm happy you're moving it forward.

I can't do anything about the past four years, but I can sure encourage you to move expeditiously here because this is going to be a somewhat tricky rulemaking, and you're in far, far better shape here on Paragraph B than the people are on Paragraph A. So get this one out because the folks in A have got some real headaches.

MEMBER ABDEL-KHALIK: I have a conflict of interest. So I'm just here to exercise my curiosity. I'm very curious I'll have to admit, Bill.

I would agree with what Dana said that we really do have enough data to support moving ahead with this new rule, and we ought to move forward.

MEMBER SIEBER: I agree with that. You never have enough data.

MEMBER RAY: I just would encourage future

discussion of this to emphasize the matters that we've just talked about here recently as opposed to sort of the historical perspective that this is performance based and something that the industry initiated and maybe the Commission endorsed, but this is more important than that.

MEMBER BROWN: I kind of shot my wad with the little graph. In my prior incarnation, if we came across something like that we would move somewhat expeditiously to make sure that whatever we put in next didn't have this particular propensity for catastrophic, potential catastrophic problems under some particular scenario.

So I guess I can do nothing more than echo the speed at which this progresses, and I want to emphasize I think his point about stay away from this, it would be nice if we could build new fuels and new cladding and all of that stuff, but it sounds like there's a safety issue associated with it that far exceeds the other issues.

MEMBER SIEBER: I think the staff did a good analysis and the presentations were good today. I think we got to the right point.

CHAIRMAN ARMIJO: Well, I want to get mine. First of all, I'd like to thank the staff and

the industry presenters for a lot of valuable information, clarified a lot of misunderstandings, and brought some things to clarity that weren't clear before.

I generally agree with what the rest of the Committee members say. I think, of course, I was a development guy. So I tend to like more data rather than less, but I think there's an adequate amount of data to do this. But in creating the rule and the related regulations, I would hope that the staff would write this rule in a way that does its intended safety function, that doesn't put a chilling effect on the development and introduction of new materials because I think the very fact that we have these superior materials today that we didn't have 20 years ago says that without any unnecessary or excessive regulations the industry has moved in the better direction, and I think the recognition of the importance of hydrogen gets us into a physical world instead of just a prescriptive, regulatory language world, and I think that's fundamentally the right way to go in any case.

I'm looking forward to see what the language looks like. I would hope there would be some flexibility so that the licensees could use the rule in an optimum way.

For example, I think initially there was a high burn-up where it's the name of the game. High burn-up, big problem. But I think I'm leaning towards the direction, and I think Ralph said it well. It's probably the second type of fuel, PWR fuel, maybe BWR as well. That's where the issues are. Plenty of energy in there, enough hydrogen to do some damage, and that's where we've got to concentrate and let's not try to get the last bit of energy of his third cycle fuel. So that kind of flexibility I think would be helpful.

MEMBER SIEBER: Burnable poisons would do it.

CHAIRMAN ARMIJO: Well, I don't know about their burnable poisons, but usually they burn out pretty quick in the first cycle.

MEMBER SIEBER: They can or they don't have to.

CHAIRMAN ARMIJO: Well, I don't know. Whatever they use.

But with that, that's all I have, and again, look at this. Five minutes ahead of schedule.

MEMBER POWERS: Once again, poor planning on your part.

(Laughter.)

CHAIRMAN ARMIJO: Ralph wants to say something.

MR. MEYER: Well, I just wanted to point out something that hadn't been mentioned before, and I'm reminded of this by Sam's comment about the general improvements that have taken place in the fuel design.

The original 17 percent was intended to be used with the Baker-Just correlation. By switching to Cathcart-Pawel and keeping 17 percent as the starting point, we've automatically given three percentage points credit for the improvements in the fuel design.

MEMBER SIEBER: That's right.

CHAIRMAN ARMIJO: Unintentional.

MR. MEYER: No. No, no, not unintentional. We saw it in the data.

CHAIRMAN ARMIJO: Back then.

MR. MEYER: And, you know, tying this to 17 percent is partly a visual trick. Everybody is used to seeing 17 percent, but it's now 17 percent with Cathcart-Pawel, which is three percentage points better than 17 percent with Baker-Just.

CHAIRMAN ARMIJO: Yeah, good point. I didn't even realize that.

Okay. With that, I think, yeah, direction

for Thursday. We have what, two hours?

PARTICIPANT: No, we have an hour and a half.

CHAIRMAN ARMIJO: An hour and a half? I think probably the bulk of the presentation should be obviously Paul and Argonne, as you see fit, you know, very condensed. I think there should be maybe half an hour for the industry to kind of pull their stuff together.

MEMBER POWERS: I would think with the full Committee you'd want to focus totally on the regulation strategies, that the technical content, the bases, what can be truthful and minimal, the advanced notice of proposed rulemaking and what you're going to try to achieve there.

MR. CLIFFORD: So you're saying minimize or skip the industry portion of the presentation?

CHAIRMAN ARMIJO: Well, I think the industry has some issues. They certainly raised the issues of implementation costs, but again, that's depending on how the rule actually winds up, but you know, they should have some time to state their top level issues, and the fact that they're continuing research on their own to fill in some gaps which they perceive exist. I think that's kind of -- you know, I

can't tell them what to say, but that's what I would hope they'd say.

But I think concentrating on the regulatory steps moving forward.

MEMBER ABDEL-KHALIK: If I may say so, I think it would be very valuable to someone who was going to listen to you for only an hour and a half to know why the current rule is non-conservative.

MR. BILLONE: Right up front.

MEMBER ABDEL-KHALIK: So if you would just focus your technical presentation on that so that --

MEMBER BROWN: I would suggest using this part of the -- something graphically to explain the old rule, the changes, because I didn't pick that up until whoever, Ralph did this at the end. That's in the response to industry comments. That wasn't very clear.

MEMBER ABDEL-KHALIK: Because if you don't do that, people will say, "Why are we doing this?"

MEMBER SIEBER: Right. Yeah, that should be the intro.

CHAIRMAN ARMIJO: Okay. If that's it, this meeting is adjourned.

(Whereupon, at 4:57 p.m., the Subcommittee meeting was adjourned.)

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Background Material
50.46(b) Rulemaking

ACRS Materials, Metallurgy & Reactor Fuels Subcommittee Meeting
December 2, 2008

Paul M. Clifford
Division of Safety Systems
Nuclear Reactor Regulation

Background Document

- In April 2000, the Nuclear Energy Institute (NEI) submitted a petition for rulemaking (PRM-50-71) which requested the NRC amend 10 CFR 50.46 to allow the use of zirconium-based cladding alloys other than “zircaloy or ZIRLO.”
  - Eliminate need for exemptions.
- On March 29, 2002, the staff issued SECY-02-0057 which recommended modifying 10 CFR 50.46 to provide for a more performance-based approach to meeting the ECCS criteria.
  - Investigate post-quench ductility of cladding on high-burnup fuel.
  - Develop embrittlement criteria that would enable licensees to use cladding materials other than zircaloy and ZIRLO without needing exemptions.

Background (Cont.)

- On March 31, 2003, the Commission issued a staff requirements memorandum (SRM) on SECY-02-0057 that approved the staff's recommendation to modify these criteria.
- On August 21, 2003, the staff updated the high-burnup research plan (EDO memorandum to the Commissioners) to develop the technical basis for establishing modified acceptance criteria at the earliest date possible.
- In March 2007, the NRC received a petition for rulemaking (PRM-50-84) from Mark Leyse (public). The petition requested the NRC to modify 50.46 to specifically address the thermal effects of CRUD and oxidation layers on fuel cladding and to establish a maximum allowable level of hydrogen in fuel cladding.

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Technical Basis

- In June 2008, the Office of Research (RES) provided NRR with technical basis information in NUREG/CR-6967 and RIL 0801 to support the cladding acceptance criteria rulemaking.
  - The staff is now evaluating the adequacy of this technical basis.
  - Considering a request for a few more items to complete the technical basis so that rulemaking may begin. These items include well documented, comprehensive test procedures.
- ACRS subcommittee has received briefings on the progress of the LOCA research program.
  - October 9, 2002, September 29, 2003, July 27, 2005, and January 19, 2007.

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Technical and Regulatory Challenges Revising 50.46(b)

ACRS Materials, Metallurgy & Reactor Fuels Subcommittee Meeting
December 2, 2008

Paul M. Clifford
Division of Safety Systems
Nuclear Reactor Regulation

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Regulatory Challenge

- Developing a performance-based rule which meets the objectives of the rulemaking plan (e.g., optional testing program) while satisfying legal requirements (e.g., specific enforceable requirements).
  - Performance-based rule more difficult to script.
  - Specifying optional test protocols within rule versus regulatory guidance document.

10 CFR 50.109

- Backfit determination per 10 CFR 50.109.
  - If the proposed change in regulation qualifies as either an exception (e.g., compliance, adequate protection) or cost-justified substantial increase in safety under the provisions of 10 CFR 50.109, an implementation schedule for applying the new criteria and guidance to both the current reactor fleet and new reactor fleet will be proposed.

Implementation

- Implementation could take several years and be costly for both industry and NRC.
  - Develop hydrogen uptake model for each alloy.
    - Review and approval of new model.
  - Revise LOCA models and application methodologies.
    - Review and approval of updated models and methods.
  - Perform plant-specific ECCS Performance Analyses.
    - Review and approval of new UFSAR Analyses-of-Record.
  - Execute ongoing periodic testing.
- If licensee/vendor elects optional testing to establish alloy or plant specific criteria.
  - Complete optional test program.
    - Review and approval of new criteria.
- Estimates provided by the industry are significant.

Revised 50.46(b) Implementation and Cost-Benefit Considerations

ACRS Materials/Metallurgy/Reactor Fuels
Subcommittee Meeting

December 2, 2008

Westinghouse

Organization of Comments

- Implications of Proposed Changes
- Expectations of Implementation Requirements
  - Assumptions
  - Steps required
    - Cost/resource/timing considerations
- Cost-Benefit Assessment
- Conclusions

Implications of Proposed Changes

- Current LOCA Evaluation Models will Likely Require Re-licensing
  - Some form of ID oxidation treatment
  - Explicit methodology for BOL through EOL

- Additional Testing Likely
  - Ring compression testing (RCT) with hydrogen-charged specimens
  - Breakaway oxidation
  - Expanded hot cell campaigns to license corrosion-hydrogen relationships
  - “Periodic” testing is also being discussed

Expectation of “Full Scope” Implementation Requirements

- Assumptions
  - All operating reactors will need to demonstrate compliance
  - Most will need to perform new small and large break LOCA analyses to do so
  - Most or all vendor LOCA Evaluation Models (EM) will need to be revised to demonstrate compliance
  - All Tech Spec Administrative Controls sections will need to be revised to reference new EM (or other basis for demonstrating compliance)

Expectation of Full Scope Implementation Requirements – Steps Required

- Vendor Updates EM and Re-submits
  - Treatment of ID oxidation, burnup methodology
- NRC Reviews and Approves
  - Methodologies likely to differ among vendors
- Licensee Obtains New Analyses from Vendor

Expectation of Full Scope Implementation Requirements – Steps Required

- Licensee Prepares and Submits License Amendment Request to Revise EM Reference in Tech Specs
  - New burnup-dependent peaking limits may be required
- NRC Reviews and Approves LAR
- Licensee Implements Revised Tech Specs, Updates UFSAR
- Licensee and Vendor Monitor Compliance with Limits on Continuous Cycle-by-Cycle Basis
  - Corrosion & Peaking factor burndown vary cycle by cycle

Cost/Benefit Assessment

- Testing Costs (Per Vendor, Per Alloy)
  - Hydrogen-charged RCT database ~ $1M
  - Expanded hot cell database ~$10M
  - Potential periodic testing (not defined) - ?
- Cost to Vendors and Licensees to Re-license EM, Re-analyze Most Plants, Update Licensing Bases, and Monitor Cycle-by-Cycle Compliance
  - Estimated as several hundred $M
- Cost to NRC in Terms of Resource Requirements
  - Estimated at 10-50 EMYr for entire US fleet

Conclusions

- Costs are Very Significant and New Rule will have Little Benefit to Public Health and Safety
  - Major diversion of resources at a critical stage in the industry's goal of supporting US energy independence
  - Several hundred $M for full scope implementation
  - Cost-Benefit needs to be considered throughout process
- Implementation Requires Multiple Vendor/Licensee/NRC Interactions
  - Phased submittals and/or reduced scope implementation a must if rulemaking proceeds

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Strategy for Revising 50.46(b) Fuel Performance Criteria

ACRS Materials, Metallurgy & Reactor Fuels Subcommittee Meeting
December 2, 2008

Paul M. Clifford
Division of Safety Systems
Nuclear Reactor Regulation

Current Regulation 50.46(b)

(b)(1) *Peak cladding temperature*. The calculated maximum fuel element cladding temperature shall not exceed 2200º F.

(2) *Maximum cladding oxidation*. The calculated total oxidation of the cladding shall nowhere exceed 0.17 times the total cladding thickness before oxidation… If cladding rupture is calculated to occur, the inside surfaces of the cladding shall be included in the oxidation

(3) *Maximum hydrogen generation*. The calculated total amount of hydrogen generated from the chemical reaction of the cladding with water or steam shall not exceed 0.01 times the hypothetical amount that would be generated if all of the metal in the cladding cylinders surrounding the fuel, excluding the cladding surrounding the plenum volume, were to react.

(4) *Coolable geometry*. Calculated changes in core geometry shall be such that the core remains amenable to cooling.

(5) *Long-term cooling*. After any calculated successful initial operation of the ECCS, the calculated core temperature shall be maintained at an acceptably low value and decay heat shall be removed for the extended period of time required by the long-lived radioactivity remaining in the core.

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Mission Statement

- Following Commission directive, develop a performance-based rule which captures the results of the LOCA research program and enables licensees to use cladding materials other than zircaloy and ZIRLO without needing an exemption.

Rulemaking Objectives

- Based upon the NRC LOCA research program, develop and implement a revised rule which accomplishes the following objectives:
  - Replace prescriptive criteria with performance-based regulatory requirements that accommodate fuel burnup effects.
    - Revise oxidation criteria within 50.46(b)(2).
    - Add flexibility of optional test program.
  - Introduce new performance requirement related to maintaining cladding ductility for extended LOCA scenarios (i.e., breakaway oxidation).
  - Expand applicability beyond “zircaloy or ZIRLO”.

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Await Further Research?

- Should the NRC await further research prior to rulemaking?
  - The LOCA research program was developed to investigate potential alloy and burnup effects on the current regulation.
  - Tests at ANL demonstrate that the current regulation is inadequate at preserving post-quench ductility (PQD).
  - A sufficient technical basis will soon be available for revising and expanding the regulation.
- It is prudent to revise the regulation and restore its margin of safety.

Applicability

Strategy:

- Replace “zircaloy or ZIRLO” with less specific terminology (e.g., approved zirconium-alloy).

Technical Basis:

- Empirical database includes wide range of zirconium alloys.
- Applicability to new alloys will need to be demonstrated by testing.

Peak Cladding Temperature

Strategy:

- No change to existing criterion.

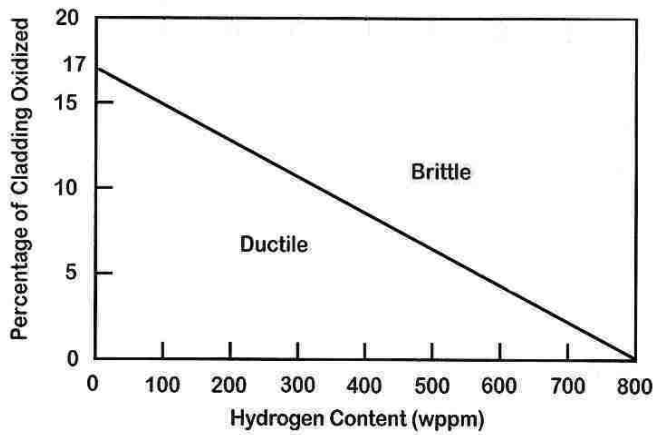
Technical Basis:

- No change required based upon PQD test results.
  - PQD decreases dramatically in oxidation beyond 2200°F.

Local Oxidation

Strategy:

- New PQD criteria specified within rule (allowable CP-ECR versus pre-transient hydrogen content)



- Optional test program for defining alloy-specific or temperature-specific PQD criteria.

Local Oxidation (cont.)

Technical Basis:

- PQD test results.
- Comprehensive test program.

ID Oxygen Diffusion

Strategy:

- Captures observed oxygen diffusion from fuel bonding layer on cladding inner diameter.
- Burnup threshold proposed to account for fuel rod design and power history effects.

Technical Basis:

- RIL0801.

Breakaway Oxidation

Strategy:

- New performance requirement related to maintaining cladding ductility for extended LOCA scenarios (i.e., breakaway oxidation).
  - Required testing to establish measured break-away time.
  - Required periodic testing.

Technical Basis:

- Break-away oxidation testing.
- Comprehensive test program.

Optional Test Program

- Regulations within 50.46(b)(2) specify general requirements for optional testing:
  - Criterion for the ductility test would be 1% plastic strain using ring-compression tests.
  - Criterion for the breakaway oxidation test would be 200 wppm hydrogen uptake.

- An acceptable experimental procedure for establishing cladding ductility criteria and breakaway oxidation limits would be detailed.

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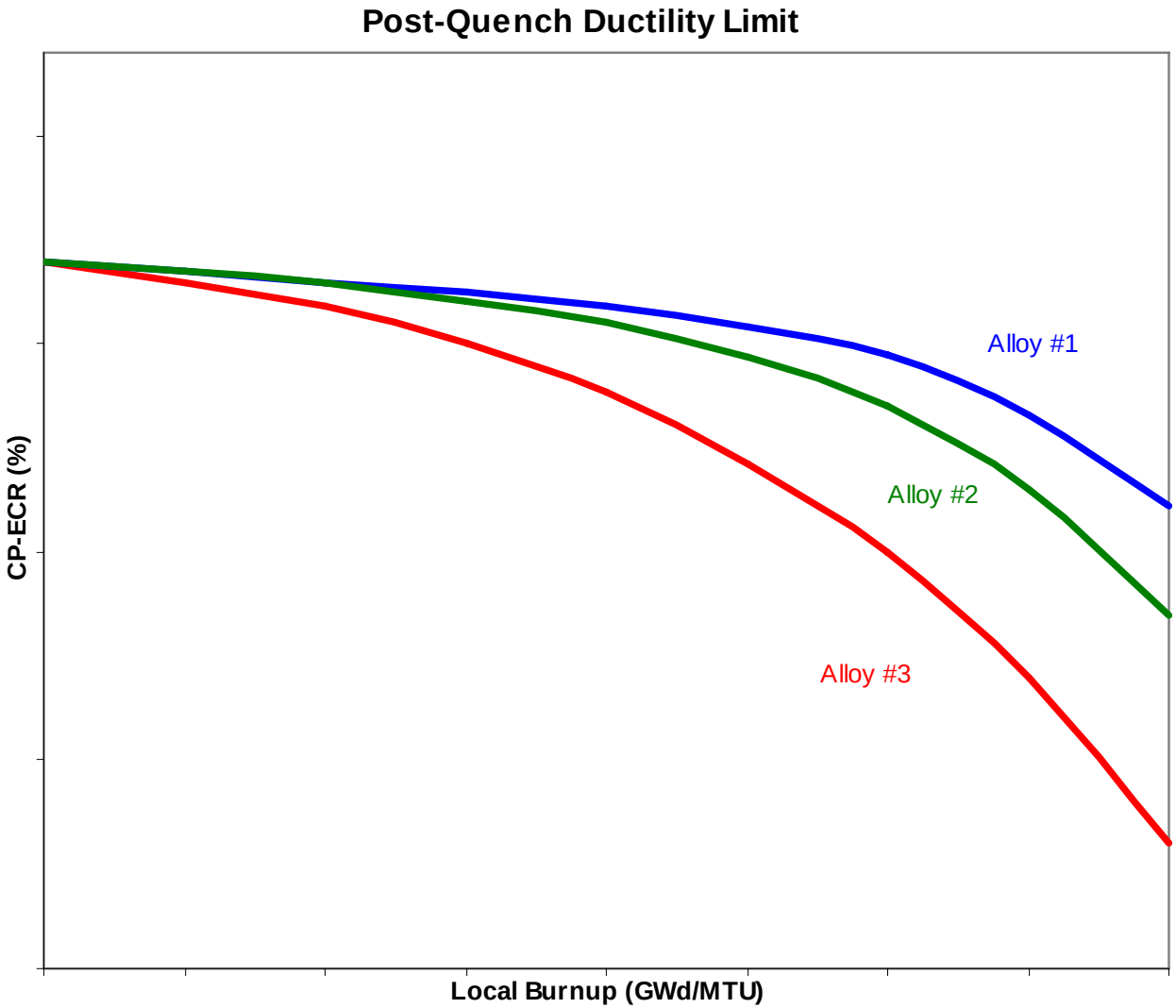
Implementing PQD Curve

(initial hydrogen content converted to burnup)



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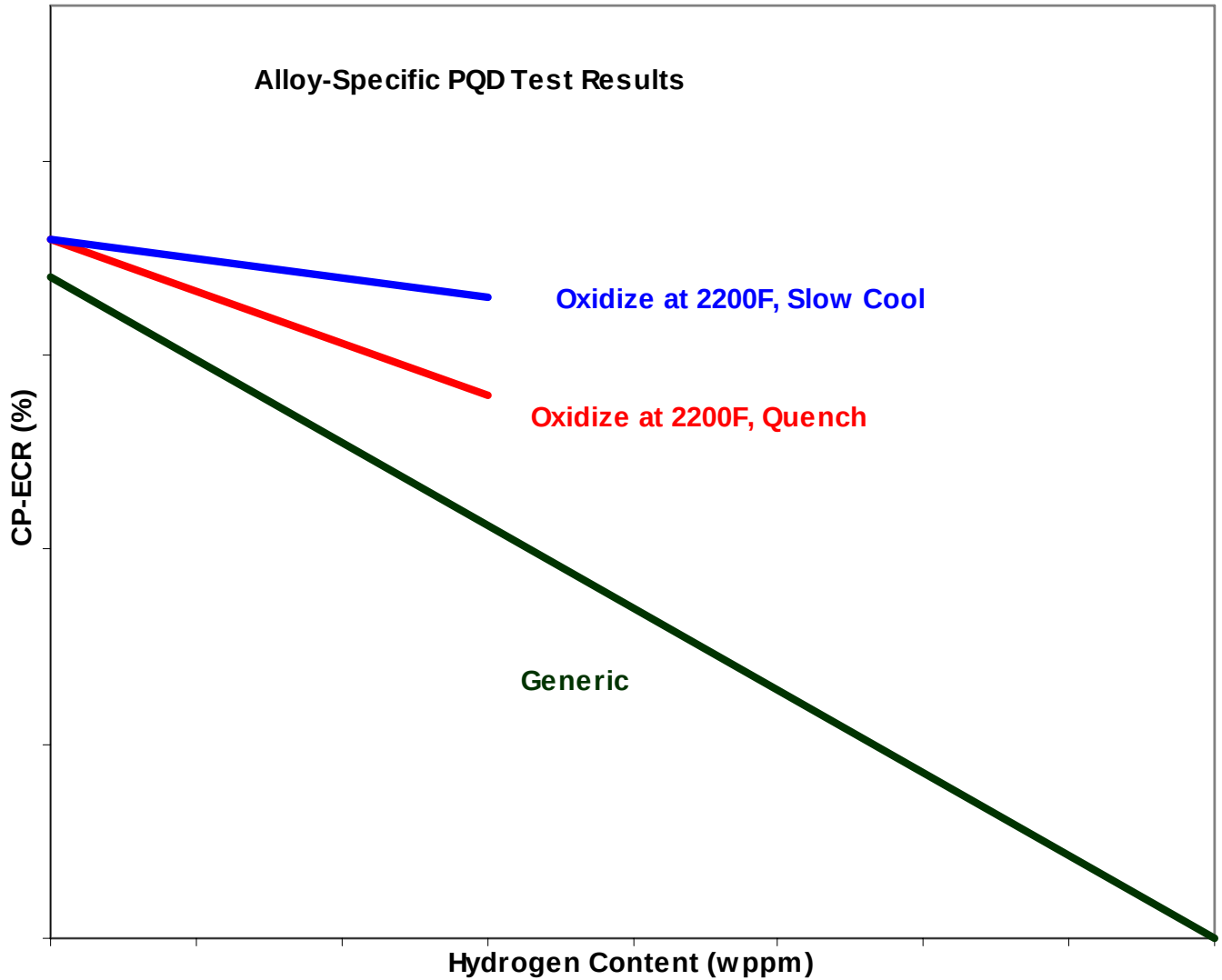
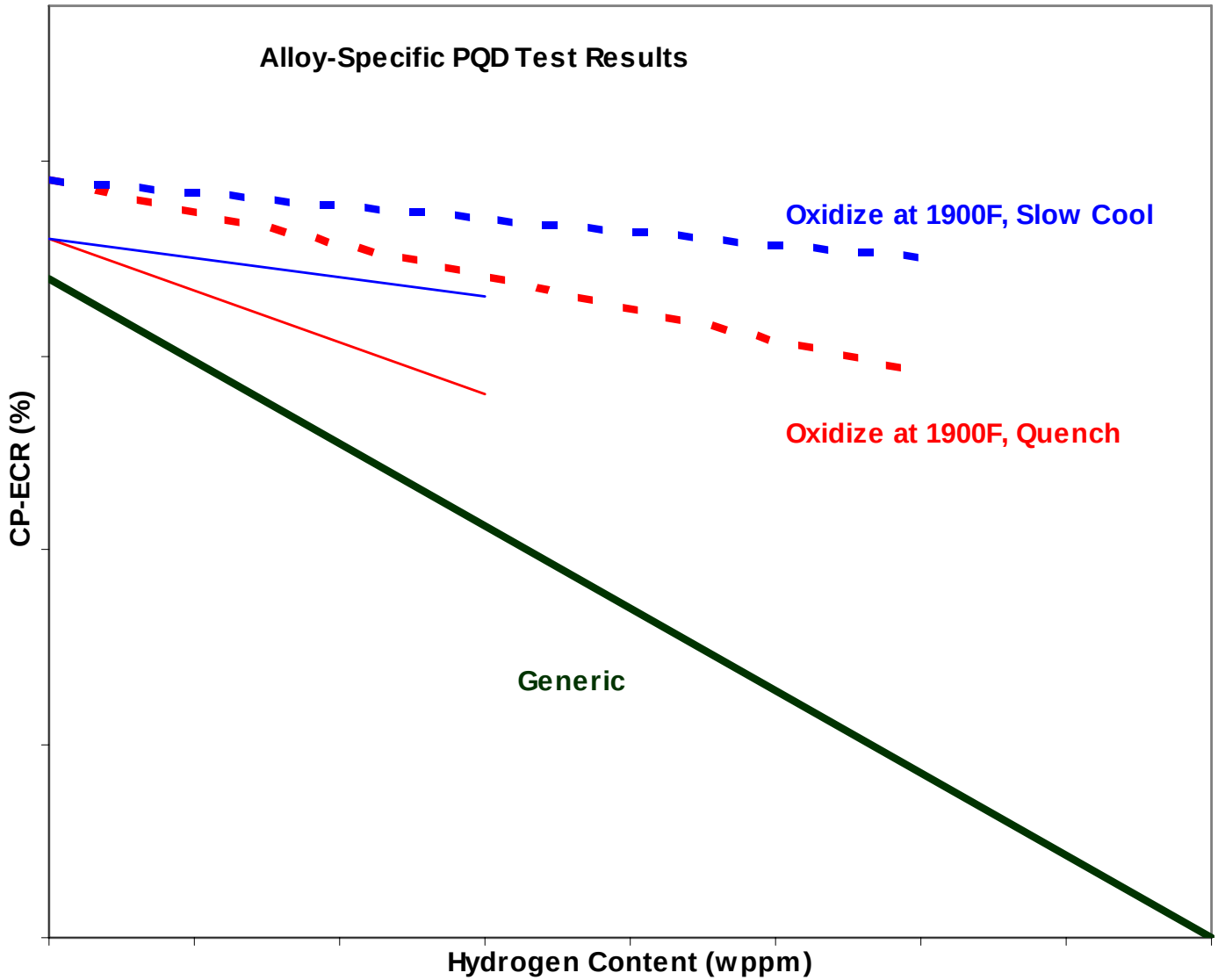
Added Flexibility



Added Flexibility (cont.)



Advance Notice of Proposed Rulemaking

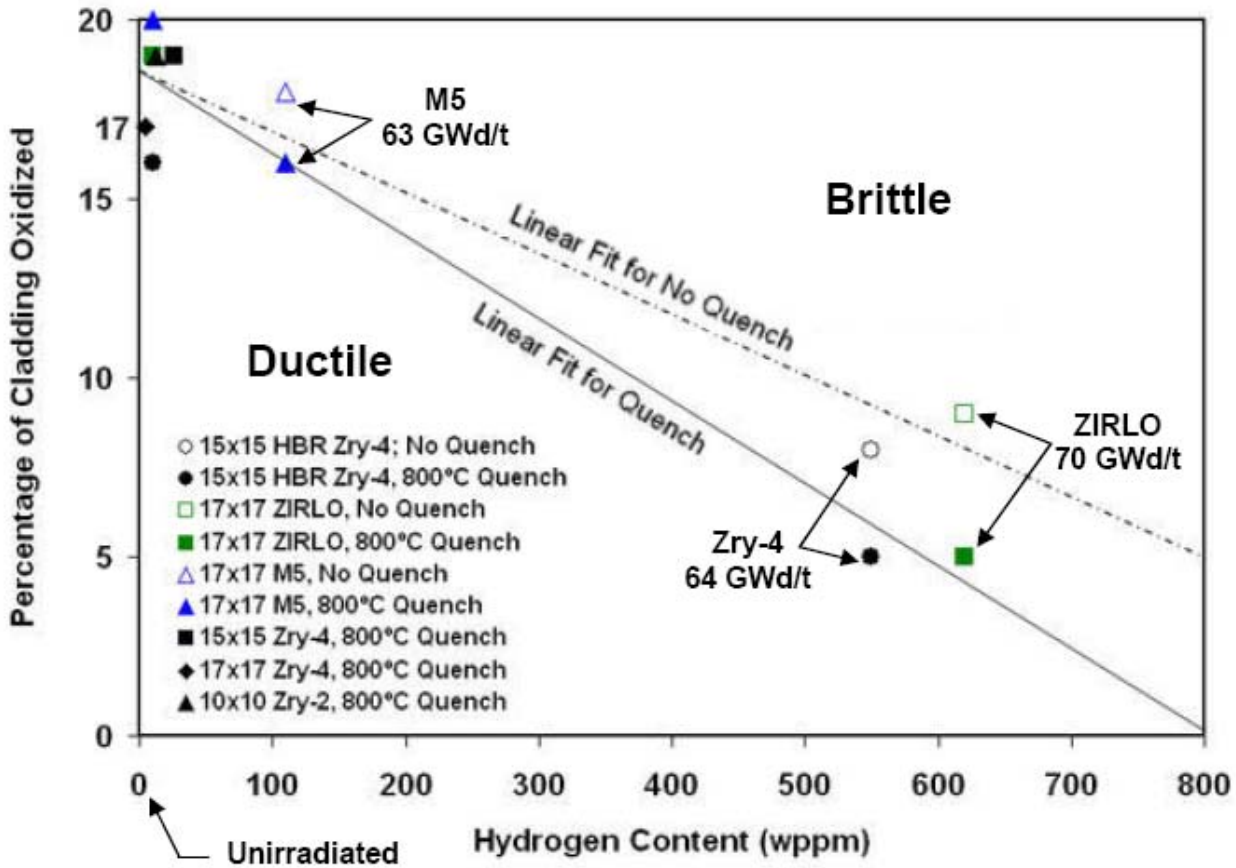
- ANPR process designed to enhance public participation during significant rulemaking campaigns. Benefits include:
  - Public response to rule concept and/or staff requests for additional information factored into the rulemaking proceeding and language of proposed rule language
  - Facilitates formal stakeholder interaction on the rulemaking while further research is acquired.

LOCA Test Procedure

- Development and validation of a comprehensive, performance-based test procedure for quantifying fuel design limits which demonstrate compliance to 10 CFR 50.46(b) criteria for all zirconium-based cladding alloys.
  - Provides an acceptable test procedure with sufficient detail to ensure consistent experimental procedures and protocols.
  - Captures variability, uncertainty, and repeatability.
  - Validation of pre-hydrided surrogate needed to support testing with unirradiated specimens.

PQD Empirical Database

- Additional PQD tests planned to address intermediate hydrogen levels.



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Breakaway Tests

- The current database on breakaway oxidation has been derived from isothermal tests.
- Additional breakaway tests are planned to investigate whether the timing of breakaway oxidation is sensitive to variations in temperature profile or thermal cycling.

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Rulemaking Process

Milestones:

1. Additional research activities
2. Conceptual rule (structure and language)
3. Comprehensive test procedures
4. Advance Notice of Proposed Rulemaking (ANPR)
5. Public comment period
6. Workshop #2
7. Proposed rule
8. ACRS
9. Public comment period
10. Final rule

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Response to Industry Comments on 50.46(b) Rulemaking in the Form of FAQs – Part 2

M. Billone
Irradiation Performance Section
Nuclear Engineering Division

ACRS Subcommittee Meeting
Materials, Metallurgy, and Reactor Fuels

NRC Headquarters

December 2, 2008

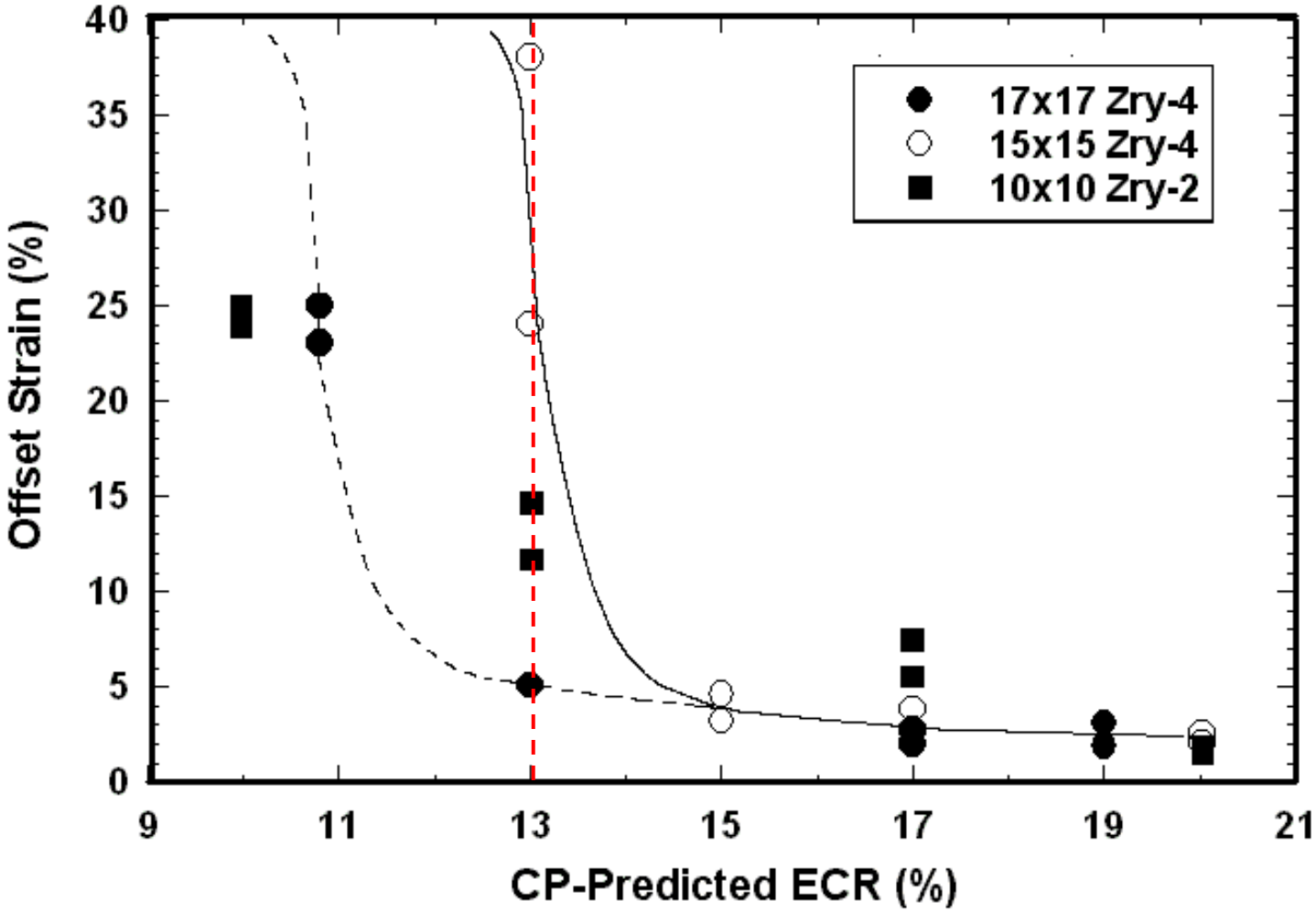
Work sponsored by the US Nuclear Regulatory Commission

Were Results from Other Laboratories Considered and are they Consistent with ANL's Results?

- **"YES" response to both questions, but some Perspective on the Term "Consistent" is Needed; "Consistent" ≠ "Same"**

- **"Consistency" within Data Scatter is Anticipated under the Following Conditions**
  - Similar materials and sample preparation techniques
  - Similar oxidation/quench temperature histories
  - Similar post-quench ductility (PQD) tests and test temperatures
  - Similar metrics for ductility and ductile-to-brittle transition oxidation level
- **"Consistency" is Better Assessed by Comparing ANL-to-ANL Data**
  - Sample preparation, heating/quench techniques, ring-compression PQD tests at 135ºC; offset and **permanent** strain metrics for ductility
  - Study effects of variables on results: cladding material, oxidation temperature and level, hydrogen content, and quench temperature
  - Wide variation of ductility values (5-40%) for Zry-4 materials; narrow range of ductile-to-brittle oxidation levels (17-19% CP-ECR)

Variation of Offset Strain for As-Fabricated Zircaloy Cladding: 5-40% at 13% CP-ECR for 1200ºC Oxidation



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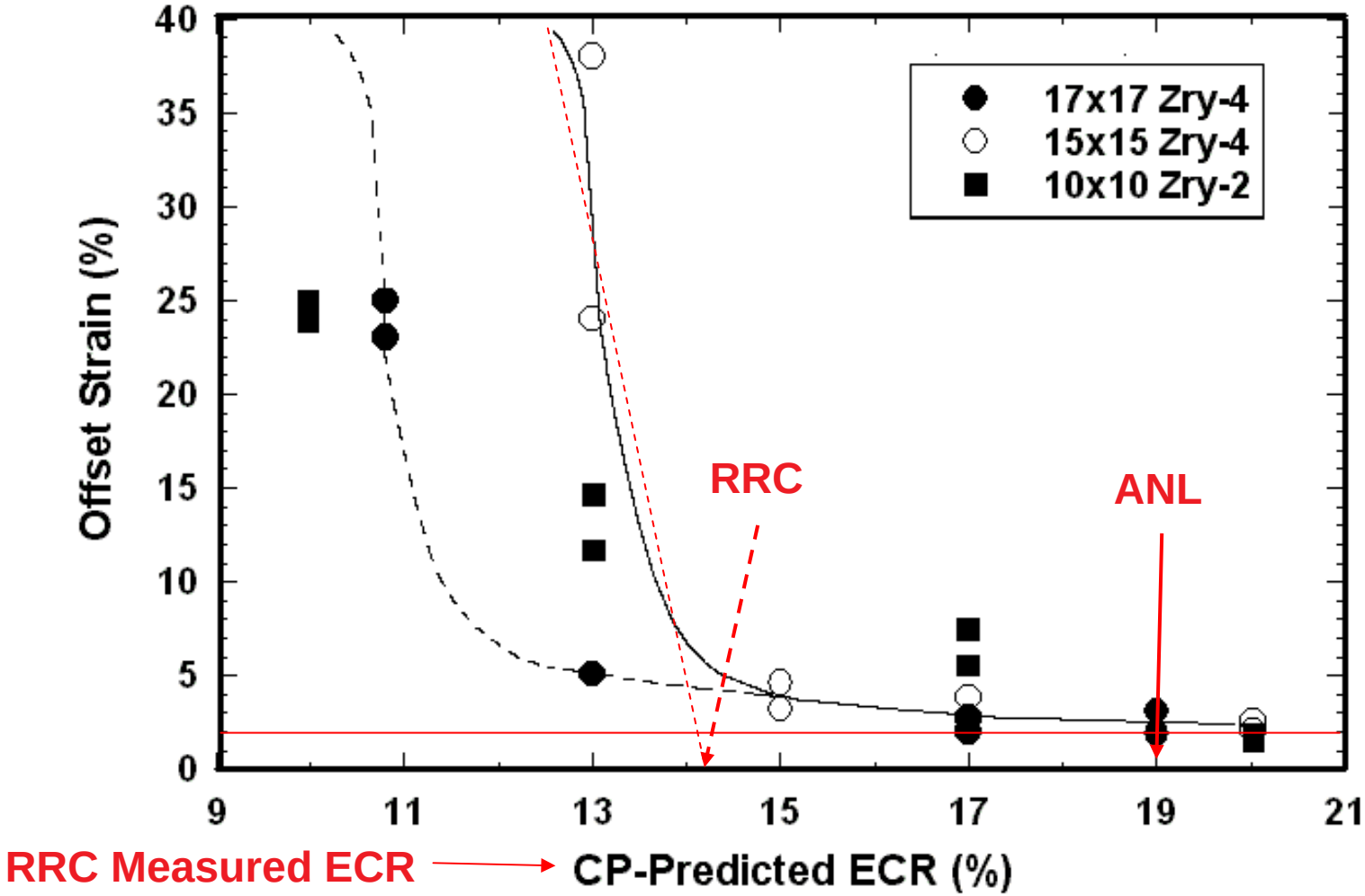
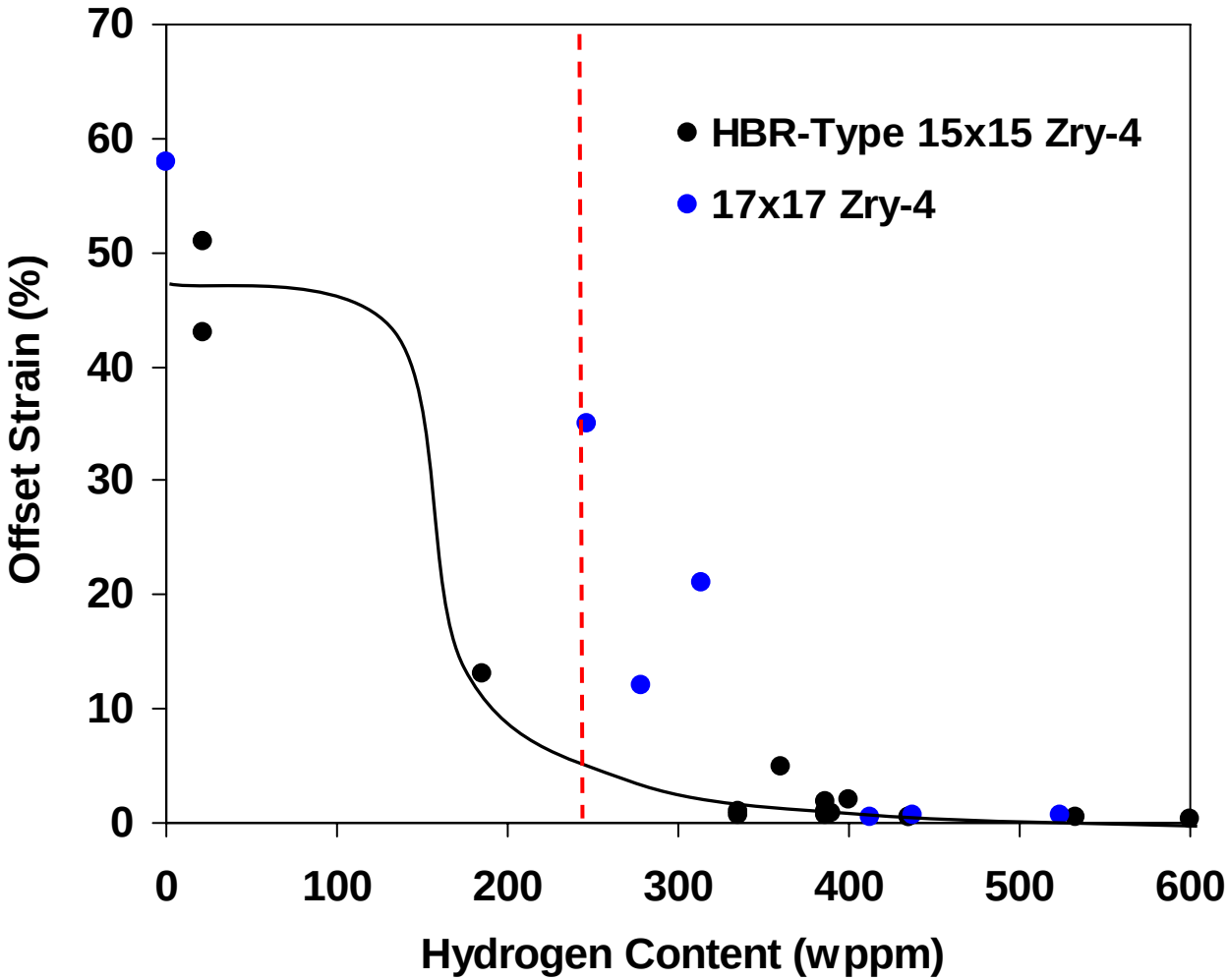
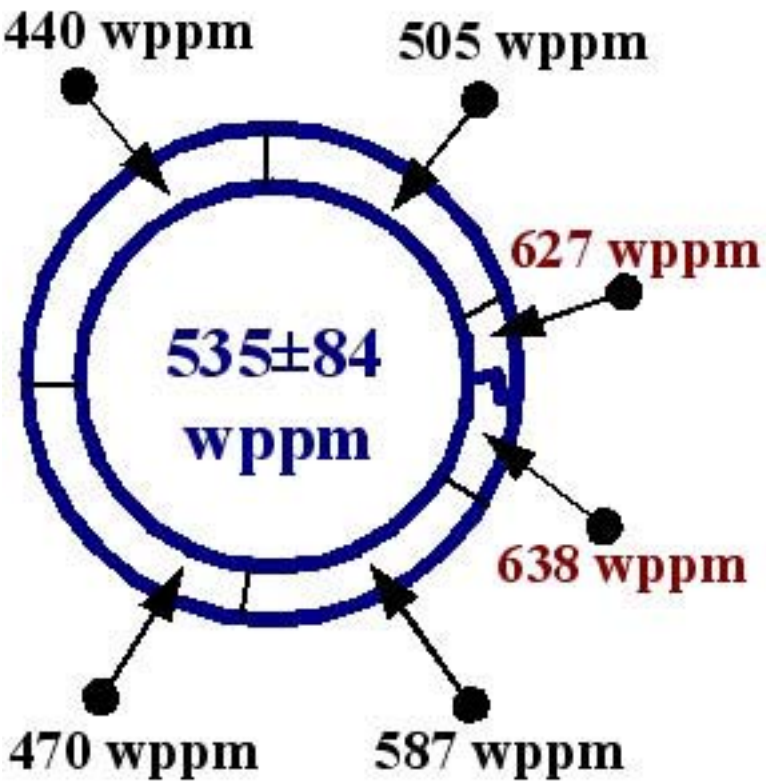
Differences in ANL and RRC Interpretation of Ductile-to-Brittle Transition Oxidation Level for Same Data Set



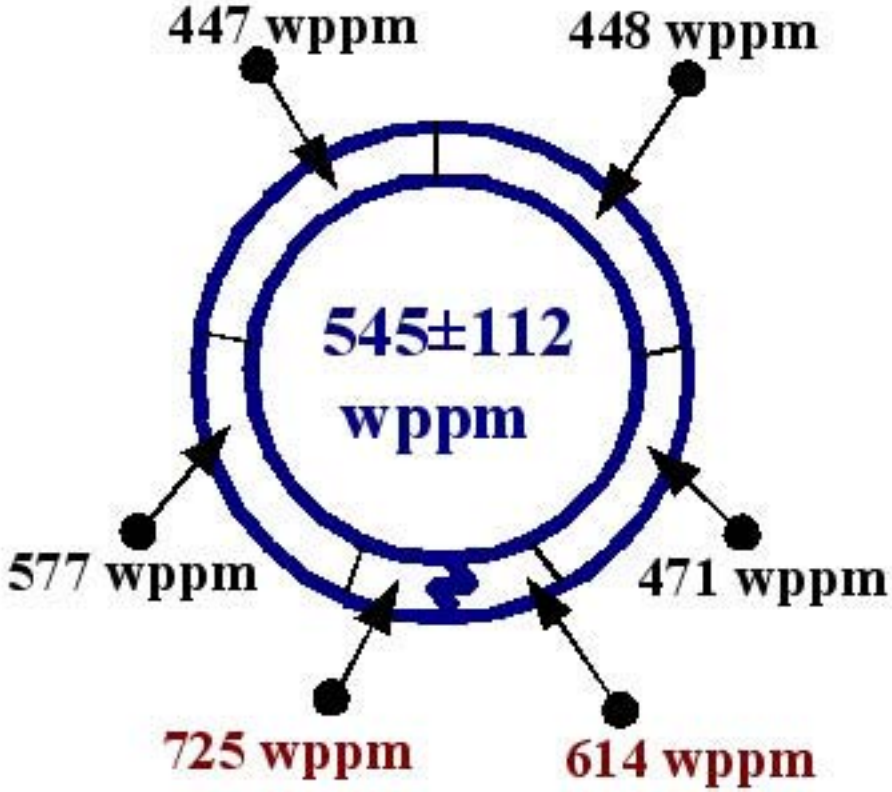
Variation of Offset Strain for Prehydrided Zry-4 Oxidized at 1200ºC to ≈8% CP-ECR: 5-35% at 250 wppm Hydrogen



High-Burnup ZIRLO Oxidized to 6.3% CP-ECR and Cooled without Quench: Offset Strains are 10% and 30%



30% Offset Strain

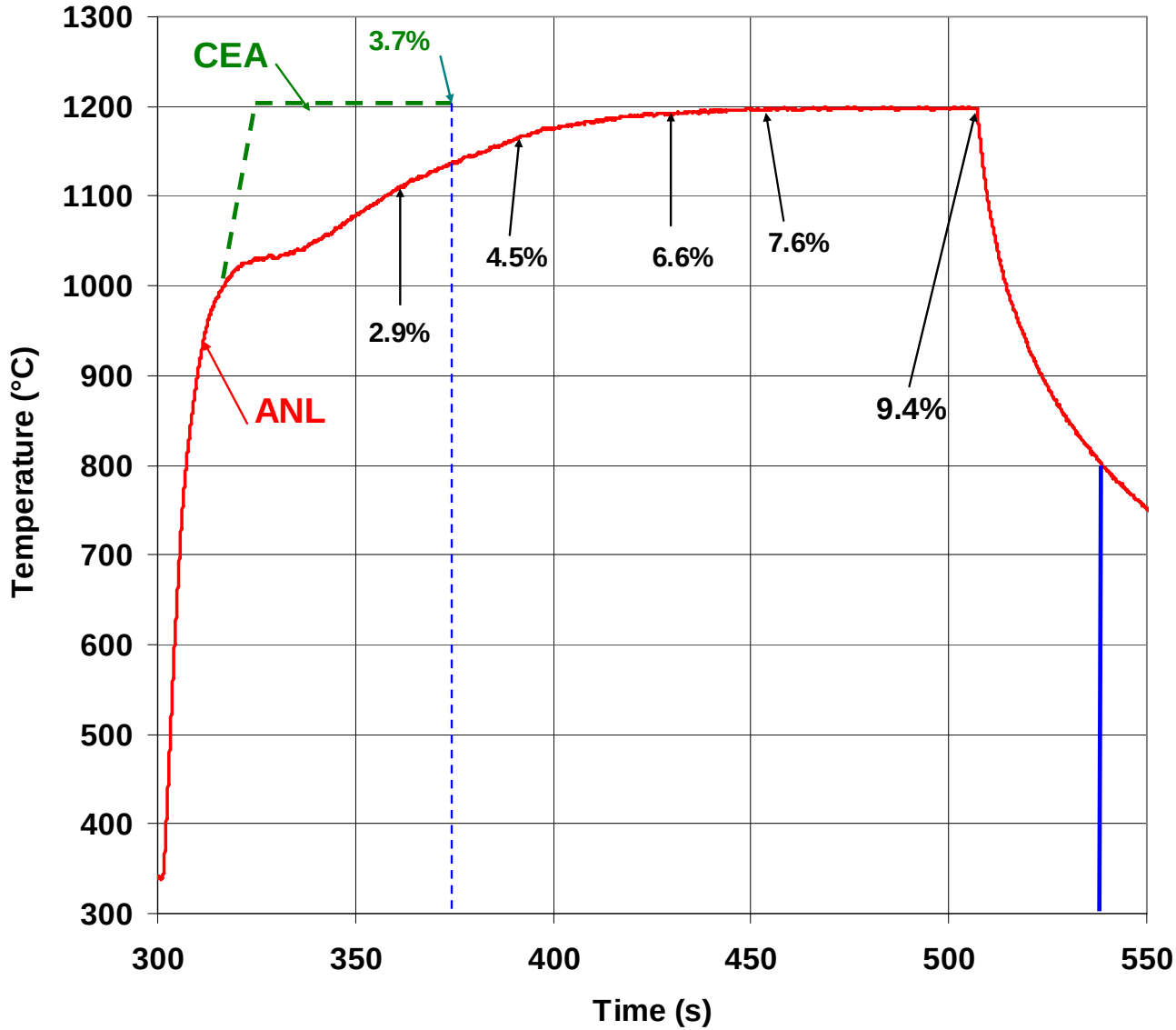


10% Offset Strain

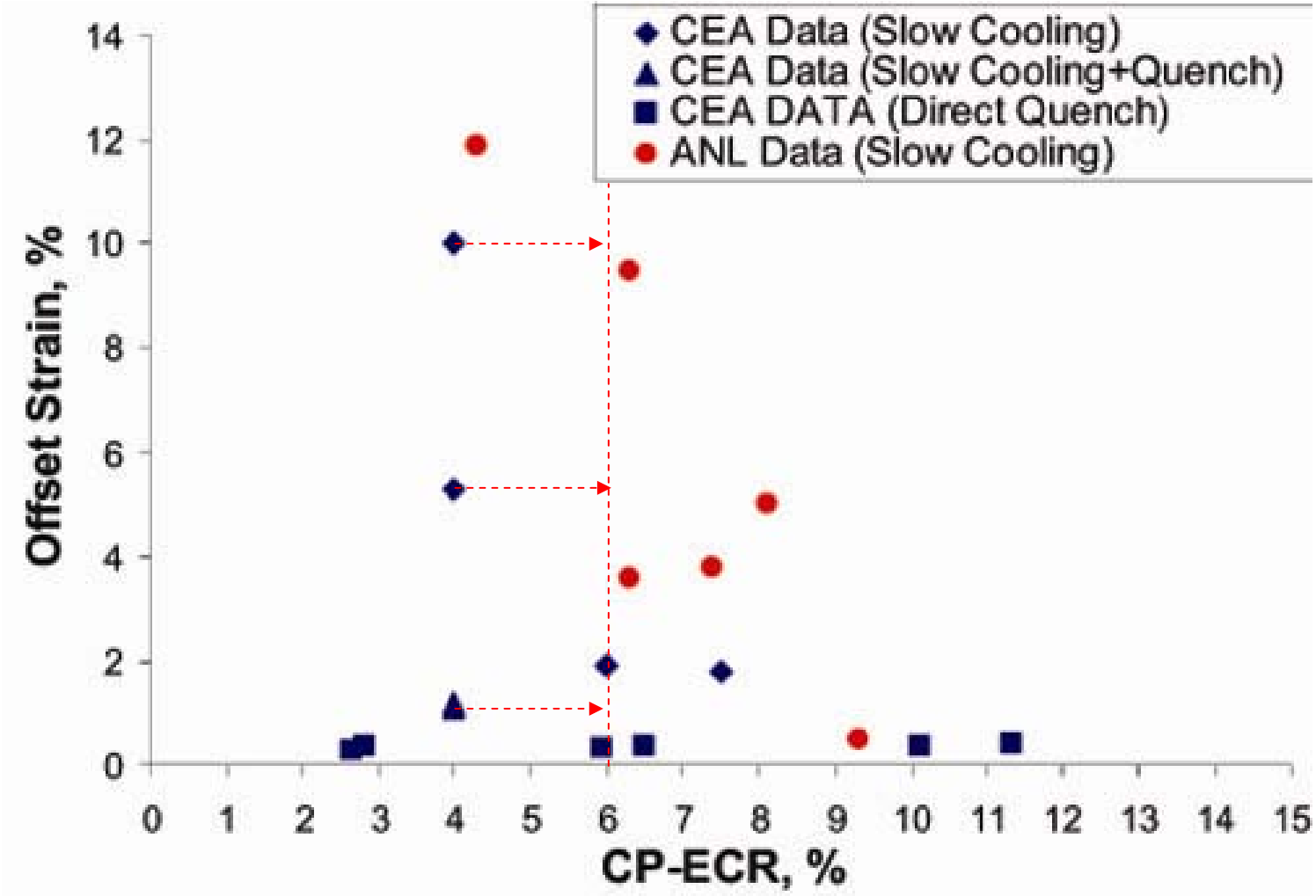
ANL and CEA Data for Zry-4

- **Test Protocols are very Different (see NUREG, pp 168-171)**
  - CEA: 1-sided; 17×17 Zry-4, 25ºC/s ramp from 1000-1200ºC; hold at 1200ºC; quench at 1200ºC or 800ºC (1000 s cooling); or 600ºC (2200 s); or cool without quench (>11000 s)
  - ANL: 2-sided; 15×15 & 17×17 Zry-4; 1-3ºC/s ramp from 1000-1200ºC; hold at 1200ºC (Note: 5-6% ECR accumulated at <1200ºC during ramp); Quench at 800ºC (38 s cooling) or 600ºC (83 s); or cool without quench (>600 s)
- **Fresh Zry-4 and M5 Cladding: Comparable Embrittlement Thresholds**
- **Prehydrided Zry-4: Comparable Results for 800ºC Quench and No Quench**
  - Results differ for 600-700ºC quench, BUT CEA cooling rates are very slow
- **CEA Prehydrided vs. ANL High-Burnup Zry-4 (NEI-EPRI Plot)**
  - Data are not comparable with respect to CP-ECR because of temperature
    - *Tmax = 1110ºC for 2.9%; 1160ºC for 4.5%, 1200ºC for ≥6% CP-ECR*
  - NEI-EPRI figure does plot CEA data correctly (4% → 6%)
- **ANL DOES Agree it would be Interesting to Study the Effects on PQD of 1-3ºC/s Cooling Rates and 400-800ºC Quench Temperatures**

Temperature History for ANL High-Burnup 15×15 Zry-4 Tests



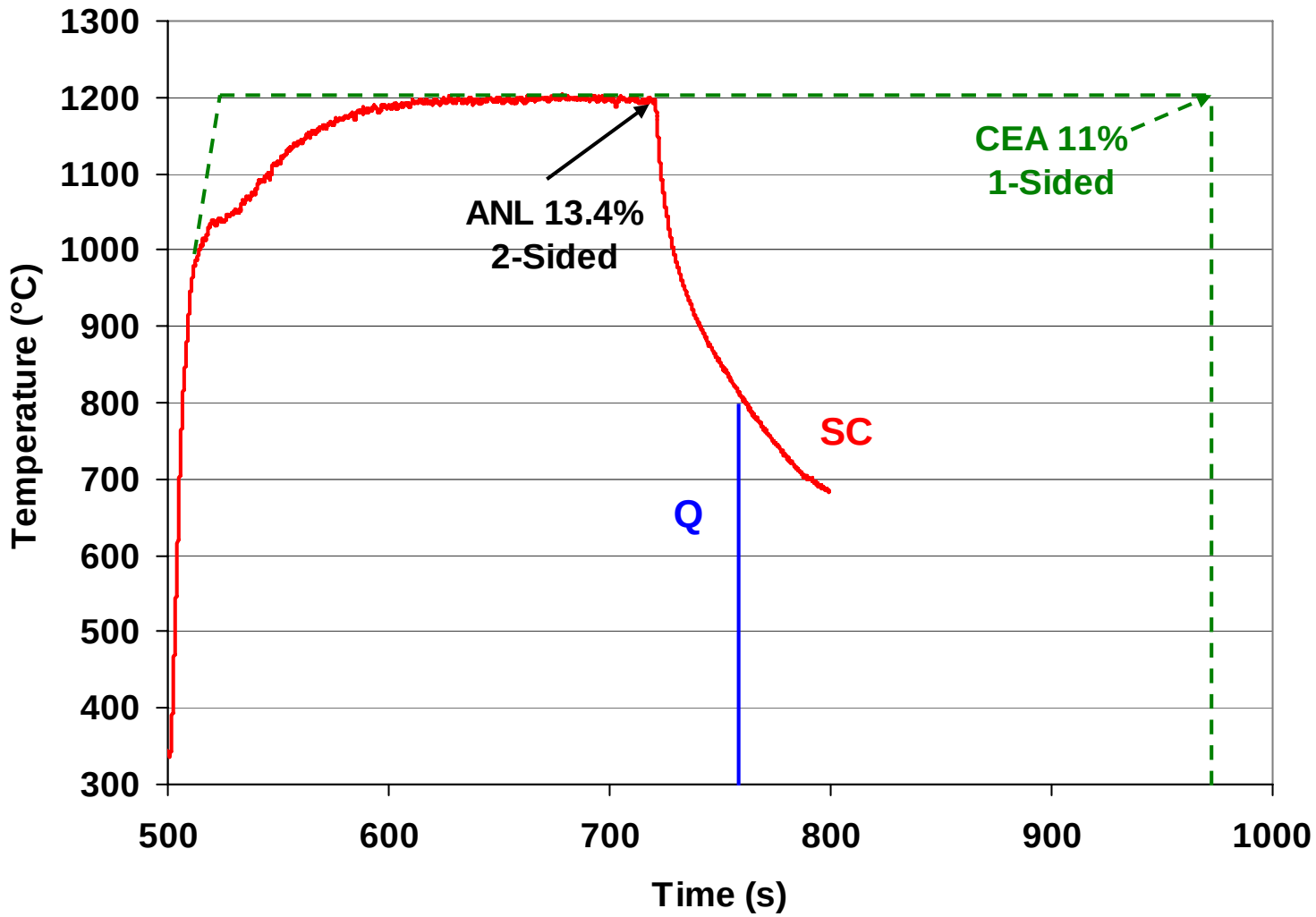
EPRI Comparison of ANL (High-Burnup 15×15) and CEA (Pre-H 17×17) Ductility Data for Zry-4 with ≈600 wppm H



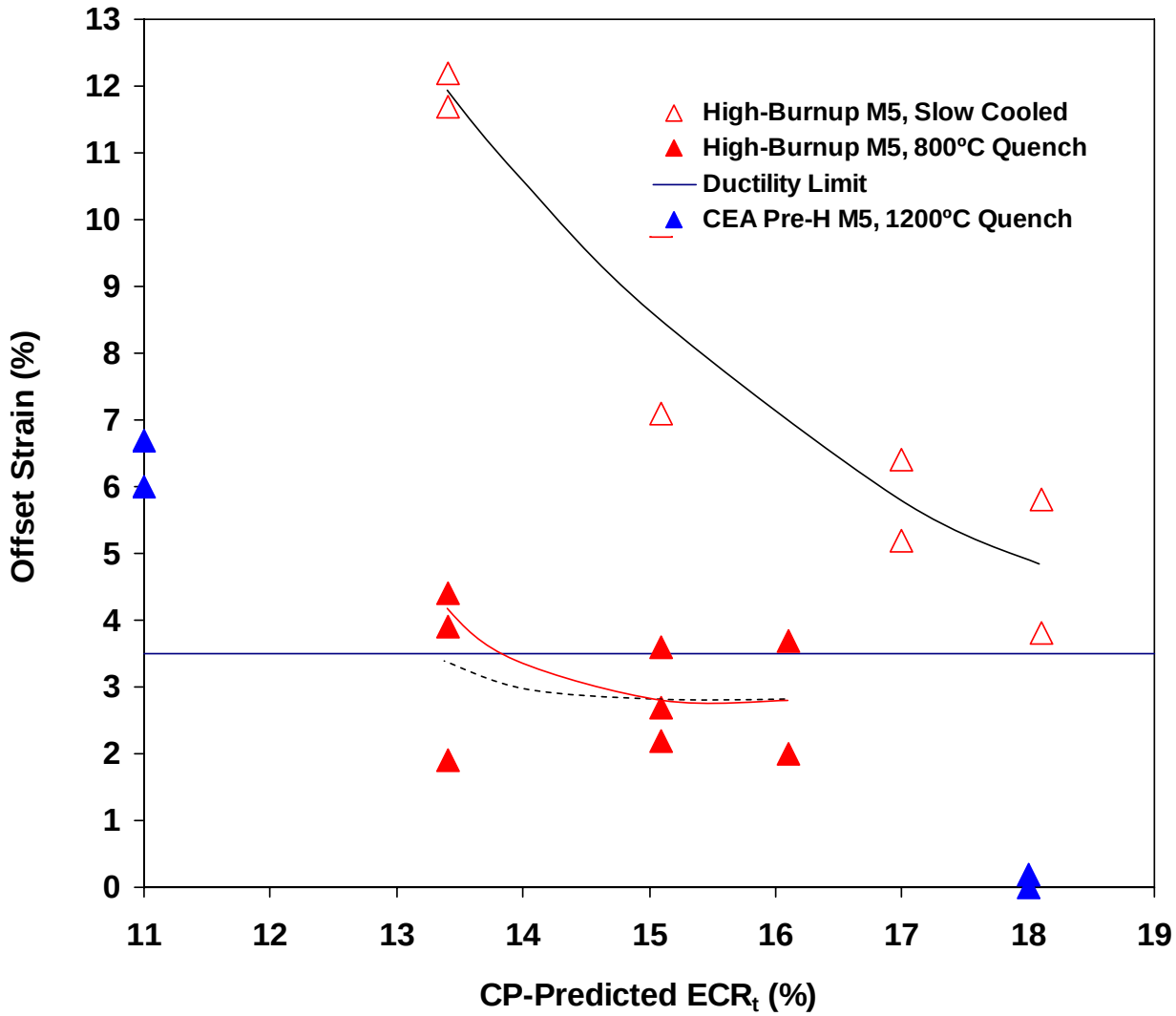
Consideration of Data from Other Laboratories

- **ANL Hosted May 2004 OECD/SEGFSM LOCA Topical Meeting**
  - Czech Republic, France, Germany, Hungary, Japan, Korea, et al.
  - Most ring compression data at RT; ductility based on total or offset strain; no data for permanent strain because tests run to multiple-crack failure
- **Close Collaboration with RRC-RIAR (E110), CEA (Zry-4, M5) & JAEA**
  - ANL participation in NRC-IRSN Reviews of Russian Program and JAEA Fuel Safety Research Meetings
  - RRC, CEA and JAEA participation in ANL Program Review Meetings
  - JAEA integral test results
- **RRC-RIAR Data for E110 (2002-2005)**
  - Based on RRC data, ANL focused studies on 1000ºC – worse than 1100ºC
  - Based on ANL data, RRC tested polished E110 tubing
- **CEA Data for Prehydrided Zry-4 and M5**
  - Zry-4: see comparison in NUREG report, pp 168-171; used CEA data for fundamental understanding of mechanisms
  - **M5: used CEA data to plan oxidation levels for high-burnup M5**

CEA and ANL Temperature Histories for M5



Offset Strain Comparison for ANL High-Burnup and CEA Pre-H (120-130 wppm) M5 Oxidized at 1200ºC



Is Further Testing Needed for Future Zirconium-Based Alloys?

- **YES for Embrittlement due to Breakaway Oxidation; Maybe NO for High-Temperature Embrittlement**

- **High-Temperature Embrittlement of As-Fabricated (Fresh) Alloys (NO)**
  - Diffusion of oxygen and oxygen solubility in metal control embrittlement; processes are relatively insensitive to low concentrations of alloying elements and impurities
  - New alloys are anticipated to have same range of ductile-to-brittle oxidation level (17-20% CP-ECR)
- **High-Temperature Embrittlement of Alloys with Hydrogen (Maybe NO)**
  - Data generated to date suggest embrittlement oxidation level of cladding with hydrogen is not alloy dependent
  - However, complete data sets at same hydrogen level are not available for all alloys tested
    - *For modern Zry-4 with 150- wppm H, embrittlement CP-ECR > 10%*
    - *For current high-burnup M5 with 110±10 (pre-test) and 130±15 (post-test) H, embrittlement threshold is 14±1%*

Is Further Testing Needed for Future Zirconium-Based Alloys?

- **Embrittlement due to Breakaway Oxidation (YES)**
- **Controlling Mechanisms**
  - Diffusion of oxygen in oxide controls growth of oxide layer
  - Stability of oxide layer is highly dependent on maintaining compressive stress and hypostoichimetric oxide [$ZrO_{(2-x)}$]
  - Certain alloying and trace elements with charge greater +4 (e.g., Nb) can cause [$ZrO_{(2-x)}$] to transition towards ZrO_2
  - Other trace-element impurities (e.g., F) can destabilize the oxide layer
  - Certain trace impurities with charge less than +4 (e.g., Ca, Mg, Al) can help stabilize the oxide layer
  - Belt or wheel polishing outer cladding surface removes surface impurities and decreases surface roughness
  - Zr-1Nb and Zr-1Nb-1Sn alloys appear to be more sensitive to pickling in HF-containing acids than Zircaloys
  - Pickling followed by polishing leads to stable oxide growth
  - Polishing followed by pickling may result in early breakaway oxidation

Is Further Testing Needed for Future Zirconium-Based Alloys?

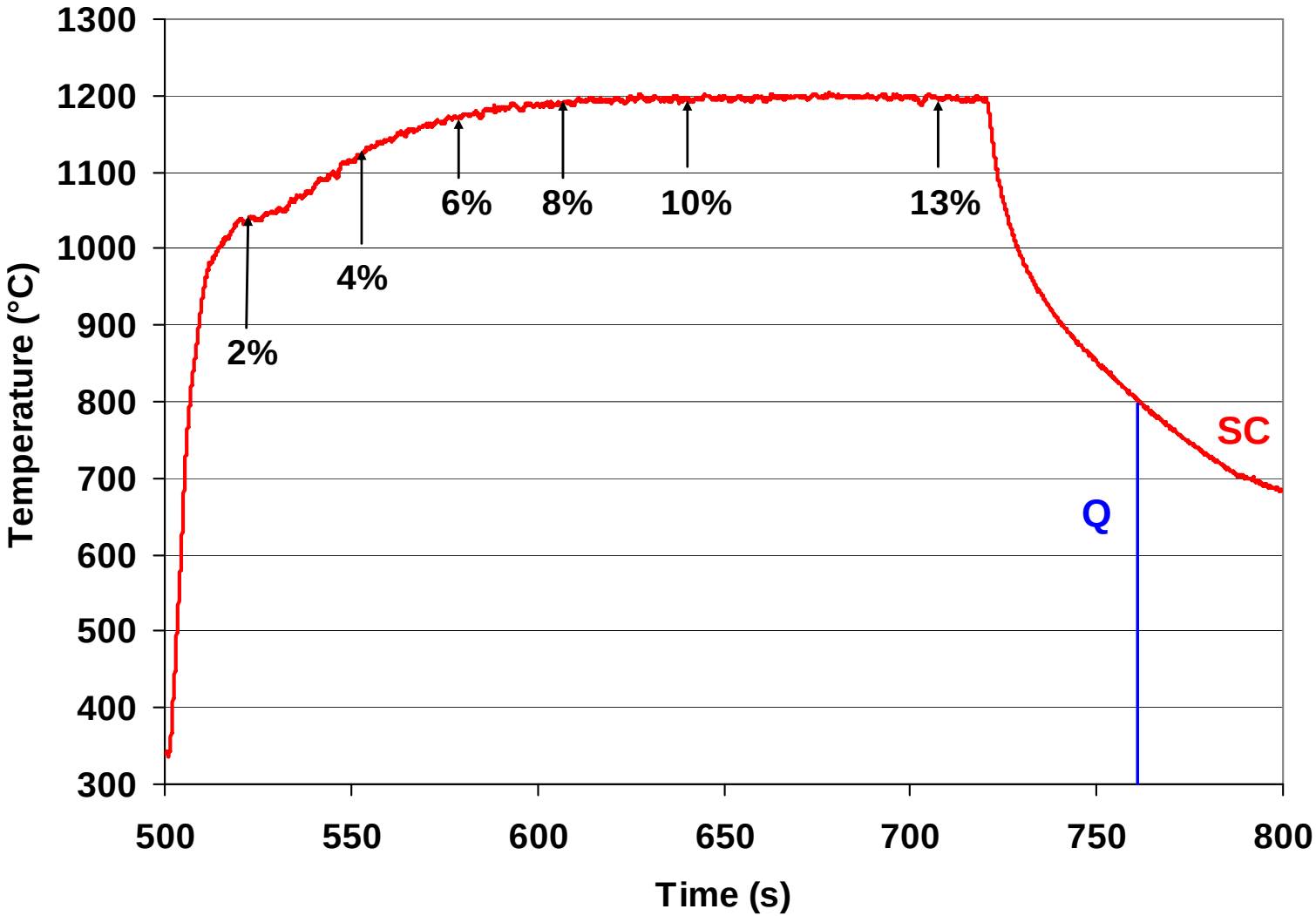
- **Evolution of Zircaloys with Respect to Minimum Breakaway Oxidation Time for Oxidation at 1000ºC Based on 200-wppm H pickup**
  - 1970s rough surface (≈0.3 μm) and pickled Zry-4: 1800 s (L-S)
  - 1970s-1980s rough surface (≈0.3 μm) 15×15 Zry-4 : 3800 s (ANL)
  - Current wheel-polished (≈0.1 μm) 15×15 Zry-4: 5000 s (ANL)
  - Current belt-polished (≈0.1 μm) 10×10 Zry-2: >5000 s (ANL)
  - Current wheel-polished (≈0.1 μm) 17×17 Zry-4: ≈5400 s (CEA)
- **Comparison of Zr-1Nb Alloys Oxidized at 1000ºC**
  - Wheel-polished (≈0.1 μm) 17×17 M5: ≈6400 s (CEA)
  - Standard E110 tubing (≈0.4 μm); pickling
    - *<300 s breakaway based on outer surface appearance*
    - *≈600 s based on 200-wppm hydrogen pickup*
- **Rationale for Breakaway Oxidation Performance Tests**
  - Alloys are optimized to improve performance under normal conditions
  - Breakaway oxidation under LOCA conditions is highly sensitive to many fabrication details, especially surface finish

Is Extrapolation of the Data to Zero Oxidation at 800 wppm Hydrogen Appropriate?

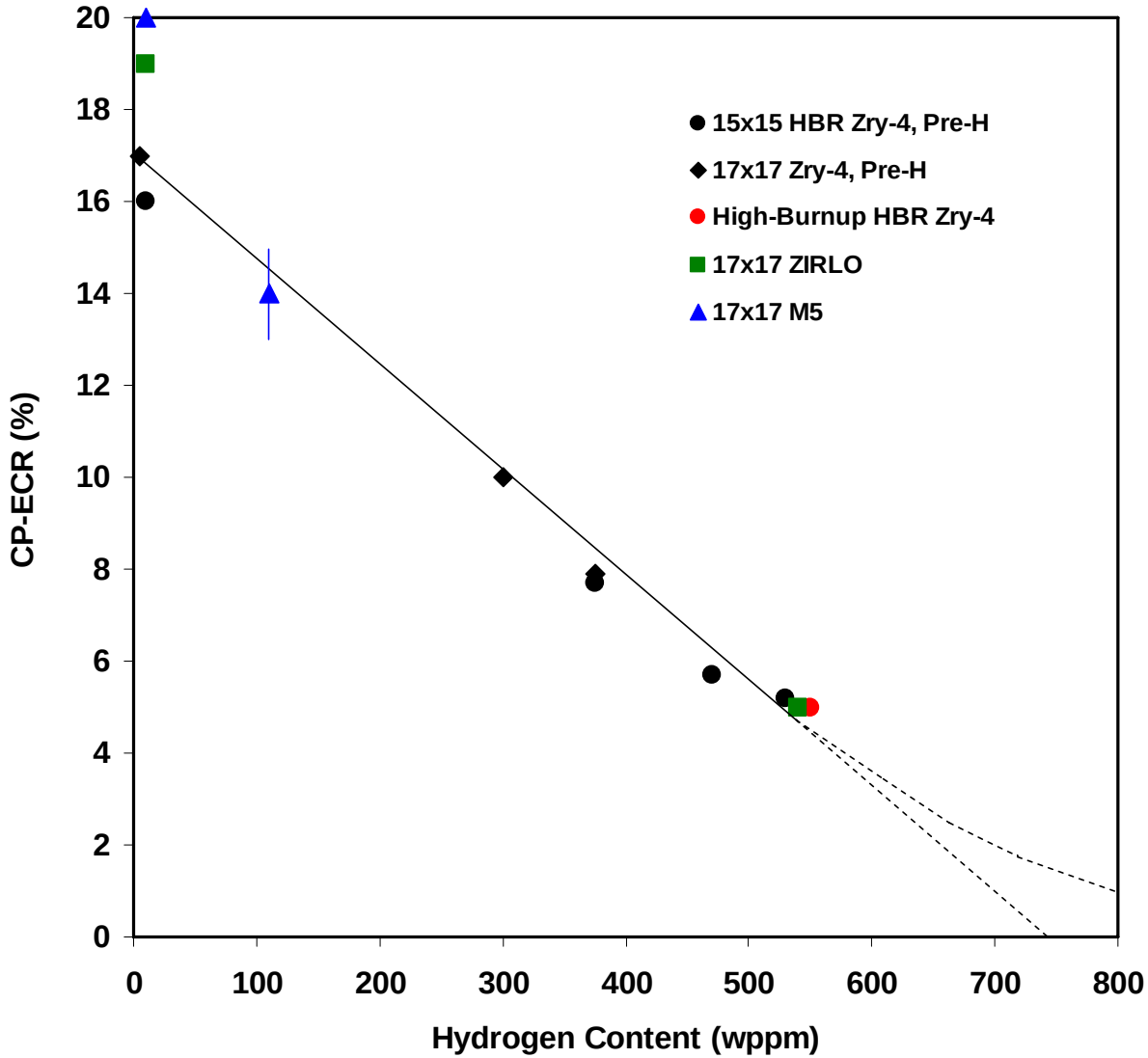
- **NO, It is not Accurate, BUT….**

- **Anticipated Results for ANL Tests with High-Burnup ZIRLO and Zry-4**
  - See temperature history during heating rate
  - Embrittlement CP-ECR of 5% occurs at 1160ºC for 540±100 wppm H
  - Maximum temperatures are 1130ºC and 1030ºC for 4% and 2% CP-ECR values, respectively
  - Anticipate 1-2% CP-ECR embrittlement thresholds for 800-wppm ZIRLO and Zry-4 for T < 1000ºC (see curved dashed line extrapolation)
  - Need input on hydrogen content of ZIRLO and Zry-4 near end of last cycle prior to high-burnup cycle (e.g., Westinghouse Cycle #2)
- **Is it Really an Issue?**
  - For high-burnup fuel located in low-power core locations, it is likely that such fuel would not experience burst and oxidation would be <1% CP-ECR
  - For high-burnup fuel located in central core location, it may be an issue if burst occurs and if T ≥ 1000ºC

Temperature History for High-Burnup 17×17 ZIRLO Tests



Prehydrided Zry-4 and High-Burnup Embrittlement Data



Is interpolation of the Embrittlement Data Reasonable between 100 wppm and 550 wppm Hydrogen?

- **YES, Based on the Data Presented in NUREG/CR-6967**

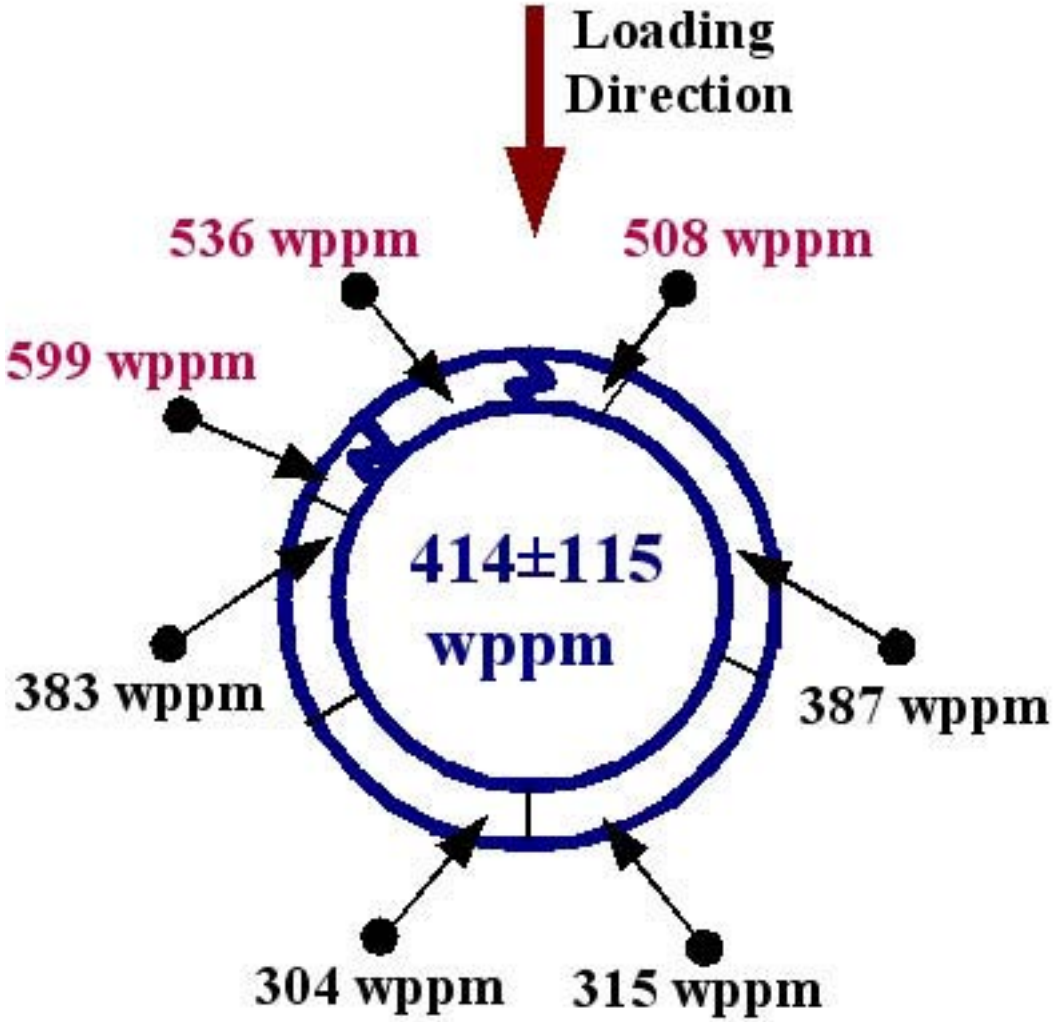
- **Additional Data for Prehydrided and High-Burnup ZIRLO with 300-400 wppm Hydrogen**
  - ANL confirmation data will be available by the end of January 2009
  - High-burnup ZIRLO with 25-30 μm corrosion layer thickness will be used for these tests; hydrogen content TBD

Can Prehydrided Unirradiated Cladding be used in LOCA Embrittlement Testing as a Surrogate for Irradiated Cladding?

- **Probably, but Sufficient Data are not yet Available to have Confidence in a one-to-one Equivalence**

- **Issues Regarding the Use of Prehydrided Cladding as a Surrogate**
  - At high hydrogen contents >400 wppm, circumferential variation in hydrogen content is on the order of ±100 wppm (see next figure)
    - *Average hydrogen content is ≈400 wppm*
    - *Local variations range from about 300-600 wppm*
    - *Ring-compression failure occurs in region of 500-600 wppm*
  - Issue with uniformly hydrided cladding to simulate high-burnup example
    - *Hydrogen content of 400 wppm may be too optimistic*
    - *Hydrogen content of 600 wppm may be too pessimistic*
- **With Proper Selection of Hydrogen Content, Prehydrided Cladding Should be a Good Surrogate for Irradiated Cladding**

Ductile (10%) High-Burnup ZIRLO Ring after 5.1% CP-ECR, 1162ºC Peak Oxidation Temperature and 800ºC Quench



Do Manufacturing Variables and Trace Elements Have a Significant Effect on LOCA Behavior?

- **YES for Breakaway Oxidation; NO for High-Temperature Embrittlement**

- **High-Temperature Embrittlement**
  - Narrow range of embrittlement thresholds (16-20%) for as-fabricated cladding materials tested in ANL program; different vintages of cladding (1970s to current) and different cladding vendors
  - Standard E110 and "over-pickled" ZIRLO are exceptions, but the embrittlement was due to hydrogen pickup from breakaway oxidation
    - *RRC-RIAR results for standard E110 oxidized at 1100 and 1200ºC*
      - 1100ºC: breakaway oxidation & high hydrogen pickup for >300 s
      - 1200ºC: breakaway oxidation & high hydrogen pickup for > 300 s
    - *RRC-RIAR results for $E110_{G(3ru)}$ (Russian Sponge + iodide + scrap Zr) oxidized at 1200ºC: high hydrogen for > 170 s*
  - ANL results for polished E110 oxidized at 1100 and 1200ºC
    - *No hydrogen pickup for 1000 s at 1100ºC and for 170 s at 1200ºC*

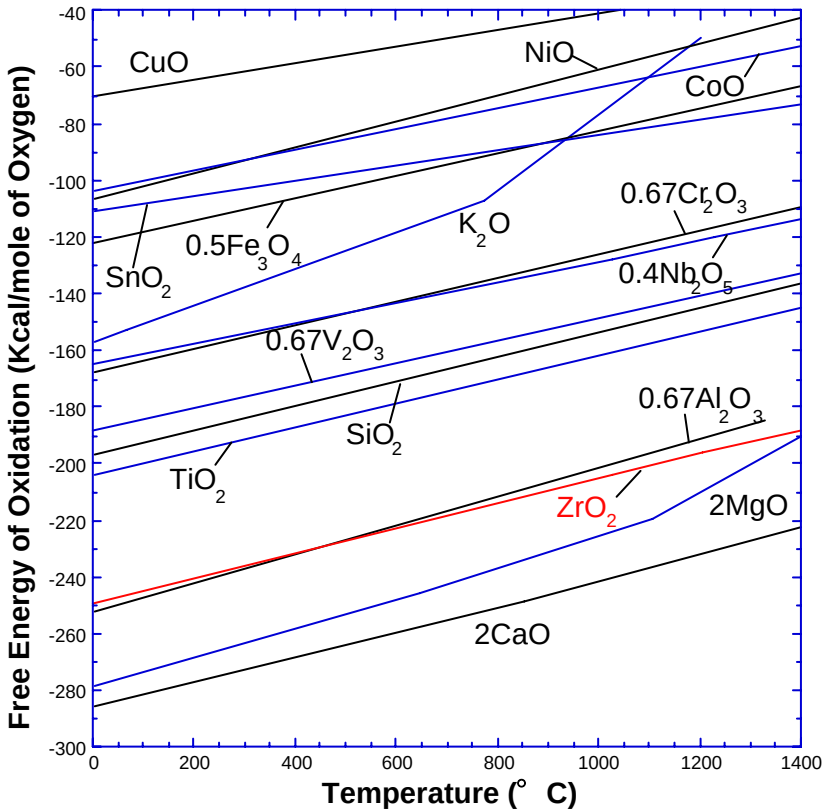
Do Manufacturing Variables and Trace Elements Have a Significant Effect on LOCA Behavior?

- **Embrittlement due to Breakaway Oxidation**
  - Increase in breakaway oxidation time for Zircaloys with fabrication improvements has already been discussed: 1800 s → >5000 s
    - *Avoid pickling in HF-containing acid mixture as final cleaning step*
    - *Belt or wheel polish to reduce surface roughness and impurities*
  - What can we learn from E110 studies?
    - *From zircon ore to alloy ingot*
      - Use Kroll process (may add beneficial Ca, Mg, Al impurities)
      - Avoid using K_2ZrF_6 + K_2HfF_6 for hafnium reduction
    - *From ingot to cladding: final cleaning & surface finish are critical*
  - Hee Chung interpretation of:
    - *Positive influence of Ca, Mg, and Al*
    - *Negative influence of F*
  - What else do we need to know about manufacturing variables and trace elements: do not know; that is why we need breakaway oxidation tests

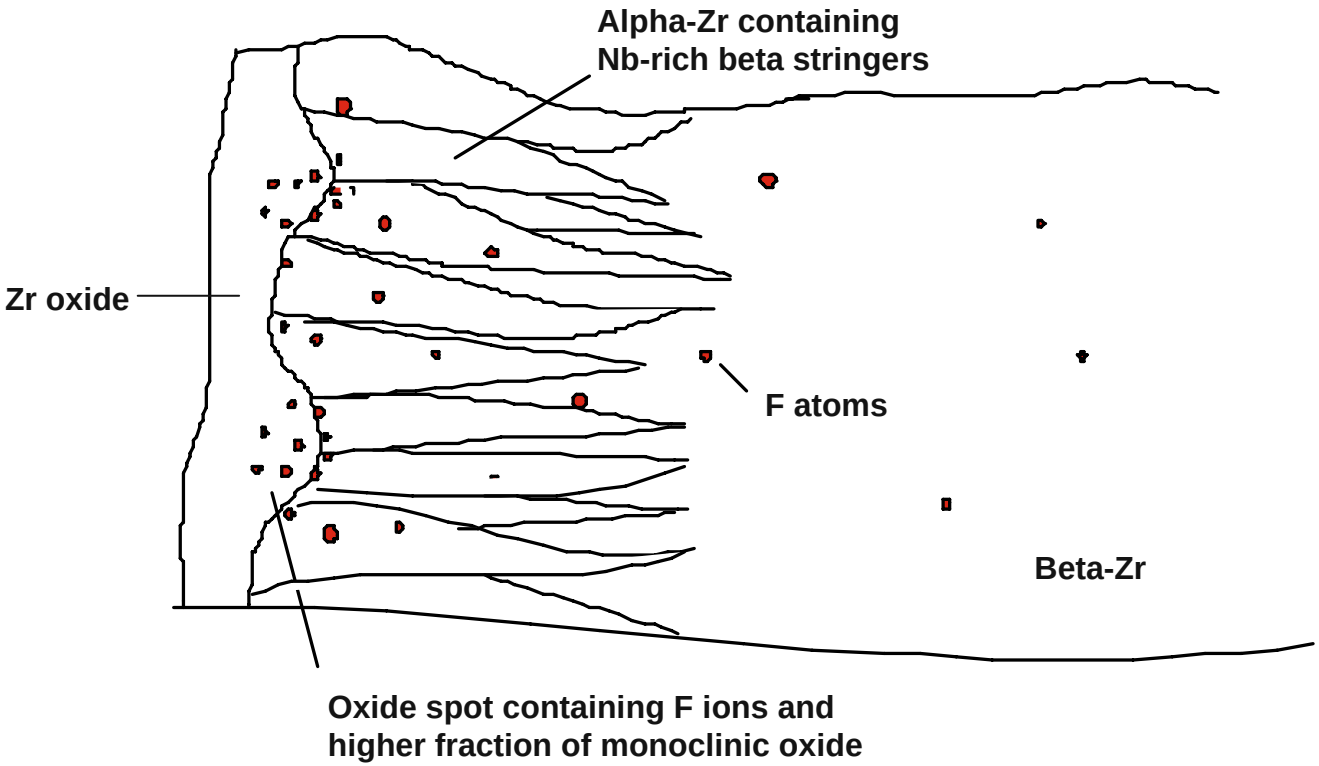
Comparison of Standard E110 and E110 Made from Western Sponge Zirconium – RRC-RIAR Results

Test Number	Material	T ºC	Test Time, s	H wppm	RT Ductility %	135ºC Ductility %
44	E110	1000	865	NM	0	NM
93	$E110_{G(fr)}$	1000	5013	12	1	54
41	E110	1100	284	1130	0	NM
90	$E110_{G(fr)}$	1100	933	≤48	17	60

Free Energy of Oxidation for Selected Elements



Behavior of Fluorine Impurities in Zr-Alloys



Is Ring-Compression Testing Non-Prototypical and Overly Conservative?

- **NO to "Overly Conservative", "Non-Prototypical" is not Relevant**

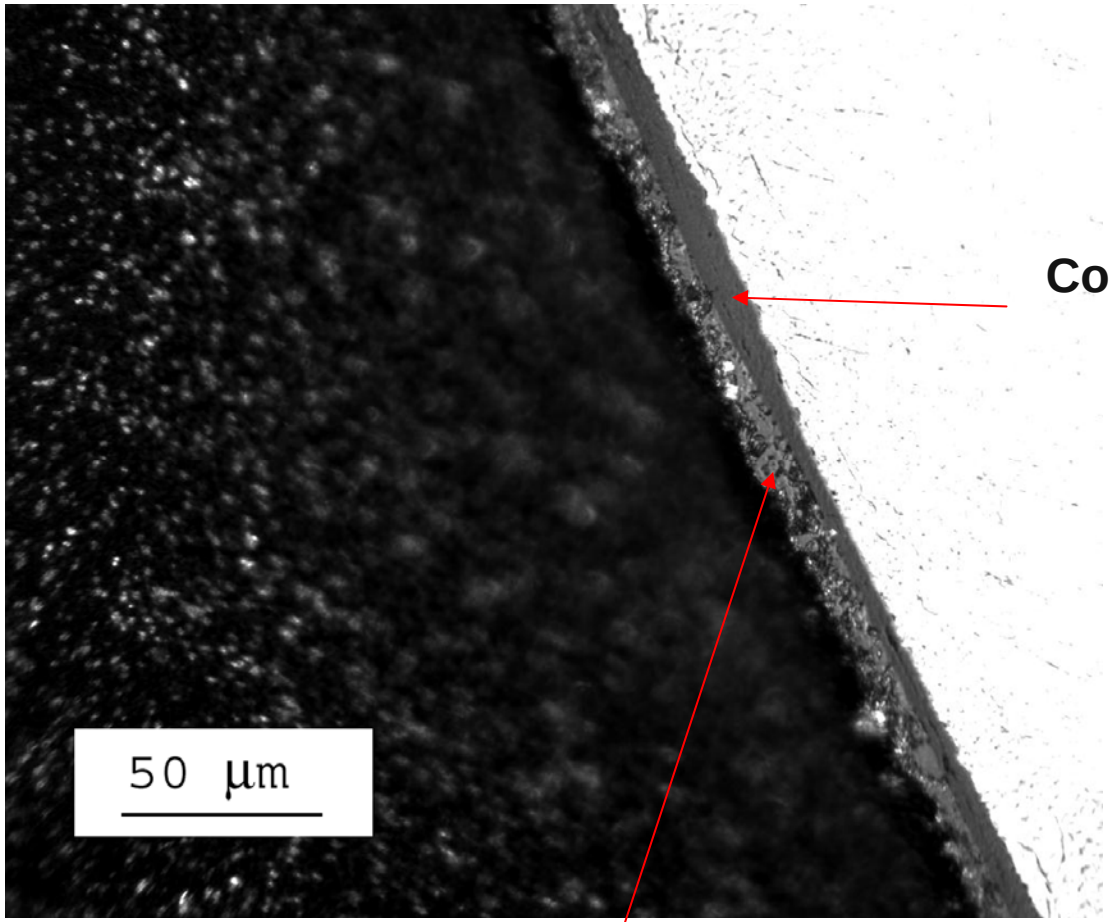
- **Ring Compression Tests are Standard Ductility Screening Tests**
  - Test sample is relatively small (8-mm-long)
  - High-burnup cladding is limited in supply and very "HOT TO HANDLE"
  - Machining of gauge sections not needed
  - Loading leads to hoop bending stresses that transition from tensile to compressive across the wall of the cladding
- **Other Forms of Ductility Tests**
  - Axial tensile tests (more severe than ring-compression tests)
  - Ring tensile tests (more severe than ring compression tests)
  - Axial bending tests (similar to ring compression tests)
- **Ductility Results from Ring Compression and Axial Bend Tests**
  - Both CEA and RRC-RIAR found excellent agreement
  - Cladding embrittled in hoop direction, also embrittled in axial direction

Should CRUD be Included in LOCA Analysis?

- **Yes for Thermal Hydraulics; NO for High-Temperature Embrittlement; Probably NOT for Breakaway Oxidation**

- **Only Tenacious CRUD Could Result in Element Diffusion into Outer-Surface Oxide Layer and Possibly into the Metal**
  - Limerick BWR cladding had tenacious CRUD
    - *Tenacious CRUD adheres to outer surface of corrosion layer*
    - *Total of corrosion layer + tenacious CRUD layer was about 15-20 μm*
  - Generally, PWR fuel rods do not have tenacious CRUD
  - Elements in CRUD (oxides): Fe, Ni, Cu, and Cr
  - Unlikely that any of these elements would diffuse into the metal
  - Even if they did, they would not affect high-temperature embrittlement
  - CRUD elements are unlikely to affect breakaway oxidation
- **High-burnup Limerick One-Sided Oxidation Results at 1000ºC**
  - No indication of breakaway oxidation at 1200 and 3600 s
  - Results at 6000 s are inconclusive without metallographic examination

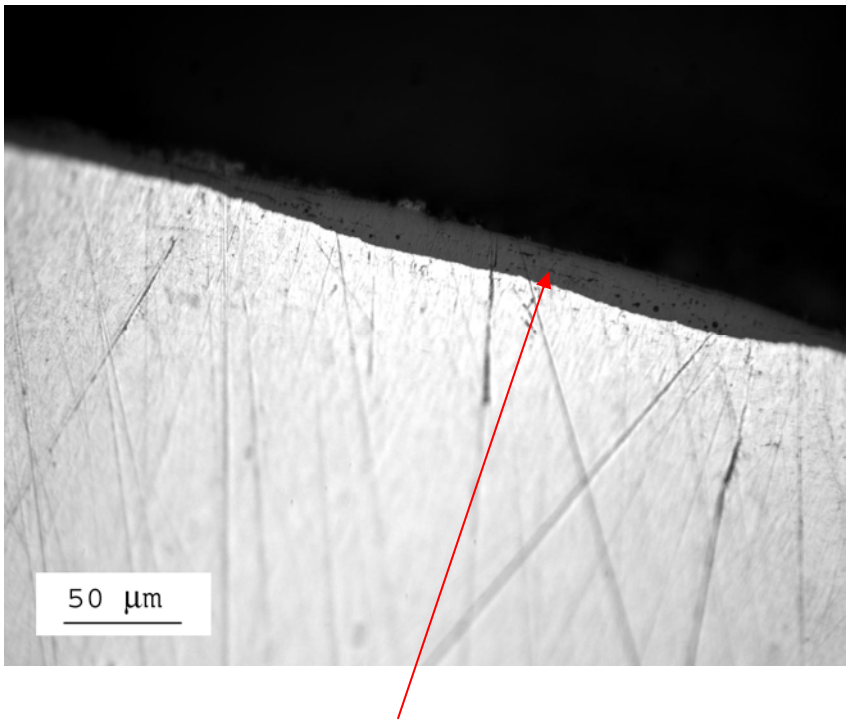
Visible Appearance of Corrosion vs. Crud layers



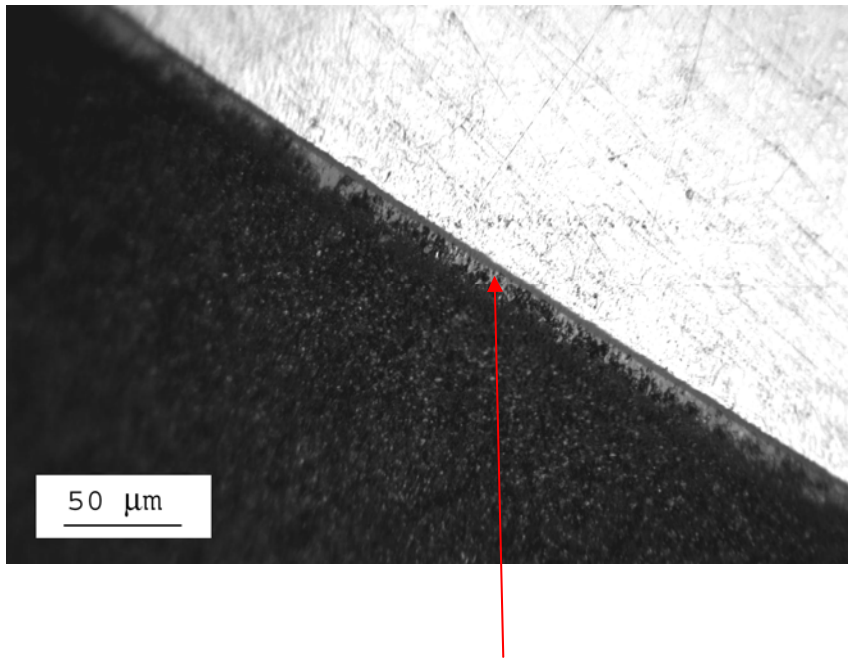
Corrosion Layer
Dark Gray

Crud
Light Gray

Tenacious Crud on Relatively Thick and Thin Corrosion Layers at the Same Axial Locations

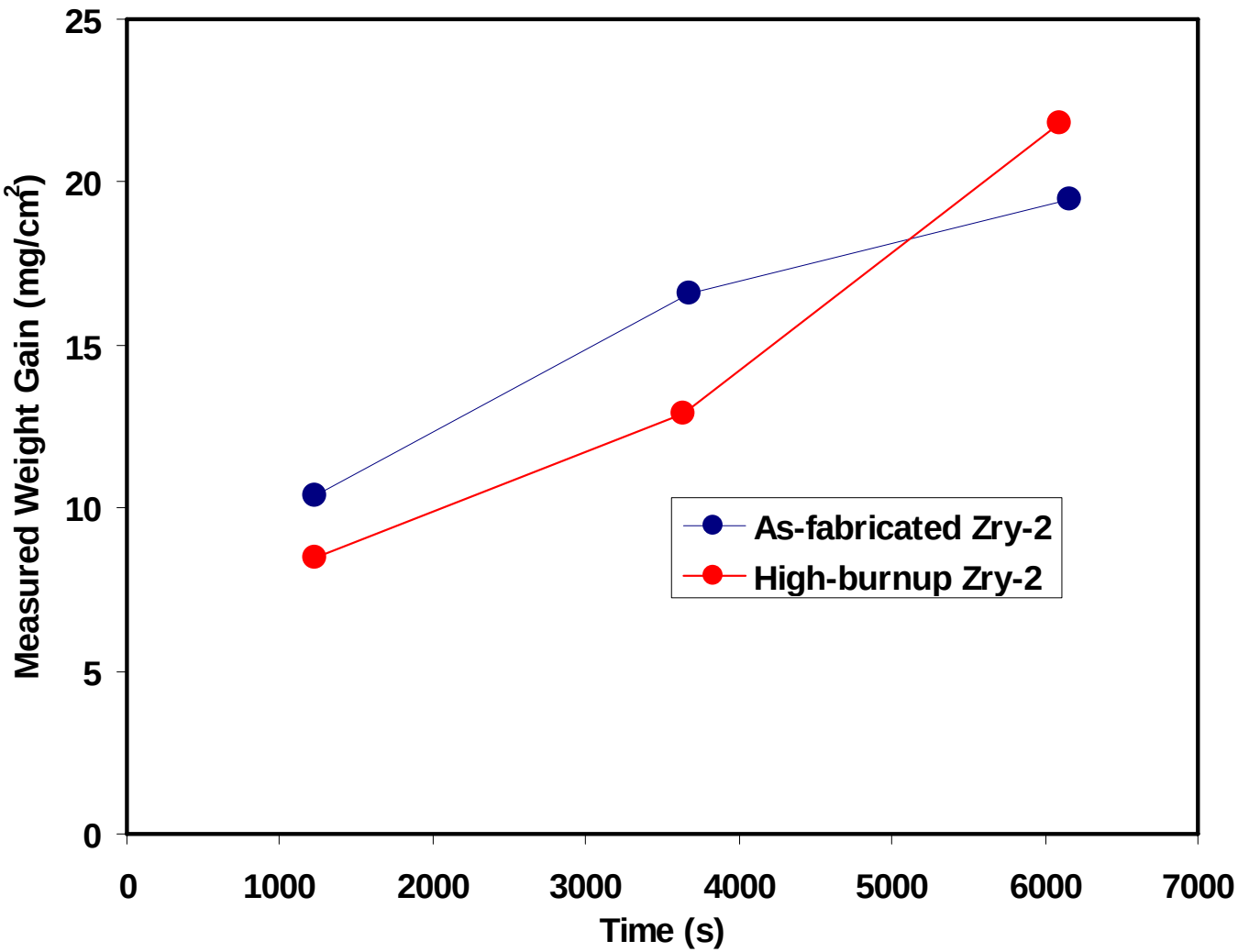


Thick Corrosion Layer
No Crud Layer

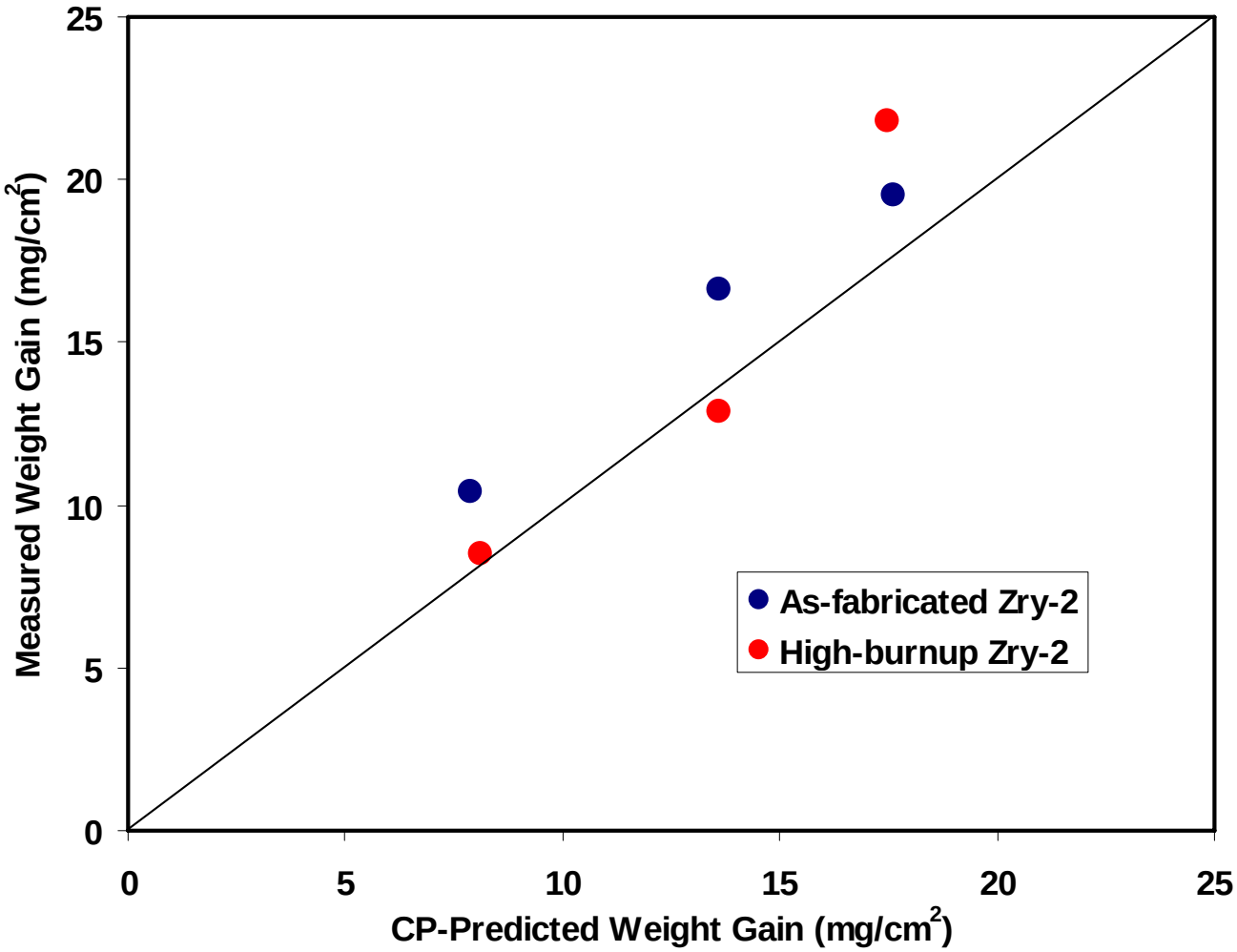


Thin Corrosion Layer
Thick Crud Layer

Zry-2 Measured Weight Gain vs. Time at 1000ºC



Zry-2 Measured vs. CP-Predicted Weight Gain at 1000ºC



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Cladding Embrittlement During Postulated Loss-of-Coolant Accidents; NUREG/CR-6967

*M. Billone, **Y. Yan**, T. Burtseva, and R. Daum*

ACRS Subcommittee Meeting
Materials, Metallurgy, and Reactor Fuels

NRC Headquarters

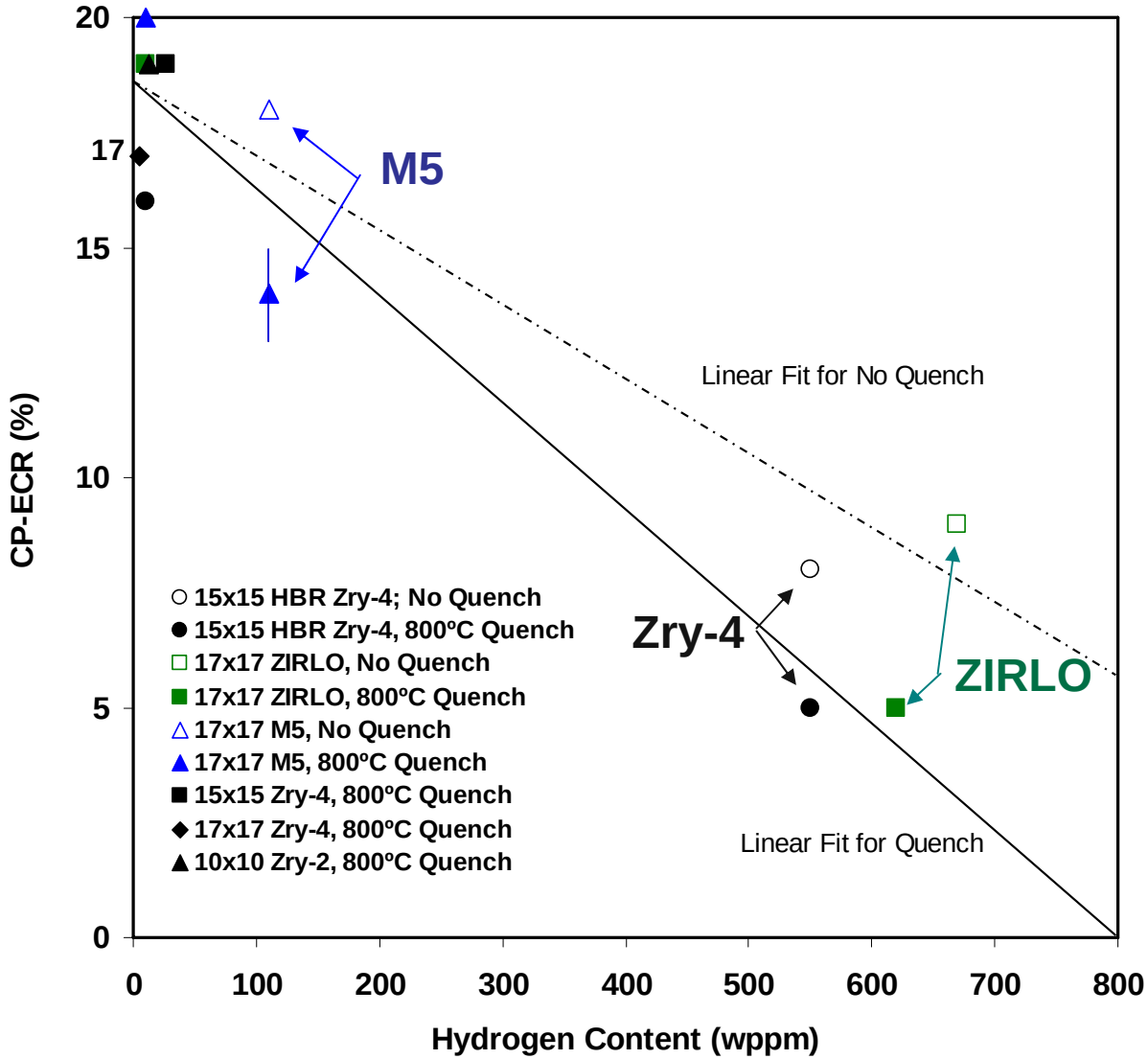
December 2, 2008

Work sponsored by the US Nuclear Regulatory Commission

Executive Summary

- **Testing Performed at ≤2200ºF (≤1204ºC)**
  - As-fabricated cladding (800-1204ºC)
  - Prehydrided cladding (1180-1204ºC)
  - High-burnup cladding (1100-1200ºC)
- **Determine Ductile-to-Brittle Transition**
  - Calculated oxidation level at high cladding temperature (1000-1200ºC)
  - Time at lower temperatures for breakaway oxidation (800-1000ºC)
- **Quantify Decrease in Embrittlement Threshold with**
  - Increase in cladding temperature (1000-1100ºC, CP-ECR > 20%)
  - Increase in hydrogen content due to in-reactor corrosion, breakaway oxidation, and secondary hydriding following burst
- **Results for Fresh and High-Burnup Cladding**
  - Fresh: Zry-2, Zry-4 (3 types), ZIRLO and M5
  - High-burnup: Zry-4, ZIRLO and M5

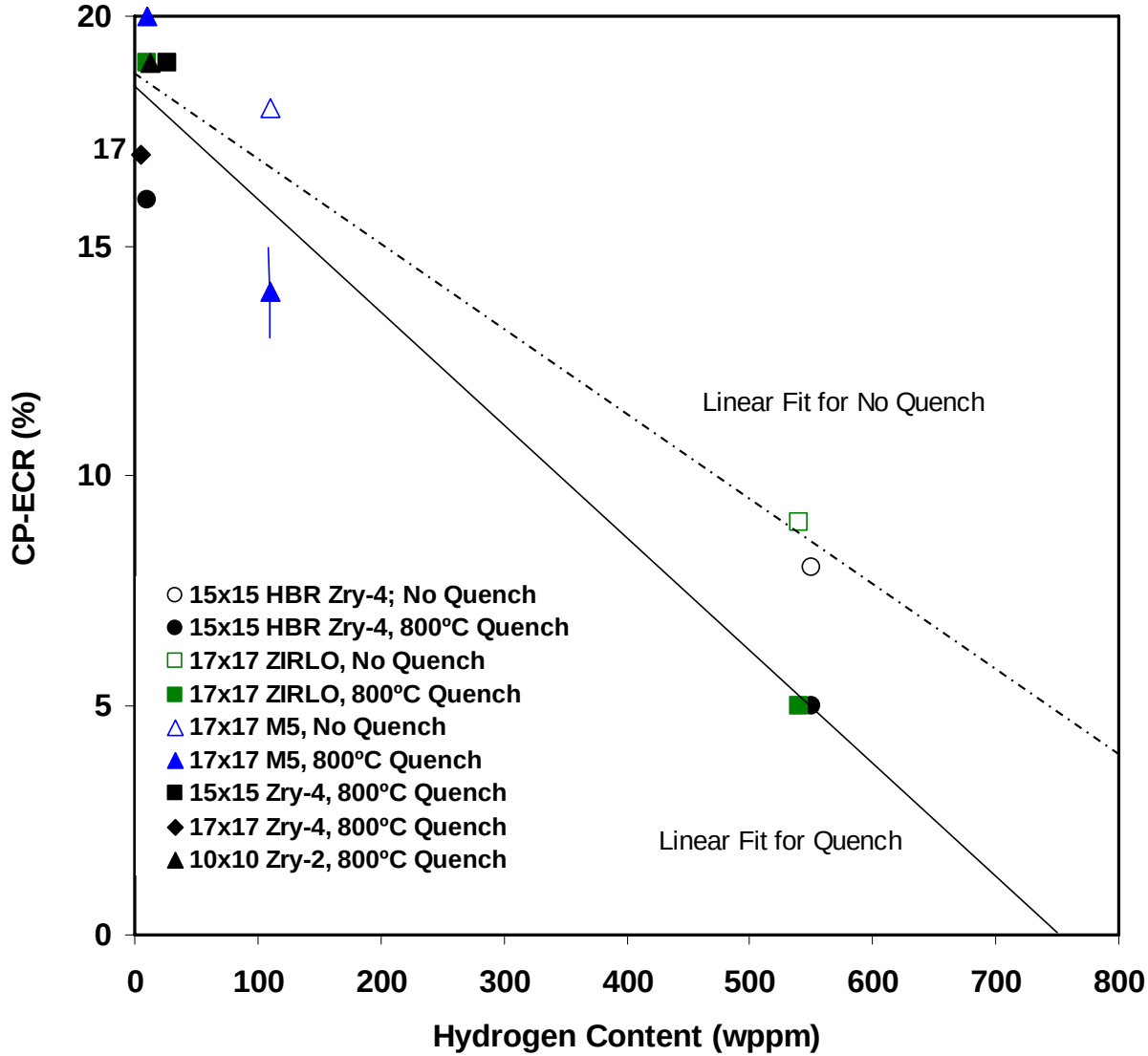
Embrittlement Threshold vs. Pre-test Hydrogen Content



Notes and Additional Embrittlement Results in Section 7

- **Notes on Embrittlement Data Shown in Executive Summary**
  - Oxidation threshold is determined to nearest % oxidation level (CP-ECR) for which cladding retains marginal ductility; brittle behavior is observed for 1% higher oxidation level then values in figure
  - Peak oxidation temperature is 1200ºC for >5-8% CP-ECR
  - Ductility is based on ring-compression tests conducted at 270ºF (135ºC)
    - *Most data points are based on a ductility limit of 1% permanent strain*
    - *Offset strain is determined for each compressed ring and used when no meaningful permanent strain can be measured (e.g., 2 cracks)*
  - Pre-test hydrogen measured for corroded high-burnup ZIRLO is about 100 wppm higher than hydrogen measured after LOCA tests
  - High-burnup Zry-4 and ZIRLO exhibit significant circumferential variation (±100 wppm) in hydrogen concentration; both pre-test and post-test
- **Embrittlement Threshold vs. ZIRLO Post-Test Hydrogen (≈40 μm corrosion layer)**
  - Slow-cooled, high burnup ZIRLO: 670±40 wppm → 540±100 wppm
  - Quenched, high-burnup ZIRLO: 620±140 wppm → 540±100 wppm

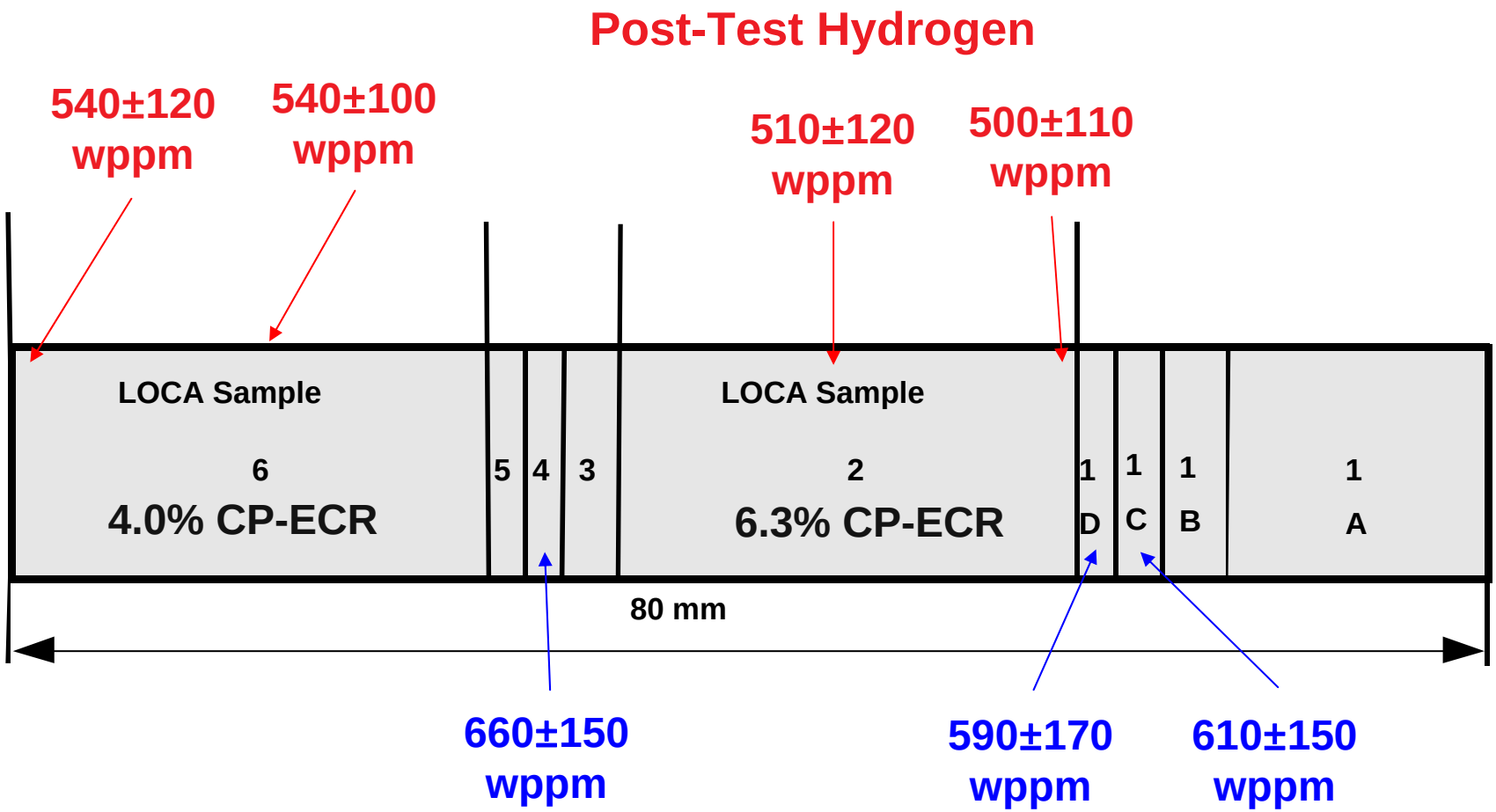
Embrittlement Threshold vs. Post-Test Hydrogen Content



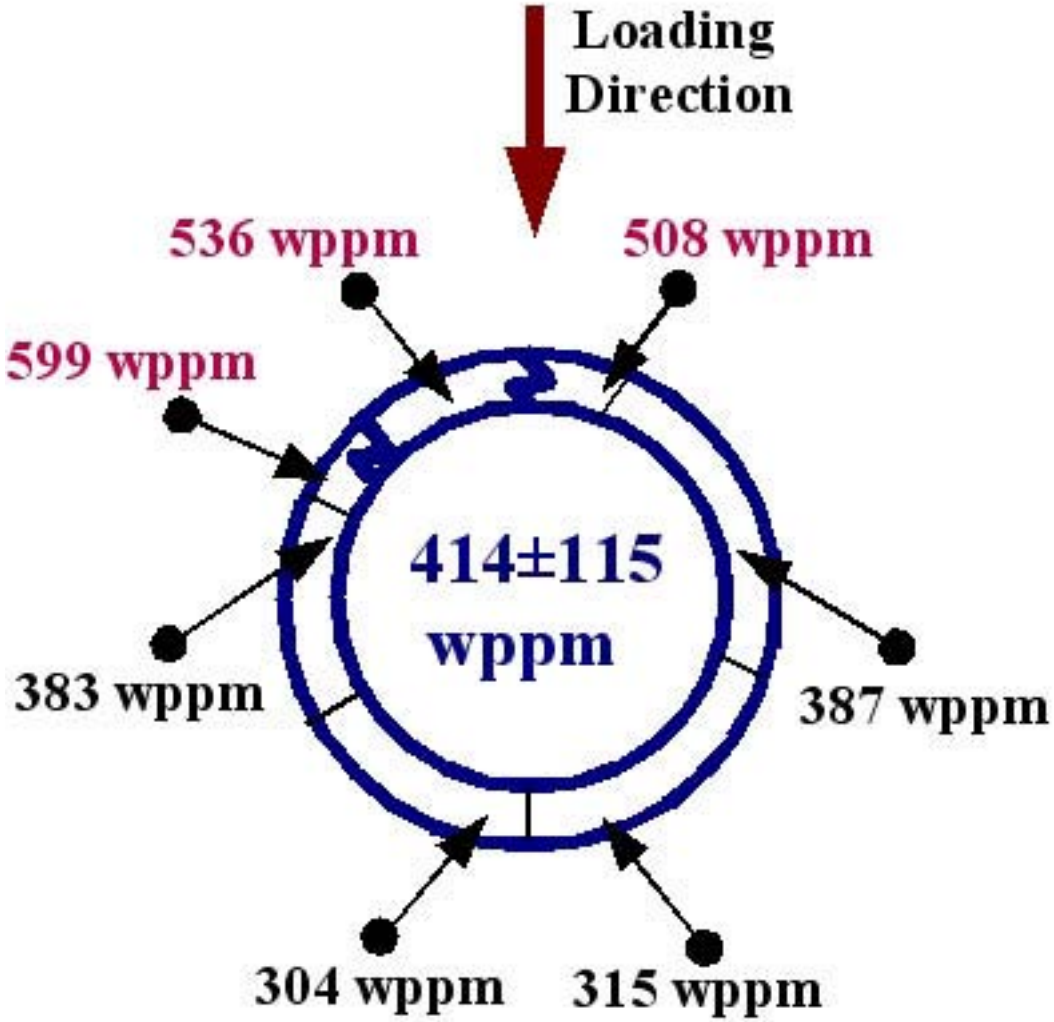
Hydrogen Concentration Variations in High-Burnup ZIRLO

- **Pre-Test vs. Post Test Values**
  - Pre-test measurements performed routinely in hot cells
    - *Small sample length (1-2 mm) and mass (0.1-0.2 g)*
    - *Sample includes corrosion layer and bond layer*
  - Post-test measurements performed by ANL
    - *Larger sample length (2-16 mm) and mass (0.2-1.0 g)*
    - *Some of corrosion layer flakes off during LOCA test cooling*
    - *Change in sample weight for <7% CP-ECR is -1 to 0.3%*
  - Higher pretest values due to hydrogen content in corrosion layer
    - *ANL working on improved technique to measure hydrogen in metal*
- **Large Circumferential Variations for High-Burnup Zry-4 & ZIRLO**
  - Supported by metallographic Images of hydride distribution
  - Dense hydride rim in ZIRLO varies systematically from ≈ 40 to 70 μm for 43±2 μm corrosion layer and 660±150 wppm pre-test hydrogen

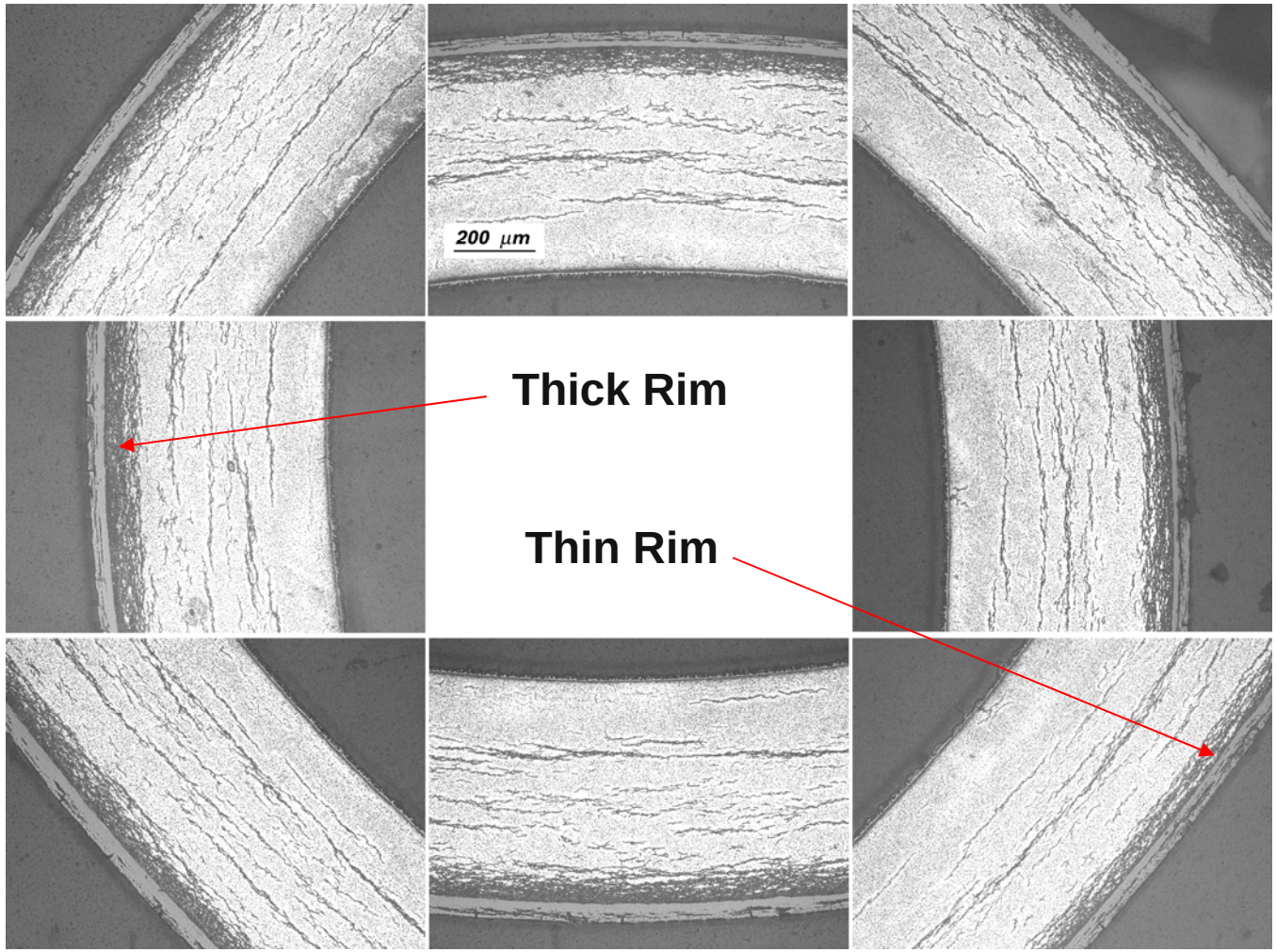
Pre-Test and Post-Test Hydrogen for High-Burnup ZIRLO



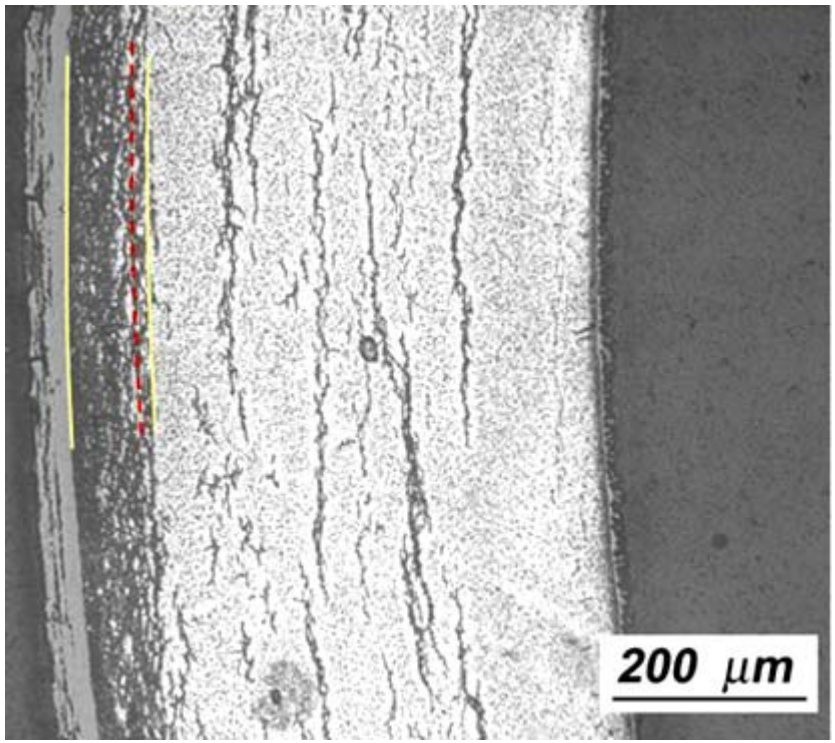
Ductile (10%) High-Burnup ZIRLO Ring after 5.1% CP-ECR, 1162ºC Peak Oxidation Temperature and 800ºC Quench



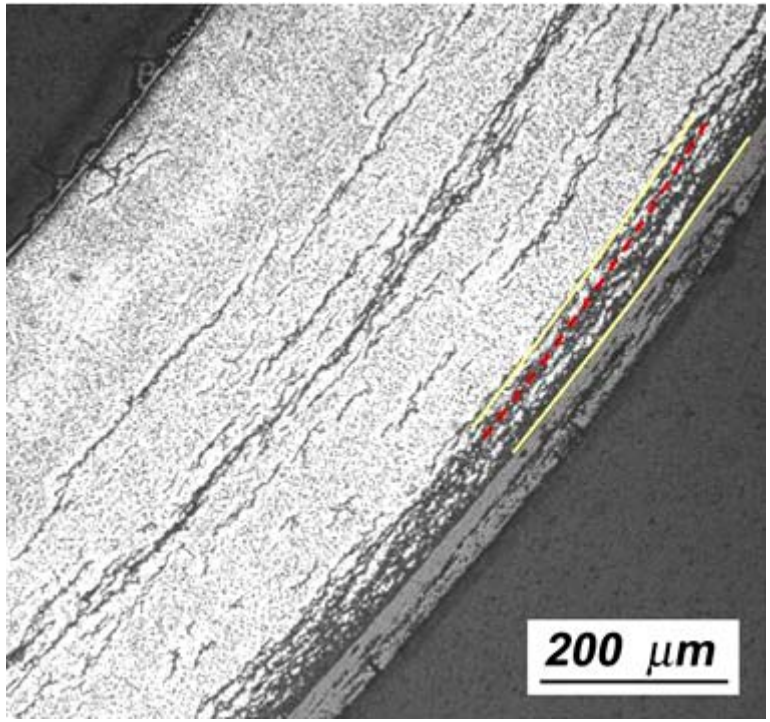
Hydride Distribution in High-Burnup ZIRLO Cladding with 43±2 μm Corrosion Layer and 660±150 wppm Pre-Test H



Regions of Minimum and Maximum Hydride Rim in High-Burnup ZIRLO with 43±2 μm Corrosion Layer



≈70-μm rim thickness



≈40-μm rim thickness

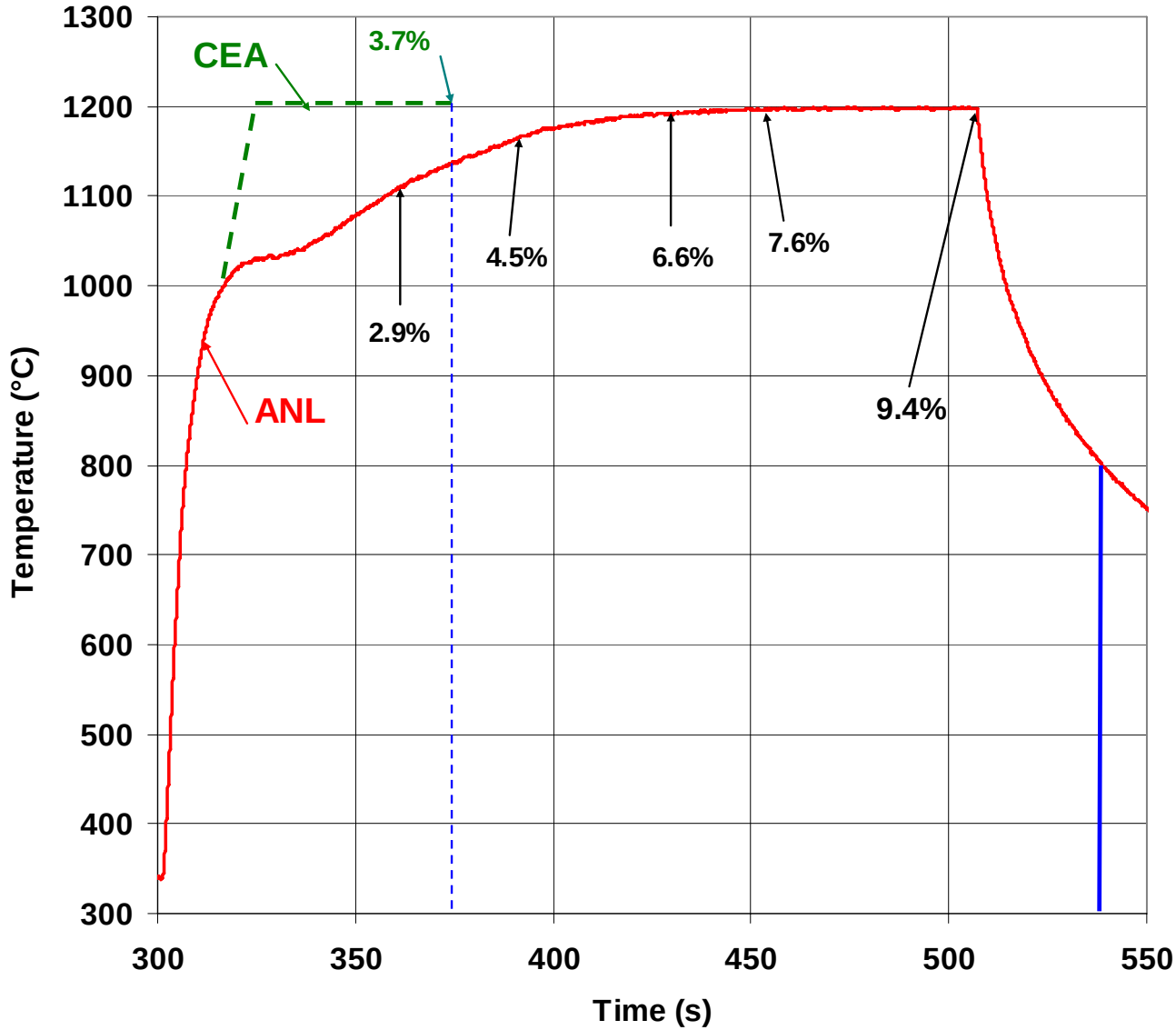
Selection of Samples for LOCA Embrittlement Tests

- **High-Burnup Zry-4 Characterization Results: MP to +0.74 m Above MP**
  - Corrosion layer thickness: 70 to 100 μm (based on metallography)
  - Pre-test hydrogen content: 550±100 to 770±125 wppm
  - **LOCA samples: 70 μm corrosion; 550±100 wppm hydrogen**
    - *Based on ANL & CEA data for prehydrided Zry-4 with 500-600 wppm H*
- **High-Burnup ZIRLO Characterization Results**
  - Corrosion layer thickness: 20 to 70 μm (based on eddy current)
  - **LOCA samples: 40-45 μm corrosion; 560±140 to 620±140 wppm H**
    - *Based on assumed hydrogen concentration values of ≈400 wppm*
- **High-Burnup M5 Characterization Results**
  - Corrosion layer thickness: 18±5 μm (based on eddy current)
  - **LOCA samples: 12±1 μm (based on metallography); 110±20 wppm H**
    - *Only 4 adjacent 80-mm-long Ringhals samples were available*

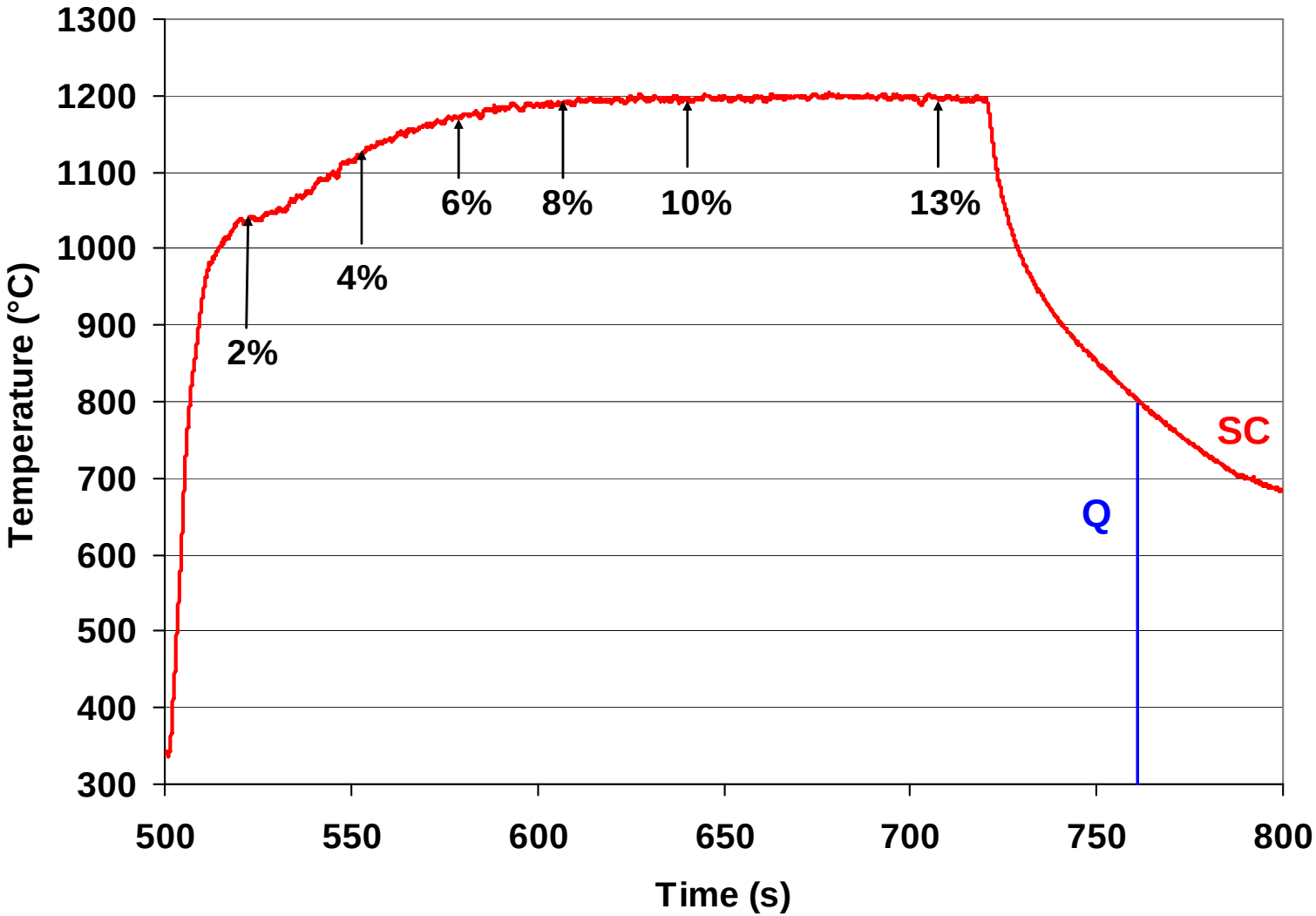
Selection of Oxidation Levels and Times for LOCA Embrittlement Tests

- **High-Burnup Zry-4 Oxidation Levels**
  - ANL data for pre-H Zry-4: Transition CP-ECR < 5% for >550 wppm H
  - CEA data for pre-H Zry-4: Transition CP-ECR <3% for >550 wppm H
  - Oxidation levels for tests without quench (3 to 9% CP-ECR)
- **High-Burnup ZIRLO Oxidation Levels**
  - ANL data for pre-H and high-burnup Zry-4
  - High pre-test hydrogen concentrations were a major concern
  - Oxidation levels for tests without quench (6-10%)
    - *Post-test hydrogen measured to be 540±100 wppm*
  - Oxidation levels for tests with quench (4 to 6% CP-ECR)
- **High-Burnup M5 Oxidation Levels**
  - CEA data for prehydrided (120-130 wppm) M5
    - *Low ductility (6% offset strain) at 11% CP-ECR*
    - *Very Brittle at 18% CP-ECR*
  - Oxidation levels: 13 to 18% for slow cooled; 13 to 16% for quench

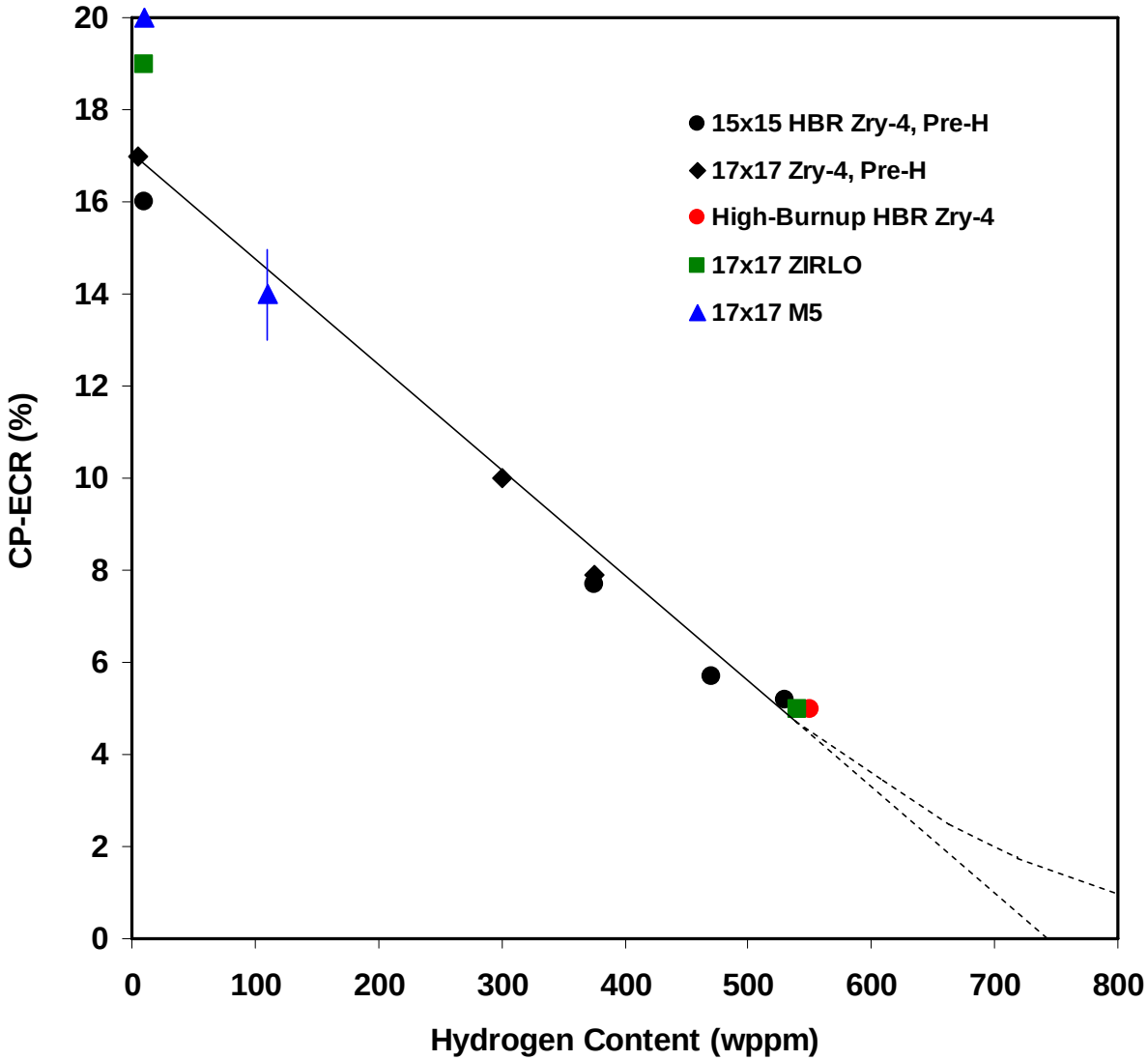
Temperature History for ANL High-Burnup 15×15 Zry-4 Tests



Temperature History for High-Burnup 17×17 ZIRLO Tests



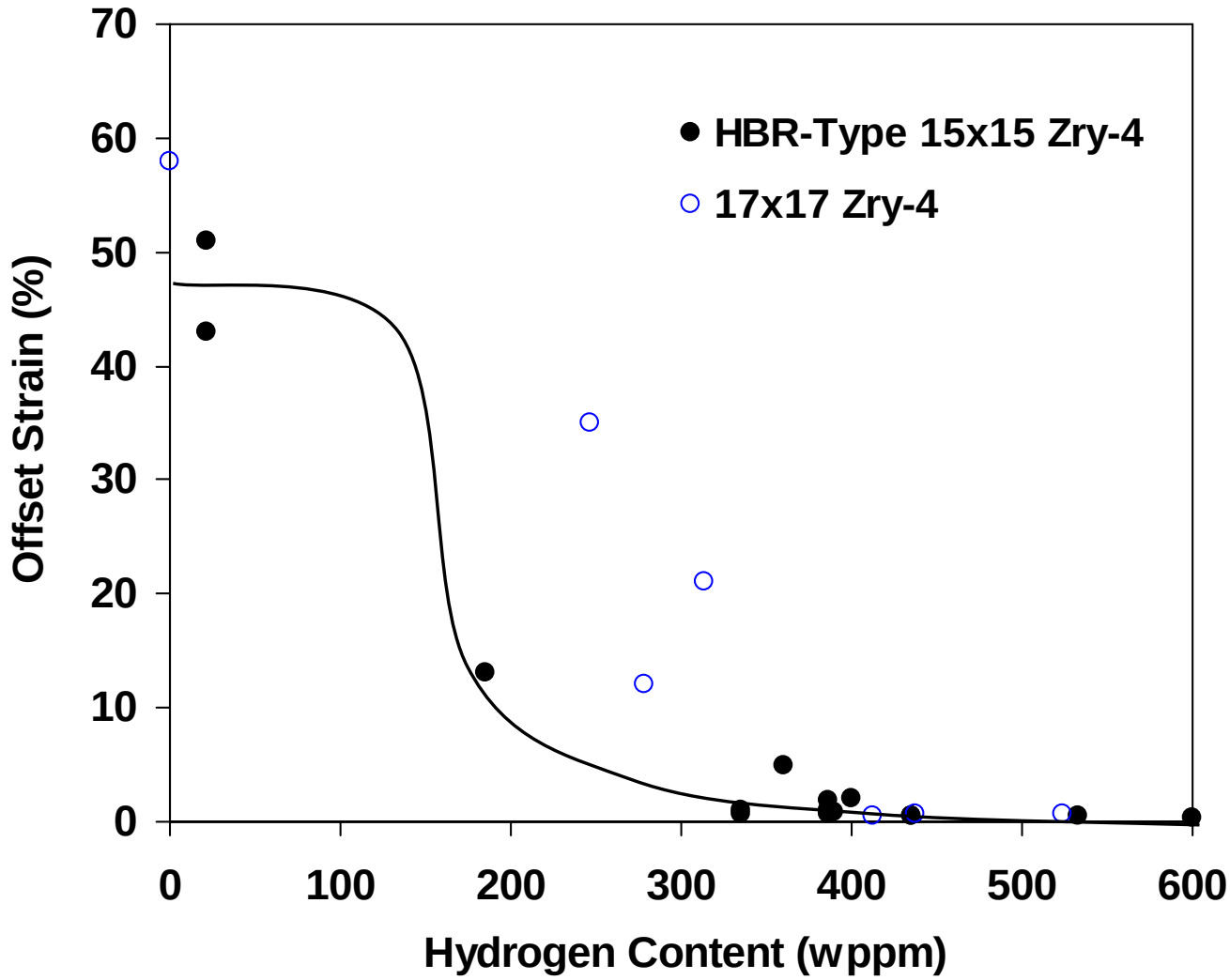
Prehydrided Zry-4 and High-Burnup Embrittlement Data



Multiple Tests Conducted to Determine Hydrogen Content for Embrittlement at ≈8% CP-ECR for Zry-4

- **Prehydrided 15×15 Zry-4**
  - Fixed oxidation level
    - *7.5% CP-ECR up through end of heating phase*
    - *7.7% total transient CP-ECR including cooling phase*
  - Tests conducted at different hydrogen contents (20 to 600 wppm)
    - *12 oxidation tests*
    - *25 ring compression tests*
- **Prehydrided 17×17 Zry-4**
  - Fixed oxidation level
    - *7.6% CP-ECR up through end of heating phase*
    - *7.9% total transient CP-ECR including cooling phase*
  - Tests conducted at different hydrogen contents (5 to 525 wppm)
    - *3 oxidation tests*
    - *7 ring compression tests*

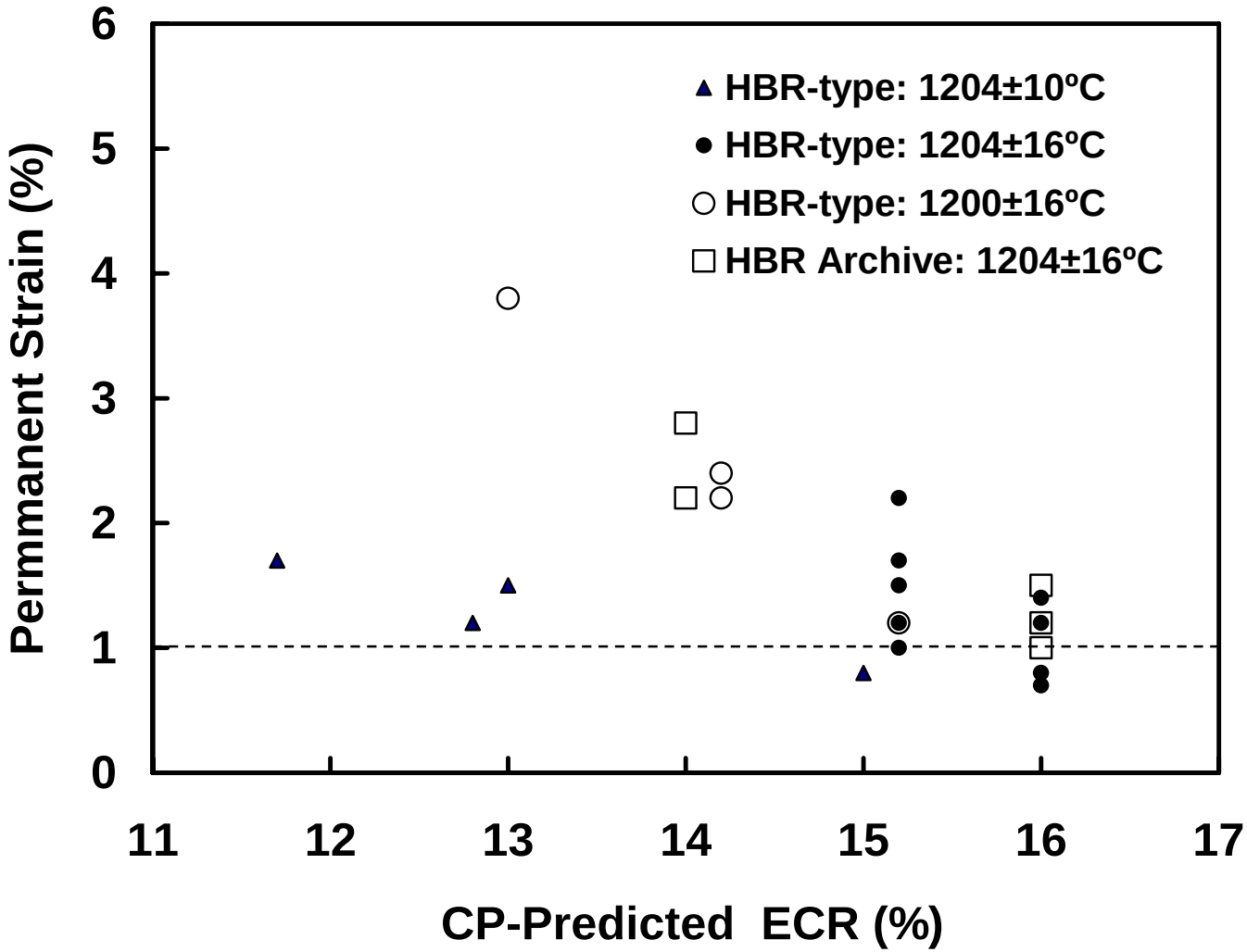
Ductility vs. Hydrogen Content for Zry-4 Oxidized at ≤1200ºC to ≈8% CP-ECR and Quenched at 800ºC



Embrittlement Threshold Uncertainties for Fresh Cladding

- **ANL Approach for As-fabricated HBR-type 15x15 Zry-4**
  - Broad-brush approach: determine trend of ductility decrease with increasing oxidation level (5, 7.5, 12-13, 15% CP-ECR) for 1200ºC
  - Focused approach: multiple tests performed for narrow oxidation range (13-16% CP-ECR) to determine ductile-to-brittle transition CP-ECR
    - *9 oxidation-quench tests*
    - *18 ring-compression ductility data points*
    - *1200 and 1204ºC; HBR-type (low-Sn) & true HBR archive (standard Sn)*
- **Results**
  - Broad-brush results: 14.3% CP-ECR transition (interpolation from 13-15%)
  - Focused approach: 15.6% CP-ECR transition (interpolation from 15.2-16%)
  - Difference = 1.3%
  - Difference based on nearest % CP-ECR: 16%-14% = 2%

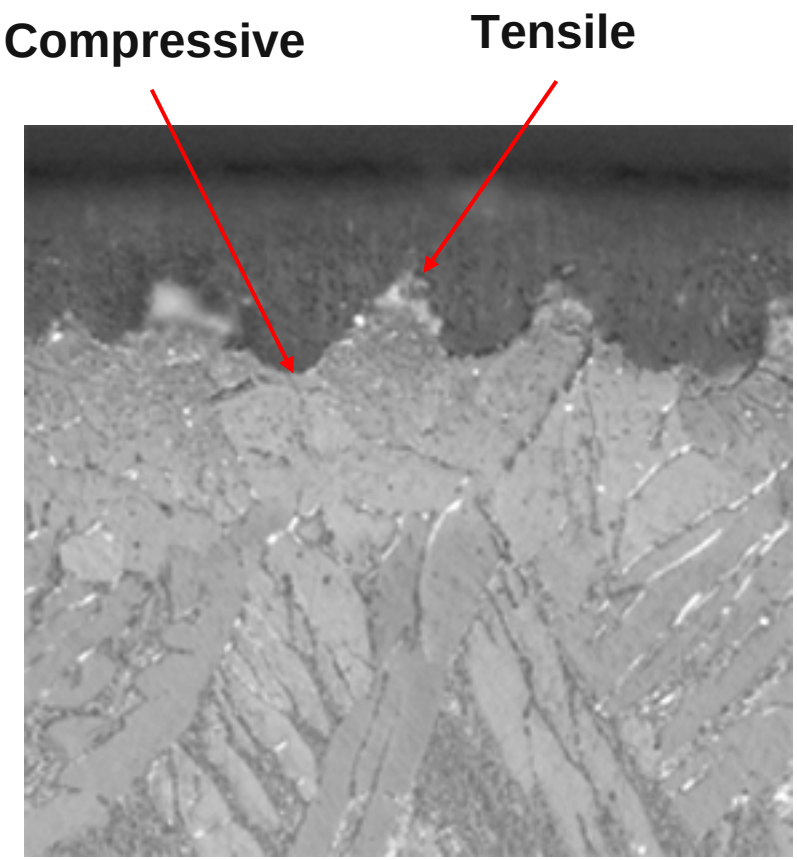
Embrittlement Threshold for HBR-Type Zry-4 oxidized at 1200ºC and Quenched at 800ºC: Results of Multiple Tests



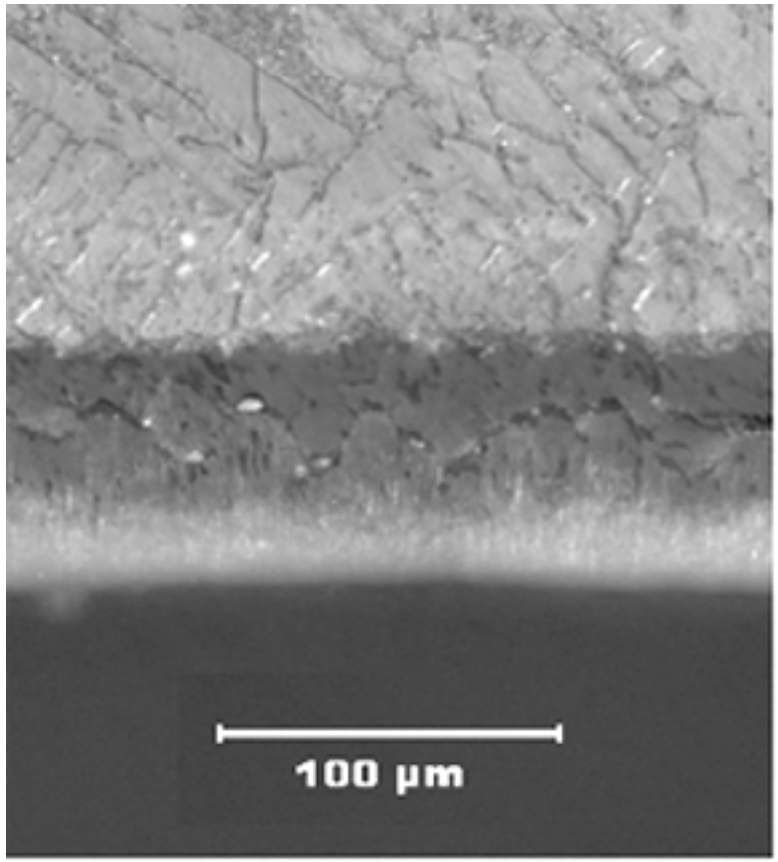
Breakaway Oxidation Studies: Background

- **Previous Results Available for Zry-4**
  - Leistikow and Schanz (1981-1985)
    - *1970s vintage standard Zry-4; samples were pickled in HF+HNO_3+H_2O*
    - *200-wppm H after 1800 s at 1000ºC*
  - ANL (2003)
    - *Modern 17x17 low-Sn Zry-4; belt polished OD; ????ID*
    - *<20 wppm H pickup after 3380 s at 1000ºC*
  - Mardon et al. (2005)
    - *Current 17x17 low-Sn Zry-4; wheel polished OD; grit-polished ID*
    - *200-wppm H after 5400 s at 1000ºC*
- **Previous Results Available for ZIRLO**
  - ANL (2003)
  - 100 wppm hydrogen pickup from ID breakaway after 3380 s at 1000ºC
  - No noticeable decrease in ductility due to hydrogen pickup

ANL Results for ZIRLO-2003 Oxidized for 3380 s at 1000ºC



Outer-surface Oxide
Scalloped Interface
Precursor to Breakaway



Inner-surface Oxide
Post-breakaway
100-wppm H Pickup

Breakaway Oxidation Studies: Background

- **Previous and Current Results Available for M5**
  - ANL (2003)
    - *Modern 17x17 M5 (0.61-mm wall); wheel polished OD; grit polished ID*
    - *No hydrogen pickup following oxidation for 4100 s at 1000ºC*
    - *Post-breakaway oxidation observed after 11,000 s at 1000ºC*
  - Mardon et al. (2005)
    - *Modern 17x17 M5 (0.57-mm wall); wheel polished OD; grit polished ID*
    - *200-wppm hydrogen content after ≈6400 s at 1000ºC*
  - ANL (2008): >5000 s at 985ºC (test performed on 12-01-2008)
- **Previous Results Available for E110**
  - All LOCA oxidation studies with standard E110 are breakaway oxidation studies (e.g. Boemert et al., 1993)
  - Concurrent testing conducted at ANL (2003-04) and RRC-KI/RIAR (≤2005)
  - E110 is basically unstable with respect to breakaway oxidation, most likely due to fluorine impurities from Hf-reduction process and pickling in acid mixture containing HF: surface, substrate, bulk all experience breakaway

Breakaway Oxidation for Zry-4 and Zry-2

Material	Temperature ºC	Test Time, s	Hydrogen Pickup, wppm	Comment
15×15 Zry-4 Low-Sn Old HBR-type	985±10	3600 3800 3900	170 20-40 1320	OD surface scratch Lustrous black OD Gray areas on OD
15×15 Zry-4 Low-Sn Modern	985±12	5000 5400	280 410	Gray line on OD Larger gray areas
10×10 Zry-2 ID Zr-liner Modern	1000±8 1000±8 985±8 970±8	5000 5000 5000 5000	4 21 15 3	Lustrous black OD OD surface scratch Lustrous black OD Lustrous black OD

Minimum Breakaway Oxidation Times:

Old 15×15 Zry-4 with no surface scratches = 3800 s

Old 15×15 Zry-4 with surface scratches = 3600 s

Modern 15x15 Zry-4 = 5000 s; Modern Zry-2 with or without 20-μm-deep scratch > 5000 s

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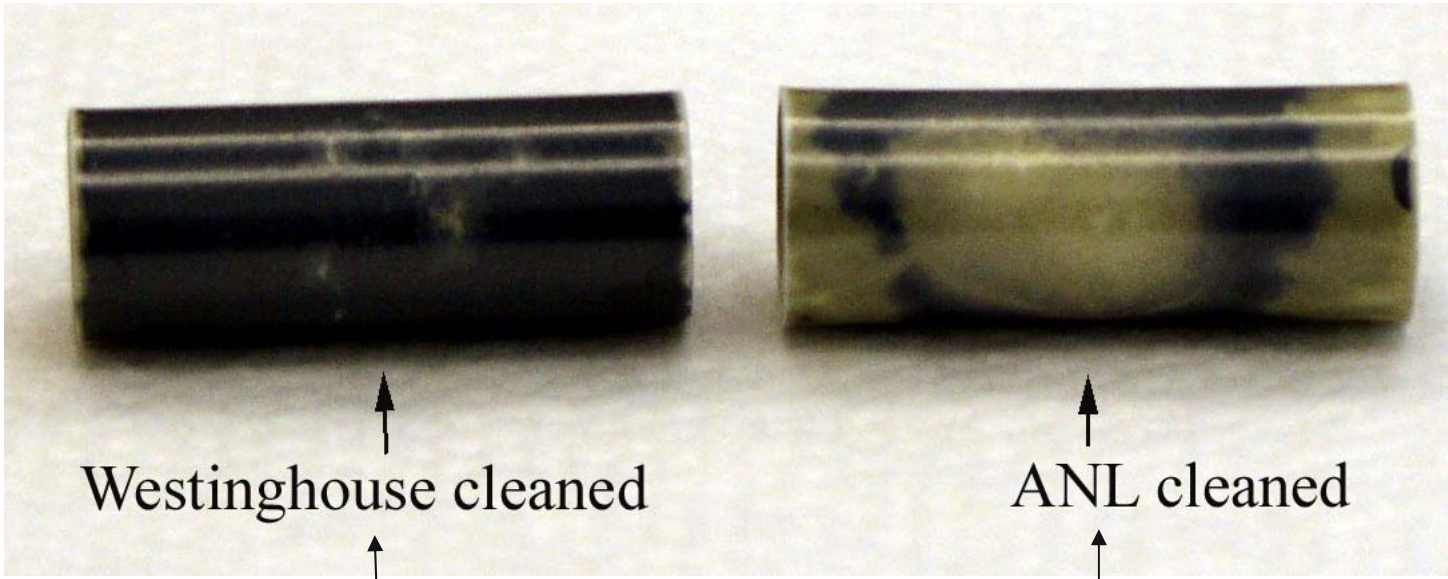
Breakaway Oxidation for ZIRLO

- **Extensive Studies Performed by ANL due to Lack of Available Data**
  - ZIRLO-2003: ID breakaway, no OD breakaway for ≈3400 s at 1000ºC
  - ZIRLO-2006
    - *Results are highly temperature dependent in 950-1000ºC range*
    - *Minimum breakaway time = 3000 s at 970ºC, 4000 s at 1000ºC*
    - *Scratched (20-μm-deep) > 2600 s at 970ºC, 3400 s at 985ºC*
    - *Prefilmed (<1- μm oxide) ≈3400 s at 985C*
    - *Minimum breakaway time for all samples: 3100±300 s at 970-985ºC*
  - ZIRLO-2008
    - *ANL-cleaned (Ethanol) vs. W-cleaned (Alconox): in progress*
- **Studies Performed by Westinghouse**
  - Minimum breakaway time > 5400 s at 950-1020ºC for 17×17 ZIRLO
  - Minimum breakaway time = 4400 s for W 15×15 Zry-4
  - Cross check with ANL-cleaned samples: 4400 s at 960-1010ºC
    - *In progress*

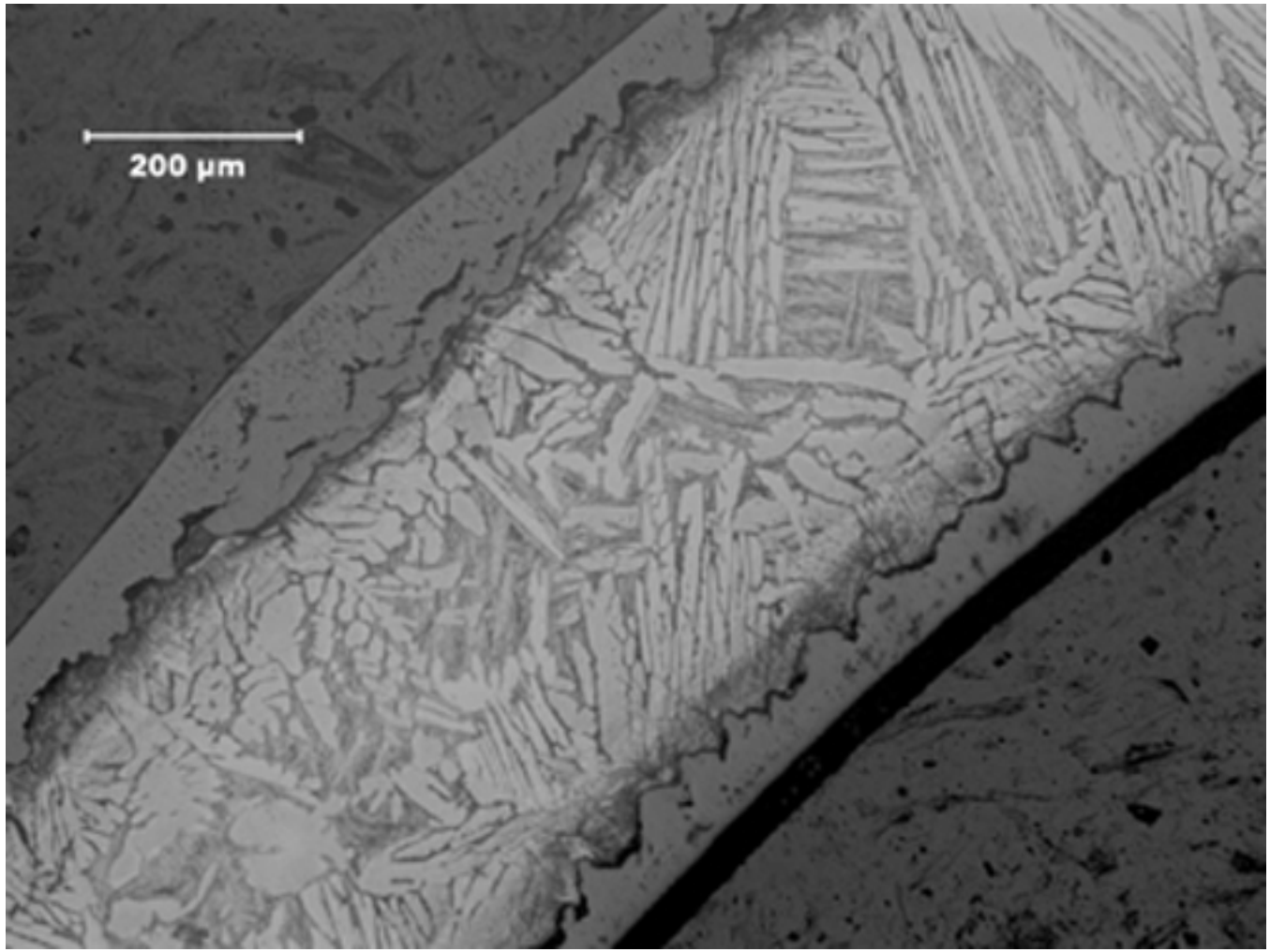
Preliminary Results for ANL- vs. W-Cleaned ZIRLO after 4000 s at 1000ºC



120±110 wppm Hydrogen Pickup

390±220 wppm Hydrogen Pickup

Local Breakaway Oxidation in W-Cleaned OD Oxide after 4000 s at 1000ºC; Local Hydrogen Content ≈ 300 wppm



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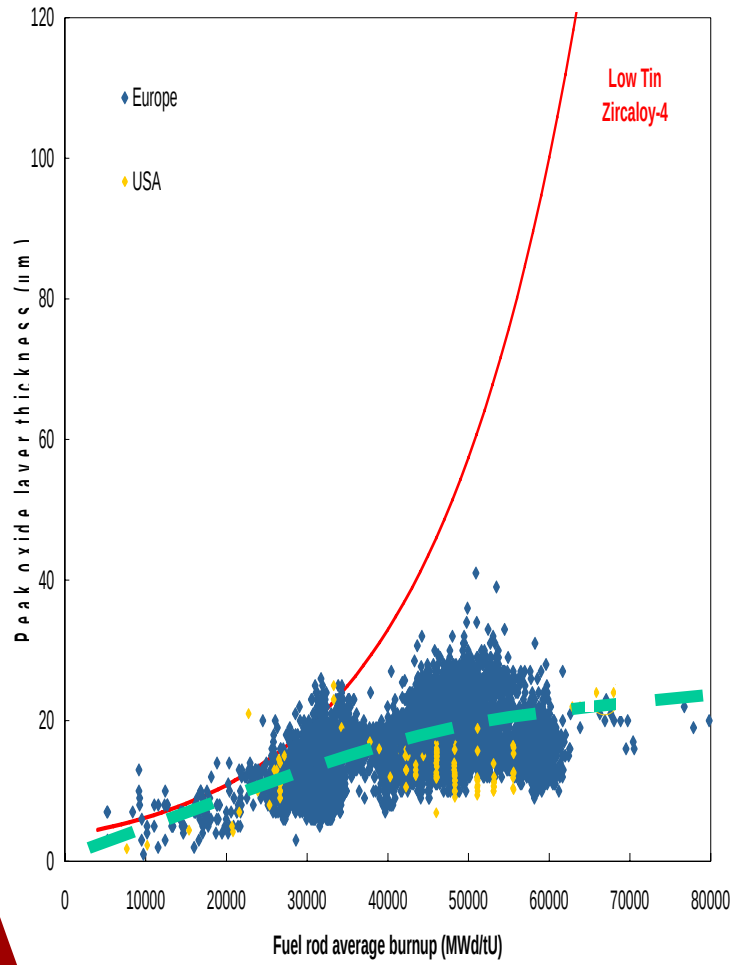
AREVA Position on Revised LOCA Criteria

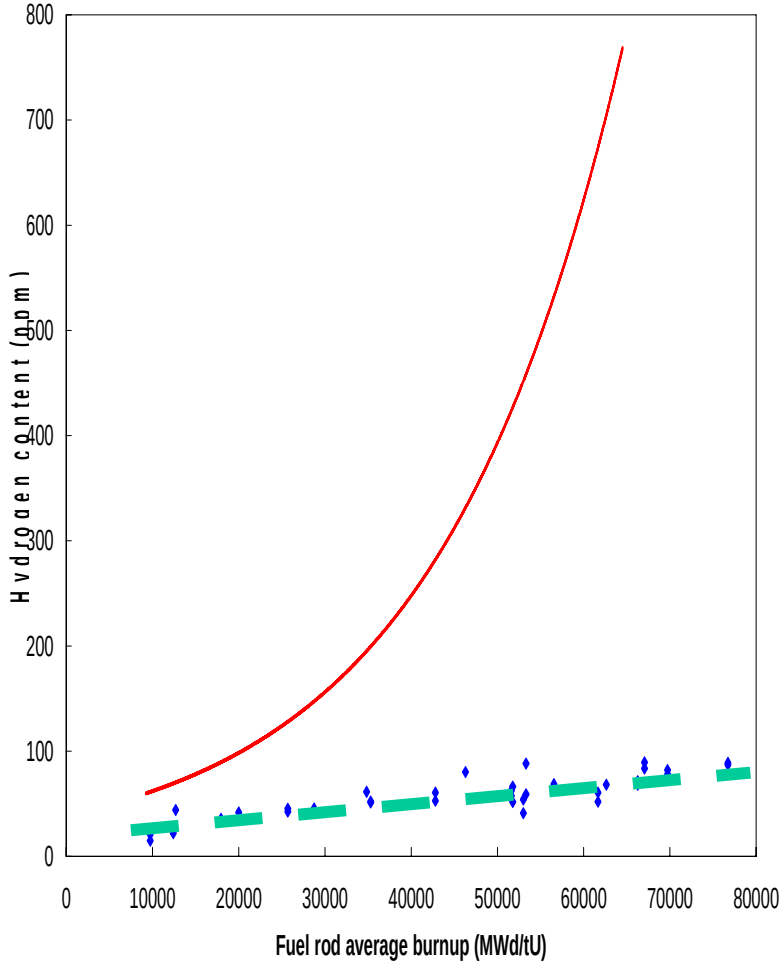
- **With the exception of Breakaway Oxidation**
  - **The existing rule implemented with IN 98-29 Is adequate**
  - **Protection for Breakaway Oxidation should be added to LOCA requirements but does not require a 50.46 change**
- **Enabling Rule for Burnup Effects on Oxidation**
  - **Example "Cladding shall retain ductility post LOCA"**
  - **This is possible to write now, however**
    - **Numeric values must be design and alloy dependent**
    - **Burnup dependencies should, to the extent reasonable, tie to basic causes (This would be Hydrogen with Corrosion as a surrogate)**
    - **The implementation should be by NuReg or Reg Guide with sufficient time allowed for development and compliance**
- **Concerns Over Definitions and Application Remain**

Why an Enabling Rule
Corrosion/Hydrogen Database

Corrosion Database in USA and in Europe



Hydrogen Data Base



Validation Issues Yet to Be Established With the Industry

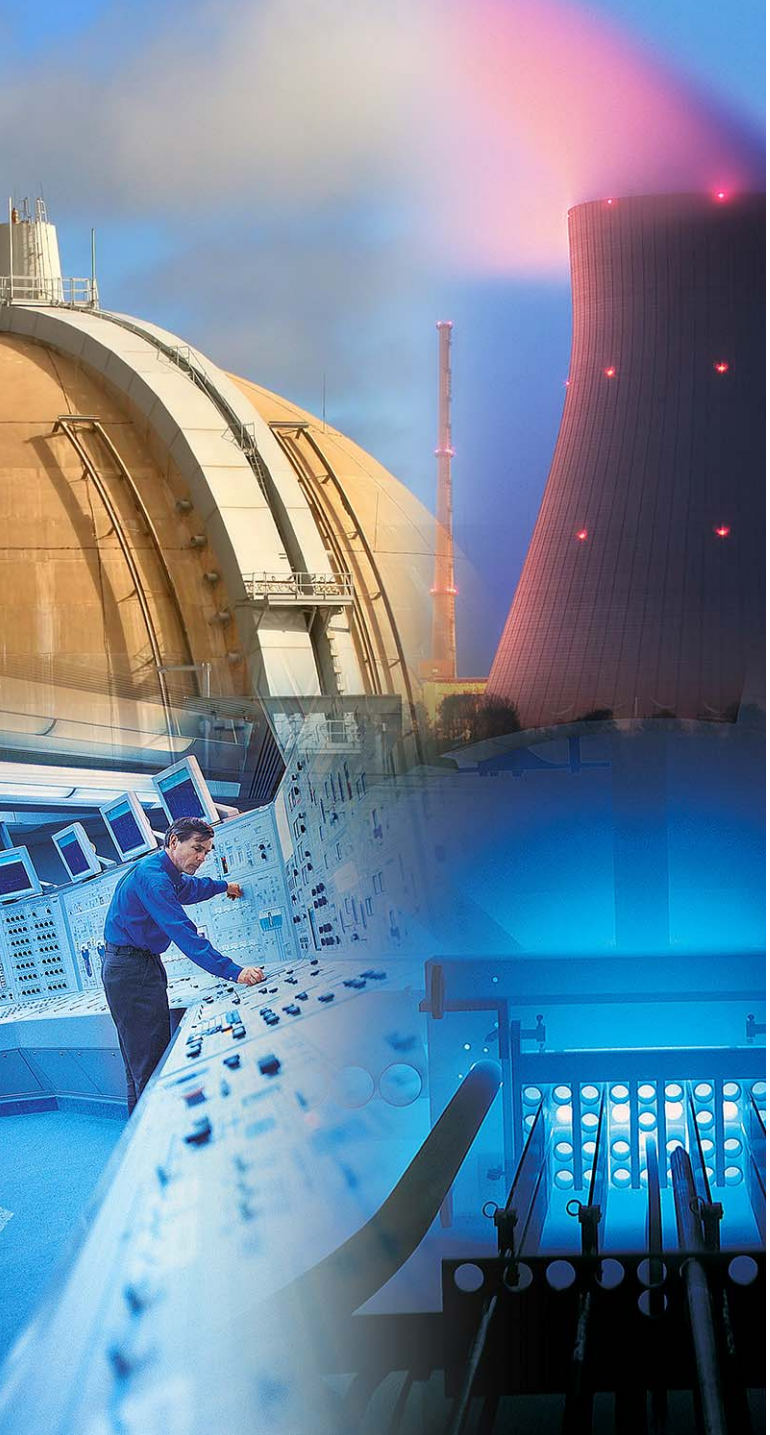
- **New Alloy**
  - **Determination (What changes constitute a New Alloy?)**
  - **Test spectrum**
    - **For new alloy?**
    - **A set of screening test for variations on a current alloy**
  - **Can burnup dependencies (Hydrogen) evolve with use of alloy?**

- **Should Periodic Testing be Mandated?**
  - **If so, what type of test?**
    - **Should be simple and non-intrusive on production**
    - **Should be clearly delineated (fair across design and alloy differences)**
    - **Should only serve a screening purpose (not for compliance)**

> LOCA Backup Slides

Issues Not Reviewed or Considered for Enabling Rule

- Definitions of Metrics (What is ductility?)
- Retained Margins (Where and how much?)
- Where Metrics are Applied (Ruptured Zone?)
- Determination of Numeric Criteria (Whom, When?)
- Cost Benefits of Back Fit Implementation
- Implementation Schedules



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Industry Position Overview

On the Technical Basis for Revision of Embrittlement Criteria in 10CFR50.46

ACRS Materials/Metallurgy/Reactor Fuels Subcommittee Meeting

December 2, 2008

Rockville, MD

Industry Presentation Outline

- Five industry presentations
  - Industry position overview
  - Industry test plans
    - Extended LOCA oxidation and PQD testing
    - ID oxidation tests
  - Inadequacy of data to support periodic testing and industry proposal
  - Implementation and cost/benefit analysis (2 presentations)

Industry Collaboration with NRC

- The industry is supportive of NRC's overall objective with regards to revision of 10 CFR 50.46(b)
  - Endorses the concept of a performance-based approach
  - Expects the new criteria will allow for cladding advances without need for rule exemptions
  - Acceptability assessments of cladding advances much faster if adequate surrogate to irradiation is identified
- The Industry's Fuel Reliability Program (FRP) has been actively participating in the LOCA tests at ANL *(with limited technical input since 2005)*
  - Supplying irradiated high-burnup BWR & PWR fuel rods with standard and advanced claddings for LOCA tests
  - Providing analytic support for design and qualification of LOCA and mechanical property tests

Industry Position Overview

- Incomplete and insufficient information provided in NUREG/CR-6967 to justify regulatory criteria proposed in RIL-0801
  - Original test and evaluation plan for ANL-NRC LOCA Program reduced due to hot-cell/lab delays/closure
- A bounding approach will have a significant negative impact on the industry with little or no safety benefit
  - Could impose criteria with excessive conservatism that is costly for the industry to implement
- Data obtained thus far does not indicate the presence of a public safety issue
  - No safety concern with current evaluation methods and design basis of operating plants

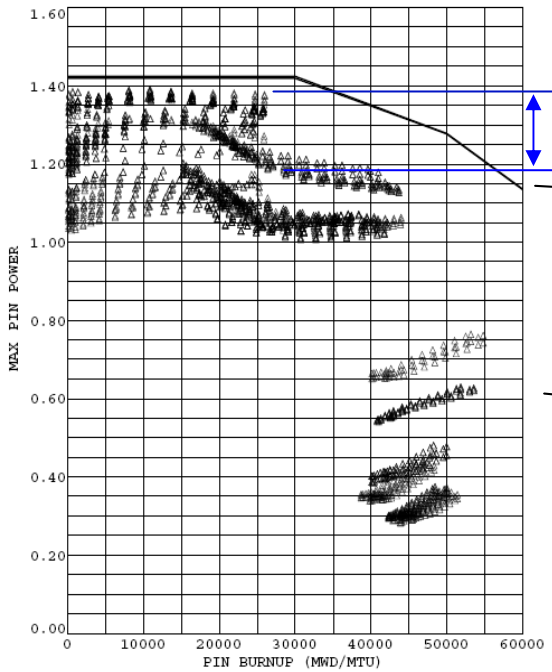
Data Gaps in NUREG/CR6967 (ANL Program)

- Post-quench ductility test scope
  - ANL testing focused on 1200°C
  - Insufficient data to understand effects of applied temperature profile and pre-LOCA hydrogen content (to be discussed in more detail in industry test plans presentation)
  - Critical PQD transition boundary recommendation not supported by data at elevated hydrogen content
  - Limited quench and alloy testing
- Requirement in RIL-0801 to use 2-sided oxidation away from the ballooned region is not supported by ANL data
  - Limerick rod integral test showed limited ID oxygen source
- Support for periodic testing of impurity effects on breakaway oxidation only from observed E110 material behavior
  - Fundamental differences between Kroll (Western process) and Electrolytic process used for E110

Range of Oxidation Temperatures

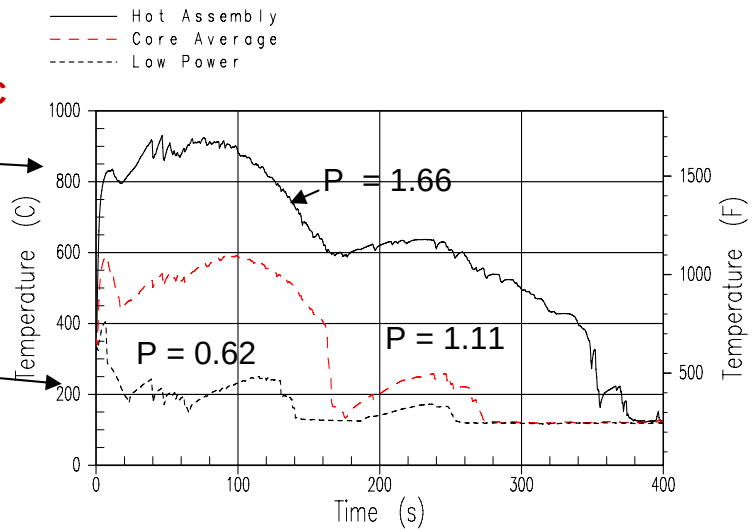
- NRC-RES efforts focused only on testing at 1200°C but high burnup fuel is not capable reaching this temperature

Typical 3-Loop PWR
Achievable Pin Power vs. Burnup



ΔT=~110°C

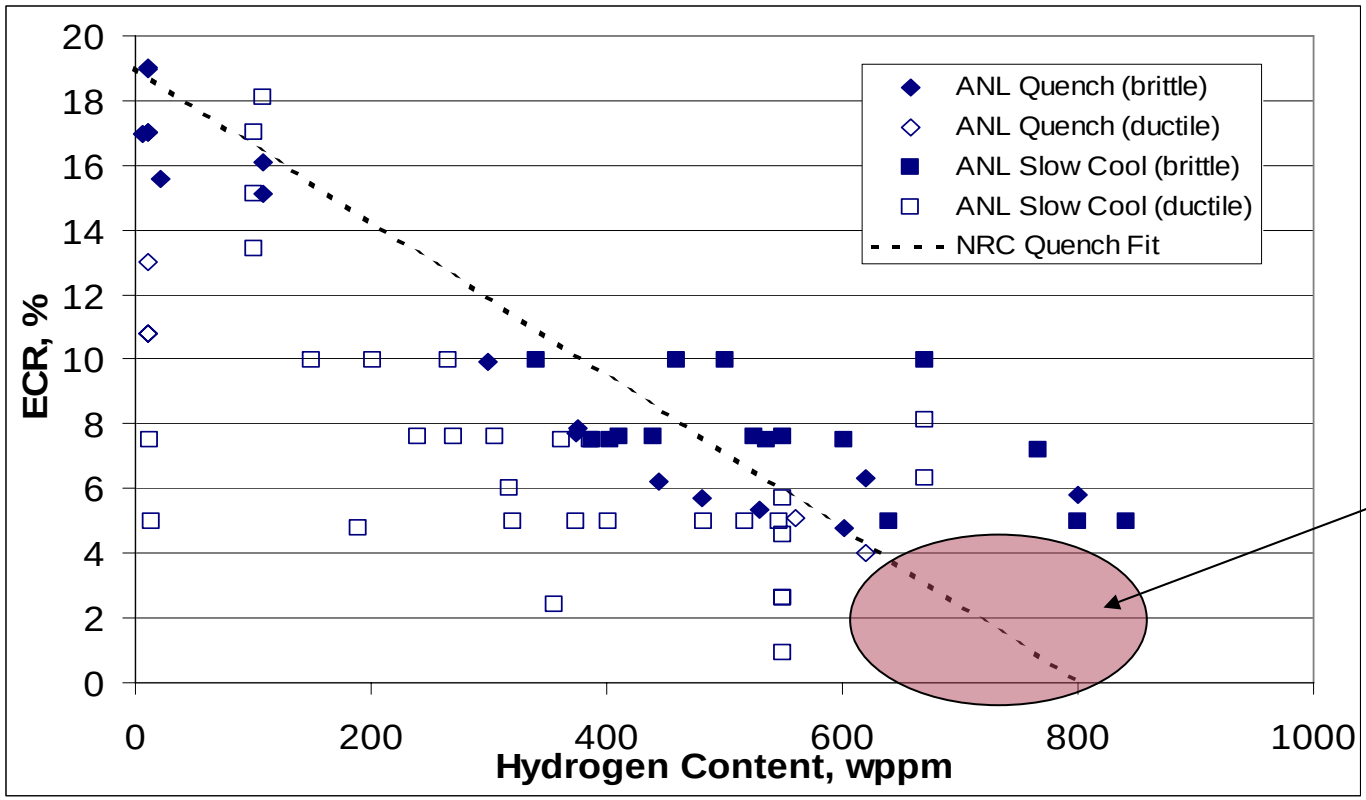
Typical 4-Loop PWR
LBLOCA PCT Response for Baseload Operation



A bounding approach will have a significant negative impact on the industry with little or safety benefit

RIL-0801 Recommendation

- ECR ductile/brittle transition limit extrapolation above 600 ppm is overly restrictive

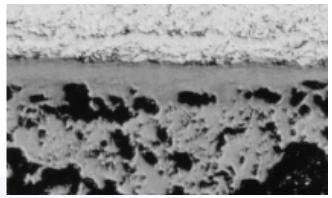


No data from ANL Oxidation Apparatus

Samples reached 5% ECR before reaching 1200°C

RIL-0801 recommended PQD transition ECR not supported by data above 600 ppm

Justification for Two-Sided Oxidation

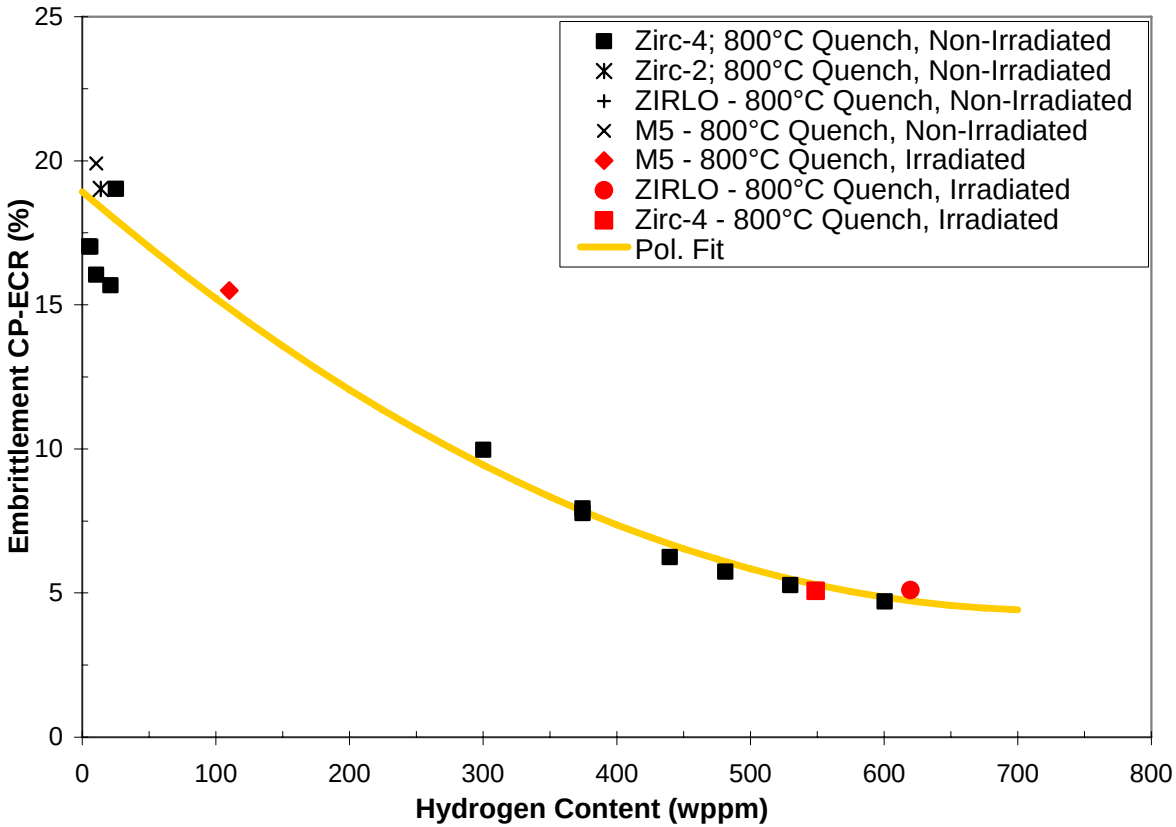


Insufficient data to support the use of 2-sided oxidation away from ballooned region

- RIL-0801 referenced Halden test IFA-650.5 as a justification for double-sided oxidation requirement throughout rod
  - Test results showed the presence of similar inner and outer surface oxygen stabilized alpha phase thicknesses away from balloon
  - Issues
    - Oxygen stabilized alpha phase thickness is only around 21 μm on both sides
    - Pre-LOCA operational oxide thickness of around 5 μm contains sufficient oxygen to generate ~20 μm of oxygen stabilized alpha phase
    - Halden IFA-650.5 test data therefore is not sufficient evidence of unlimited oxygen source at cladding inner surface
- No evidence of unlimited inner surface oxygen source in high burnup Limerick integral test

Pre-Hydrided Material PQD Behavior

- Zircaloy-4, Zircaloy-2, ZIRLO and M5 PQD ductile-to-brittle transition ECR



- Samples of different alloys from multiple vendors fit on the same trend line

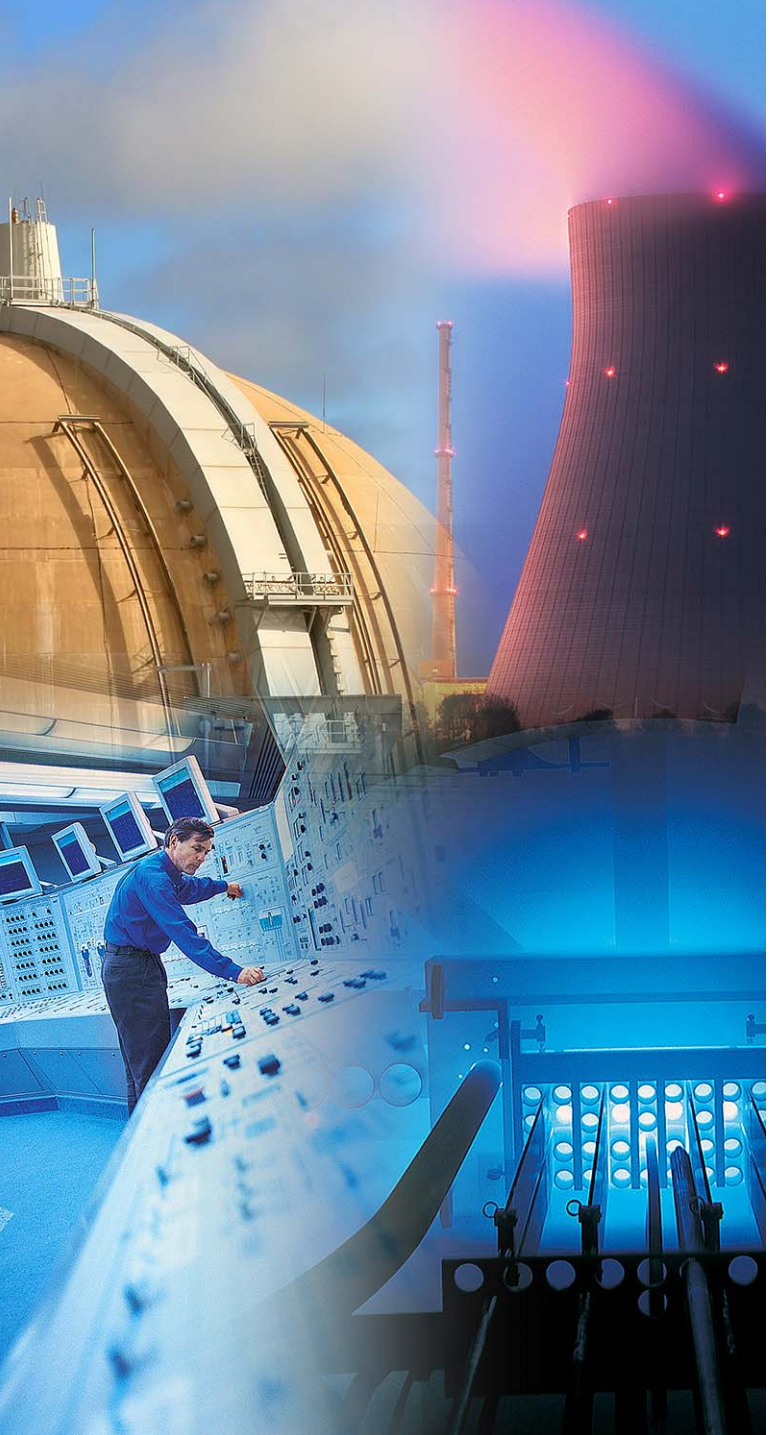
Pre-hydriding appears to be a good surrogate for irradiation

Summary of Technical Concerns on RIL-0801

- LOCA experiments conducted at ANL have verified previous test results and provided new insights into the embrittlement phenomenon but many important questions are still unanswered and will require additional data to resolve
  - Two-sided oxidation, inner surface oxygen uptake and supply
    - Integral LOCA and other tests to resolve inner surface oxygen uptake
  - Breakaway oxidation
    - Further testing to determine if impurity effects really exist
  - PQD testing in the 1000-1150°C temperature range
  - Zircaloy-2 PQD in both irradiated and non-irradiated and hydrogen charged conditions

Industry Position on Current Approach and Rule-Making

- Maintaining PQD has been the historical approach to ensure fuel rod integrity, but this approach is not adequate to bound the ballooned area and is unnecessarily conservative
  - Will the industry be asked to license a second requirement for the ballooned area in the future?
  - Cost estimate for compliance is expected in the range of several hundred million dollars
- Other approaches, such as quench survivability used by JAEA, are better suited at demonstrating the entire fuel rod integrity
- If rule-making is to proceed based on PQD it should be performance based and allow the industry flexibility in demonstrating compliance



EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Industry LOCA Oxidation Test Plans

ACRS Materials/Metallurgy/Reactor Fuels Subcommittee Meeting

December 2, 2008

Rockville, MD

Industry Test Plans – LOCA Oxidation & PQD

Motivation for Test

- ANL work focused on testing at 1200°C
  - Limited ANL test data indicates ECR accumulated at lower temperatures are not as detrimental to ductility for Zircaloy-4

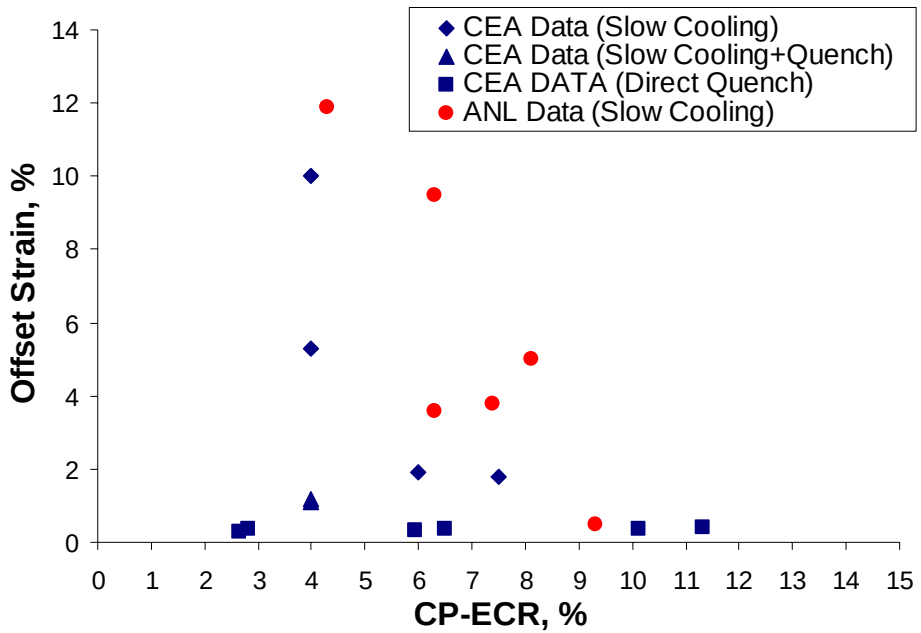
Oxidation Temperature (°C)	Target ECR (%)/ WG (mg/cm^2)	RT Offset Strain
1000	15/9.8	7.5
1100	15/9.8	5.4
1200	15/10.2	0.8

  - Since most fuel rods will not reach 1200°C during LOCA it may be appropriate to collect data in support of alternative LOCA criteria not tied only to 1200°C PCT
- Attempt to demonstrate PQD is not reduced to zero at elevated hydrogen levels at 1200°C

Industry Test Plans – LOCA Oxidation & PQD

Motivation for Test

- Effects of cooling and quenching results from different international laboratories not well understood
  - Significant differences in ductility results from different laboratories
    - Quench temperatures and cooling rates, oxygen diffusion and hydrogen effects



- Samples oxidized at 1200°C with ~600 ppm Hydrogen
- CEA slow cool to 700°C and 800°C quench temperatures → different ductility
- ANL cooling rate to same quench temperatures result in negligible ductility difference

Industry Test Plans – LOCA Oxidation & PQD

LOCA Oxidation Test Goals

- Develop a mechanistic understanding of embrittlement mechanisms
  - Evaluate entire ranges of relevant oxidation temperatures and hydrogen contents
    - 800 to 1200°C, focus on 1100 and 1200°C
    - As-built to 800 ppm hydrogen
  - Full characterization of test samples (in addition to RCT)
    - Oxygen, hydrogen, micro-hardness, prior-beta and oxide/oxygen stabilized alpha phases thickness measurements and localized oxygen stabilized phases
- Generate sufficient test data to propose alternative PQD criteria
- Resolve if ductility is reduced to zero at elevated hydrogen content after oxidation at 1200°C

Industry Test Plans – LOCA Oxidation & PQD

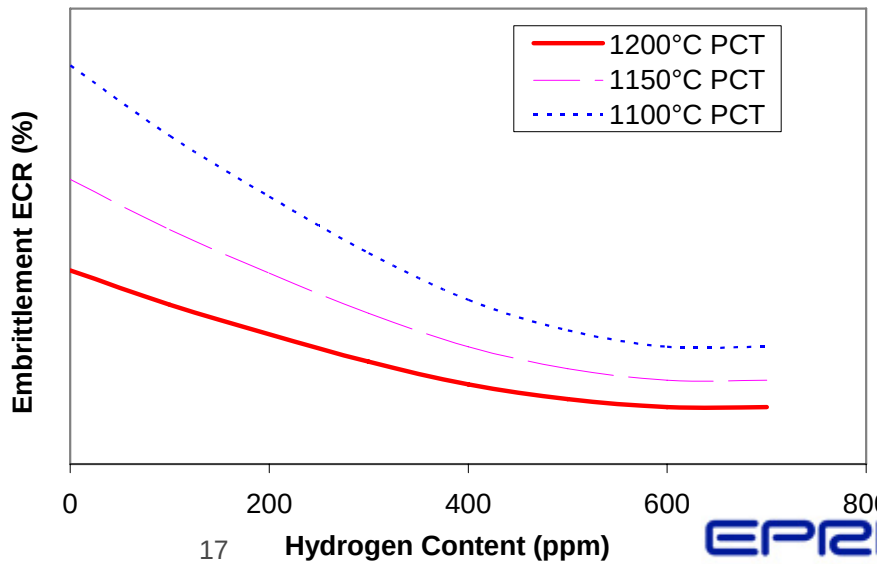
Test Approach

- Test divided into three areas
  - Evaluate oxygen diffusion coefficients
    - Samples quenched from oxidation temperatures
    - Focuses on 1100 and 1200°C
    - 3 ECRs and 5 levels of hydrogen
  - Evaluate cooling effects
    - Micro-structural and oxygen distribution evaluation at different oxidation temperatures, cooling rates and quench temperatures
  - Evaluate metallurgical conditions at critical embrittlement ECR
    - Different combinations of oxidation temperatures, hydrogen content, cooling rate and quench temperatures
- Tests to be completed by end of 2009

Industry Test Plans – LOCA Oxidation & PQD

Industry Goals

- Generate sufficient data to determine the feasibility of developing an embrittlement model
- Two potential pathways
  - Allowable ECR dependent on both hydrogen concentration and peak clad temperature
    - (1) Maintain ductility based on model predictions
    - (2) A family of ECR vs Hydrogen curves with different peak clad temperatures



Industry Test Plans – ID Oxidation

Motivation for Test

- RIL-0801 justification for two-sided oxidation based on Halden IFA-650.5 test
  - Peak test temperature at 1050°C
    - Exposure relatively short and oxygen diffusion distance should be small
  - Oxygen stabilized alpha phase only ~20 μm
    - ~5 μm pre-LOCA in-service oxide has sufficient oxygen content to generate ~20 μm of oxygen stabilized alpha layer
- Verify and extend previous work conducted by Hofmann et al to different test conditions
  - Hofmann concluded contact is necessary for pellet/clad reaction (contact pressure 10-100 bars used)
  - A thin oxide can prevent direct pellet/clad interaction below 1100°C
  - Industry intents to conduct further testing at around 1100°C

Industry Test Plans – ID Oxidation

Industry test goals

- Determine if oxygen contained in a thin oxide can generate an oxygen stabilized alpha layer similar to the Halden IFA-650.5 test
  - Evaluate impact from such an oxide
- Determine if pellet/clad reaction takes place at temperatures around 1100°C and if so to what extend can it be an oxygen source
  - With or without pre-oxidation
  - With or without contact pressure

Industry Test Plans – Summary

- Work conducted at ANL has advanced our understanding of high temperature oxidation but significant relevant gaps still remain
- Industry is conducting a series of complementary LOCA oxidation tests to fill some of the gaps (to be completed by end of 2009)
  - Effects of oxidation temperature on PQD over entire range of relevant hydrogen concentrations
    - Support alternative criteria not tied to 1200°C
  - Generate PQD data at 1200°C and elevated hydrogen content to support or dispute RIL-0801 recommendation
  - Develop a mechanistic understanding of the embrittlement phenomenon
  - Develop a better understanding of ID oxidation
    - In-service oxide effects
    - Pellet/clad reaction at around 1100°C
  - Work with ANL to investigate breakaway oxidation causes

Together…Shaping the Future of Electricity

Alternative to Periodic Testing

Qualification and control of breakaway oxidation behavior

ACRS Materials/Metallurgy/Reactor Fuels
Subcommittee Meeting
December 2, 2008
Rockville, MD

Global Nuclear Fuel
A Joint Venture of GE, Toshiba, & Hitachi

Periodic Testing and Alternative

- Key points from September presentation
  - Rationale for periodic testing:
    - PQD variability concern appears to arise from apparent manufacturing variability
    - Breakaway oxidation concern appears to arise from surface condition effect and performance of E110
  - Weak technical justification for periodic testing
  - NUREG/CR-6967 data and wording in NUREG/IA-0211 suggest no effect in E110 due to trace element in the bulk; additional ANL data to be published
  - Recommended identify and control parameters that affect PQD or HT oxidation
- Key take-away
  - Alternate approach to periodic testing could be considered
  - Industry to clarify alternate approach
  - Focus on breakaway oxidation

Periodic Testing and Alternative

- Industry position
  - Periodic testing not justified by published ANL data
  - Periodic testing for breakaway oxidation is practically not workable for vendors
  - Alternate approach is preferred in which vendor QA program is leveraged to qualify and control key process steps
  - Results from investigation of bulk or near-surface trace element effect will be factored into plans for qualification and control
  - If rulemaking proceeds, 10 CFR 50.46 would be enabling and NUREG would address details such as breakaway oxidation

Periodic testing vs. process control

- Published ANL data insufficient to justify periodic testing of as-fabricated cladding
  - PQD (hydrogen effect dominates when present)
  - Trace element concern on breakaway oxidation confounded by bulk vs. near-surface effects from cladding process of E110
  - No breakaway oxidation issue with current Western claddings made from sponge Zr
- Industry understands NRC concern – E110-like breakaway oxidation behavior is undesirable for current and future cladding
- Prevention of E110-like breakaway oxidation behavior is not addressed by periodic testing
- Better understanding of cause of E110 behavior would benefit control of cladding manufacturing process and avoid E110-like behavior
- Need to establish if breakaway oxidation is a concern for claddings from sponge Zr. If so, a better approach is to control relevant process step
  - Need to identify and control relevant process steps
  - Only some but not all key parameters are currently identified

Alternative based on qualify and control

- Alternate approach based on leveraging vendor QA programs
  - Identify key parameters and process steps affecting breakaway oxidation
  - Qualification of control limits for key process step addresses breakaway oxidation
  - Process step would be controlled to be within qualified range
  - Likely involve monitoring of key parameters (e.g. surface finish)
  - Requalify if process change goes outside of qualified range
  - Address NRC concern and optimizes vendor process control
- Currently identified key parameters or issues
  1. Impurities on surface, e.g. Fluorine from pickling
  2. Surface roughness
  3. Trace element effect in the bulk (from ingot melting or earlier)
  4. Trace element effect in near-surface region (from processing)

  - 1 and 2 are already controlled under current QA programs
  - Control of 3 and 4 will require additional information
- Additional investigation of bulk trace element or near-surface effect through EPRI/ANL collaborative effort

Periodic Testing and Alternative

Summary

Industry Position

- Periodic testing not justified by published ANL data
- Periodic testing for breakaway oxidation is practically not workable for vendors
- Alternate approach is preferred in which vendor QA program is leveraged to qualify and control key process steps
- Results from investigation of bulk or near-surface trace element effect will be factored into plans for qualification and control
- If rulemaking proceeds, 10 CFR 50.46 would be enabling and NUREG would address details such as breakaway oxidation

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Response to Industry Comments on 50.46(b) Rulemaking in the form of FAQs

ACRS Subcommittee
December 2, 2008

(Part 1)

Ralph Meyer
Division of Systems Analysis
Office of Nuclear Regulatory Research

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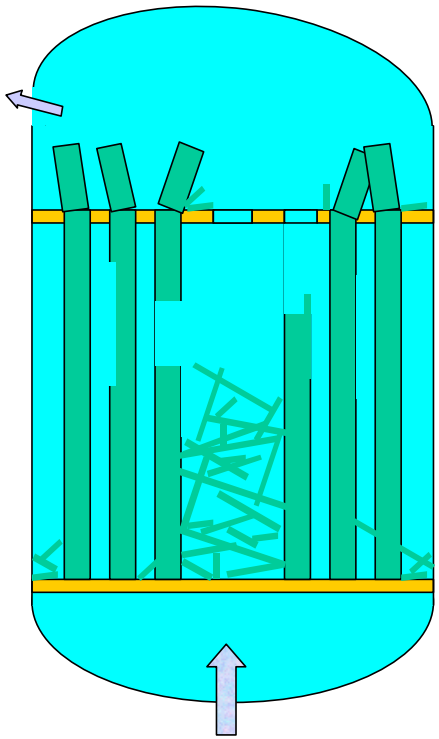
Relevance of Oxidation Limit

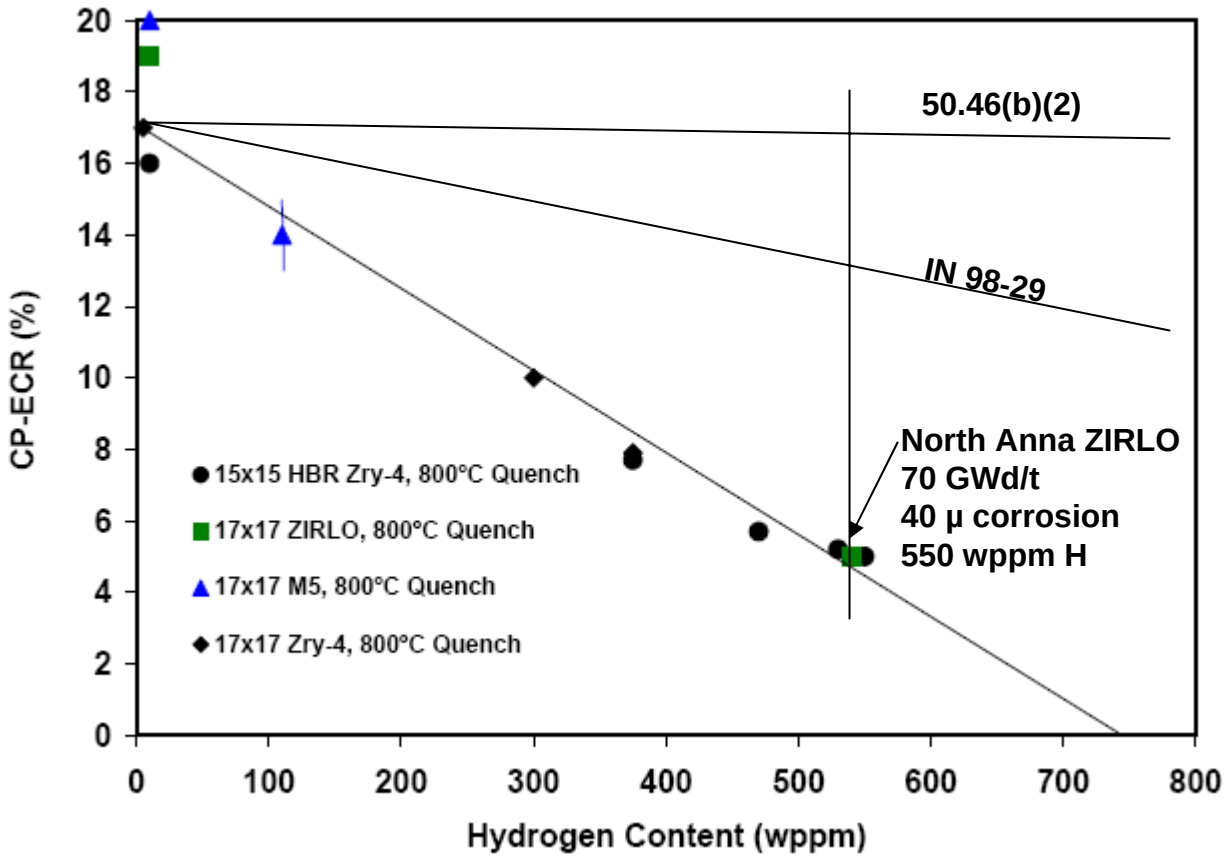


Collapse of fuel with severely oxidized cladding in low-flow incident in cleaning tank at Paks-2 plant in Hungary

The oxidation limit in 50.46(b) is used to preclude this behavior.

Hozer at OECD meeting Studsvik 11/04

Measured Embrittlement Threshold and Licensing Limits: an Example



The difference is significant.

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Is a Better Understanding of Balloon Embrittlement needed before Rulemaking?

- Planned changes to 50.46(b) address regulatory non-conservatisms (hydrogen-related oxidation limit, breakaway oxidation limit, two-sided oxygen pickup).
- The staff is working to further analyze the behavior of the balloon and determine if additional changes are necessary
- The planned changes for this rulemaking would not allow the licensees to change their operation such that the balloon region would become any more embrittled during a LOCA than the current method of analysis would indicate when combined with the planned changes to address non-conservatisms.
- At present, the existing 50.46(b) method of analysis for balloons will not be revised along with this rulemaking because there is not yet consensus on the need or the most effective means of treatment.

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Is 1200ºC (~2200ºF) too high for LOCA Embrittlement Tests?

- "The high-burnup testing … was done at bounding conditions that cannot be achieved in commercial reactors." Westinghouse
- If testing had been done at 1100ºC or 1000ºC, the embrittlement threshold would have been higher (perhaps +2 to 4% CP-ECR).

Power Levels for 1st, 2nd, and 3rd Cycle Fuel

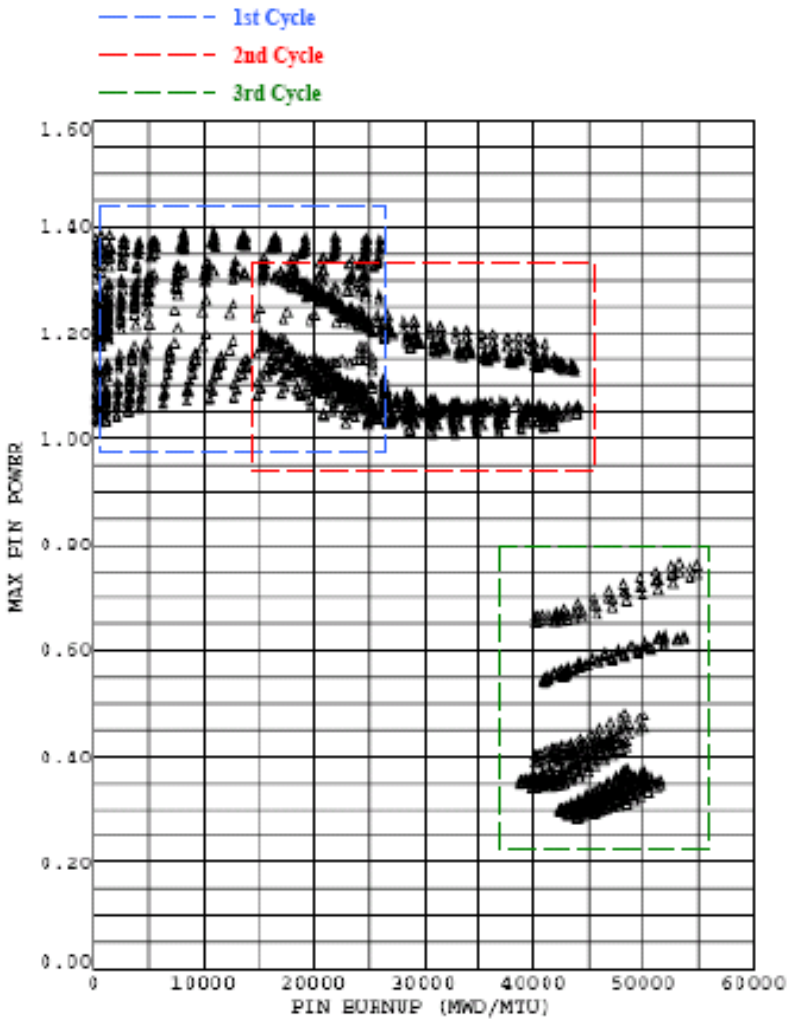

Figure I-1. Achievable Pin Power vs. Burnup for Typical Westinghouse 3-loop PWR

Typical Westinghouse core

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Comments

Industry concern is about fuel that has high burnup **and** low power.

- The corrosion level (and hence hydrogen concentration) for the samples tested are reasonable upper bounds for some fuel in 2nd cycle (i.e., at high power levels)
- The temperature in the test that produced the 5% CP-ECR value did not reach 1200ºC (1160ºC max) so that value already reflects lower temperatures.
- Some core designs with high burnable poison concentrations reach their peak power in 2nd cycle fuel.
- 3rd cycle fuel is sometimes located in higher power interior core locations.

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Conclusion

Test results for 1200ºC are appropriate for 1st and 2nd cycle fuel and any high-burnup fuel that is placed in high-power locations.

- If very low power fuel becomes limiting, a generic analysis might be able to show that this fuel would not rupture and therefore could be removed from consideration for oxidation.
- Under the rule language being considered, a licensee or supplier would be able to do additional testing to justify a higher limit for fuel that remains at lower LOCA temperatures.
- No unnecessary penalty needs to be applied.

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Is Double-Sided Oxygen Pickup needed in LOCA Analysis for Non-ballooned Axial Nodes?

- Bonding appears to be necessary to enable ID oxygen pickup
- Bonding only occurs in high-burnup fuel
- Onset of ID oxygen penetration with burnup is not known

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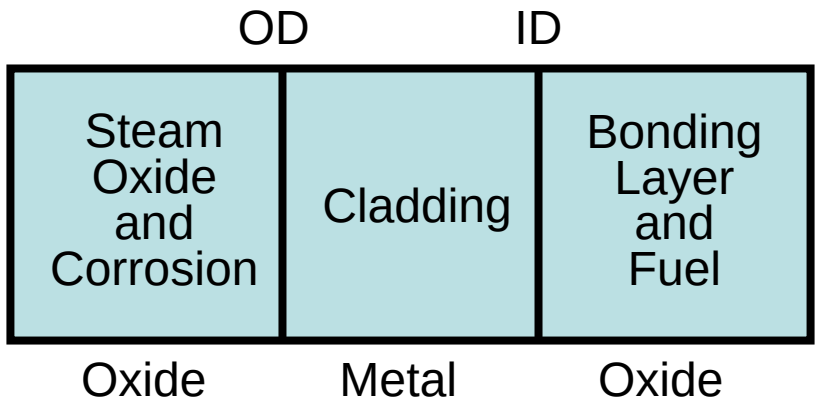
Sandwich of Oxides and Metal in High-Burnup Fuel



Double-Sided Oxygen Pickup is already calculated in Every Rod

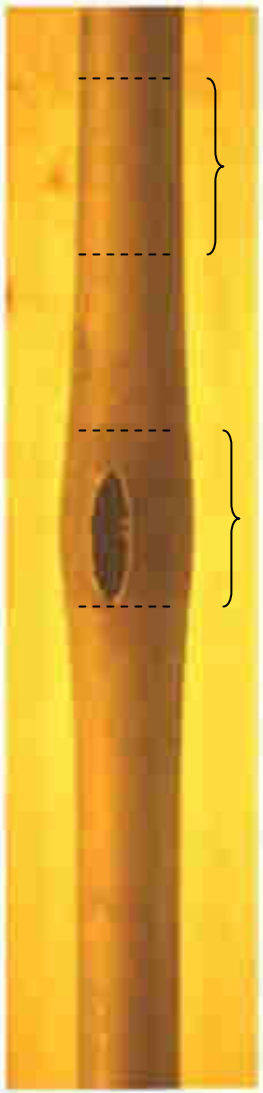


Fig. 226 ICL#2 modified

- Rupture occurs at relatively low temperature and significant oxidation does not take place until later.
- Therefore, every fuel rod that approaches its oxidation limit will already have a rupture for which two-sided oxygen pickup must be assumed.
- Although PCT node may have a little higher temperature than the rupture node, oxidation is enhanced in the rupture node by wall thinning in the balloon.
- In two cases we have examined, the CP-ECR was higher in the rupture node than in the PCT node with two-sided oxidation.

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Conclusion

- It is important to include two-sided oxygen pickup in the rule because the effect is real and some non-rupture nodes in high-burnup fuel might be limiting.
- Under the rule being considered, a licensee or supplier would be able to determine when (i.e., at what burnup) an oxygen source is present on the inside surfaces to avoid any unnecessary penalty.

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Could Strength be used Instead of Ductility as a Performance Indicator during a LOCA?

"The stress calculations, the measurements of strength and flexibility of oxidized rods, and the thermal shock tests all are reassuring, but their use for licensing purposes would involve an assumption of knowledge of the detailed process taking place in the core during a LOCA that we do not believe is justified."

p. 1098 Commission opinion 1973

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Comment

- The NRC research program was designed to modify the existing ductility-based criteria
- Only a few strength measurements are being made and these do not cover all loading types (e.g., lateral impact)
- No research has been done to investigate LOCA loads, which would be needed to establish strength requirements
- EPRI inquired about this in 2003.
  - NRC's reply was that such a change would require a revision of the scope and funding of our research. No revision was made.
  - The reply also stated that NRC could be petitioned under 10 CFR 2.802. No petition was received.

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Does Axial Fuel Relocation need to be addressed in the Revised Rule?

- Axial relocation of fuel particles into the balloon will increase the heat source in the balloon
- An increase in heat source in the balloon will increase the cladding temperature in the balloon
- An increase in cladding temperature will increase the calculated oxidation (CP-ECR) in the balloon
- But none of this will alter the embrittlement threshold, which is measured as a function of CP-ECR and pre-test hydrogen

Axial fuel relocation should be accounted for in LOCA evaluation models, but it will not affect the revised rule which addresses the measured embrittlement threshold.

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Are more data needed on Cooling-rate Effects before Rulemaking begins?

- The proposed limit on calculated oxidation is sufficiently conservative for all cases.
- The proposed rule would allow licensees to modify the oxidation limit based on test data.
- ANL data for slow-cooled cases are available for use by licensees.
- It is not necessary for NRC to provide additional data or alternate limit curves for the convenience of the industry.

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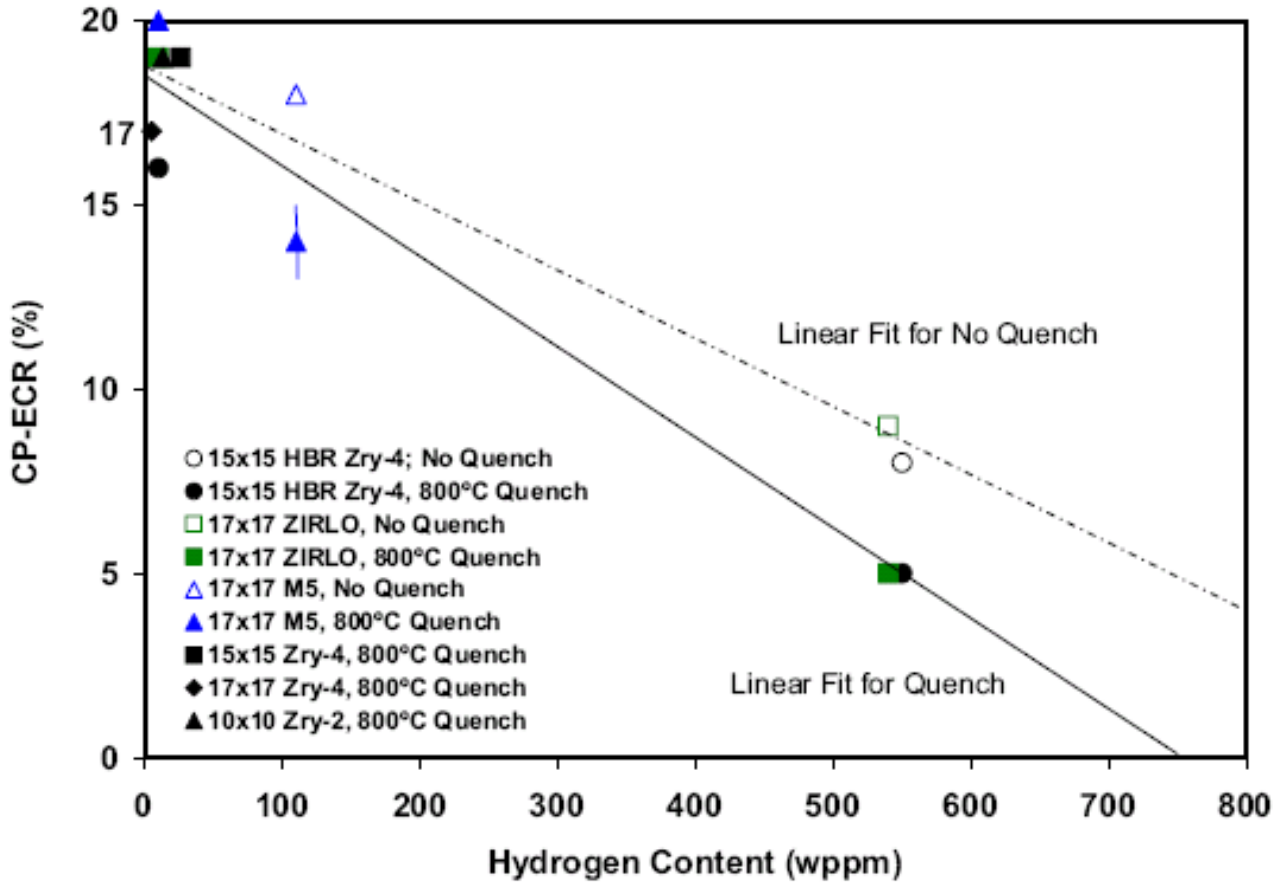
Embrittlement Threshold as a function of Post-test Hydrogen



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Are more data needed on Ballooning and Flow Blockage before Rulemaking begins?

- Ballooning strains and the amount of related flow blockage are used in LOCA evaluation models.
- Some of the models being used may be out of date.
- Additional research will be performed in these areas to assist NRC in its review of LOCA safety analyses.
- But these models are not prescribed in 10 CFR 50.46(b) and will thus have no impact on this rulemaking.

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LOCA Research Information Letter RIL-0801 (May 30, 2008)

ACRS Subcommittee
December 2, 2008

Ralph Meyer
Division of Systems Analysis
Office of Nuclear Regulatory Research

Mandate for This Work

On March 31, 2003, the Commission approved the staff's recommendation to modify the criteria in 10 CFR 50.46 to provide for a more performance-based approach that would enable licensees to use cladding materials other than Zircaloy and ZIRLO without an exemption.

SRM on SECY-02-0057

Research Support for RIL-0801

- Argonne National Laboratory – funded by NRC with industry cooperation, NUREG/CR-6967
- Kurchatov Institute – funded jointly by NRC and IRSN (France) with additional funding from TVEL (Russia), NUREG/IA-0211
- Halden Reactor Project – bilateral project funded by NRC, IFE/KR/E-2008-004

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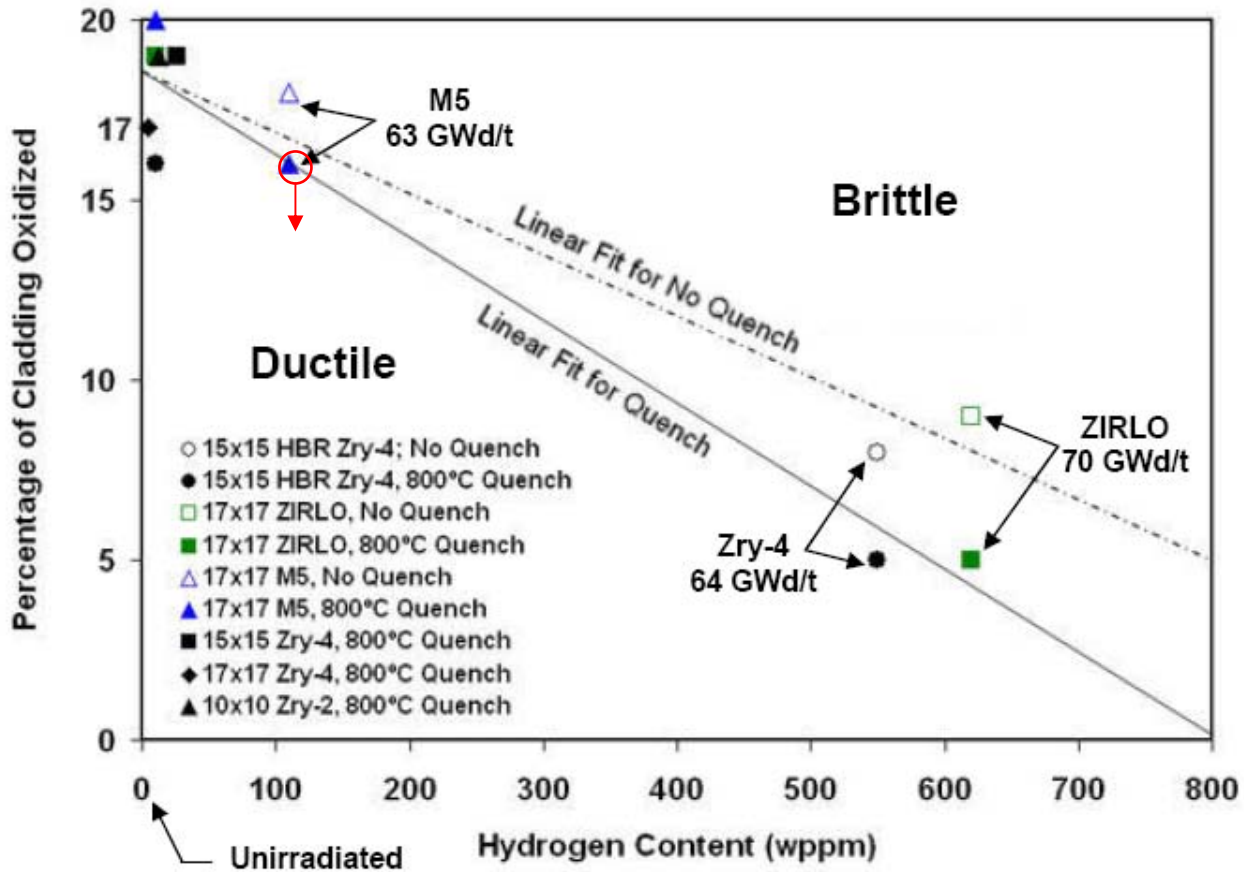
Summary of Embrittlement Data



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Applicability of Embrittlement Data (1 of 2)

- Cladding temperatures would have to remain no higher than 1204ºC (2200ºF) because embrittlement occurs at lower oxidation values for higher temperatures.
- Calculations of cladding oxidation use the Cathcart-Pawel equation for weight gain of fresh Zircaloy because all of the data in Figure 1 (of the RIL) were correlated with that parameter.
- Manufacturers or licensees would have to provide hydrogen-versus-burnup correlations because hydrogen absorption might vary for different materials and operating conditions.
- Some periodic testing would be needed to ensure that manufacturing processes had not changed in a way that would degrade the performance of the cladding material under LOCA conditions. Such testing could be done on as-fabricated material and would be relatively easy to conduct. Appropriate testing procedures could be defined.

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Applicability of Embrittlement Data (2 of 2)

- The Cathcart-Pawel equation for two-sided oxidation is used for high-burnup fuel to account for oxygen diffusion from the inside diameter of the cladding, although there would be no heat associated with a metal-water reaction on the inside diameter.
- Breakaway oxidation would have to be avoided by using an additional time limit based on tests for each cladding material. These tests could be done on as-fabricated material and would be relatively easy to perform. Appropriate testing procedures could be defined.
- The embrittlement thresholds described above would apply only to fuel rods made with zirconium-alloy cladding and containing oxide fuel pellets.

Adequacy of Embrittlement Data

The present set of data is substantially larger and more precise than the data set on which the original rule was based, and the staff of the Office of Nuclear Regulatory Research recommends that the data summarized in this RIL be considered as the basis for rulemaking to revise 10 CFR 50.46(b).

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Industry Cooperation

- Formal industry cooperation in ANL project since 1998
- EPRI has provided the high-burnup fuel rods used in this project
- Areva, GNF, and Westinghouse have provided unirradiated cladding for testing in this project
- Detailed (2-day) program review meetings have been held each year with industry representatives
- Non-industry representatives from international organizations have also participated in the program review meetings

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Major Industry Comments

- Basis for criteria (strength or ductility) questioned in 9/9/03 EPRI letter and 10/24/03 public meeting. Resolved in 2/25/04 NRC letter to EPRI.
- "F-factor" and corrosion approach criticized by industry at 2/2/07 ACRS meeting. Approach dropped and replaced with hydrogen concentration.
- Validity of ID oxygen pickup away from balloon questioned by industry at 2/2/07 ACRS meeting. NRC funded special Halden investigation to confirm this phenomenon.
- Absence of testing with irradiated M5 and ZIRLO cladding criticized by industry at 2/2/07 ACRS meeting. NRC delayed project to complete those tests.
- Westinghouse letters 9/24/07 and 6/12/08 describe discrepancies in breakaway oxidation testing. Issue being actively addressed by ANL and Westinghouse and will not impact rulemaking.
- Other comments have been made in response to the 7/31/08 Federal Register notice, and we are prepared to discuss them today.

Other LOCA Phenomena

Several other fuel-related LOCA phenomena are under investigation or consideration in the NRC's research programs, but they are not needed to revise this part of the rule and they are not the subject of this RIL.

- Axial Fuel Relocation
- Loss of Fuel Particles through a Rupture Opening
- Ballooning and Flow Blockage