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NUCLEAR REGULATORY COMMISSION

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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

(ACRS)

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SUBCOMMITTEE ON MATERIALS, METALLURGY AND

REACTOR FUELS

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TUESDAY

JANUARY 14, 2014

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ROCKVILLE, MARYLAND

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The Subcommittee met at the Nuclear Regulatory Commission, Two White Flint North, Room T2B1, 11545 Rockville Pike, at 8:30 a.m., Ronald G. Ballinger, Chairman, presiding.

COMMITTEE MEMBERS:

RONALD G. BALLINGER, Chairman

J. SAM ARMIJO

JOY REMPE

PETER C. RICCARDELLA

STEPHEN P. SCHULTZ

GORDON R. SKILLMAN

NRC STAFF PRESENT:

CHRISTOPHER L. BROWN, Designated Federal Official

JOHN BURKE

MICHAEL CASE

GANESH CHERUVENKI

AL CSONTOS

DARRELL DUNN

BOB EINZIGER

ISTVAN FRANKL

MIRELA GAVRILAS

MAKUTESWARA SRINIVASAN

APPAJOSULA RAO

DAVID RUDLAND

GARY STEVENS

BRIAN THOMAS

ROB TREGONING

A G E N D A

P R O C E E D I N G S

8:30 a.m.

Opening Remarks and Objectives

CHAIR BALLINGER: Okay. The meeting will now come to order. Before I read the obligatory stuff, I feel comforted by the ghost of Bill Shack next to me. This is my first chair of this kind of a meeting. This is a meeting of the Materials, Metallurgy and Reactor Fuel Subcommittee.

I'm Ron Ballinger, the chairman of the Subcommittee. ACRS members in attendance are Steve Schultz, Dick Skillman, Sam Armijo, Joy Rempe and Pete Riccardella. The ACRS staff, Chris Brown is the -- of the ACRS staff is the Designated Federal Official of this meeting.

Today's meeting is open to the public. The purpose of this meeting is to receive a briefing from Research on Materials and Metallurgy research topics. In particular, the Corrosion and Metallurgy Branch will be presenting a brief overview of the following research topics:

Aging of neutron absorbers in spent fuel pools, stress SCC of dry storage canisters, vacuum drying of spent fuel canisters, functional monitoring of dry cask storage systems, containment liner corrosion, leak

path assessment of the North Ana CRDM Nozzle 63, the radiation assisted degradation, primary water stress corrosion cracking, a subsequent license renewal, expanded materials degradation assessment, steam generator research, and will provide a highlight on stress corrosion cracking susceptibility, austenitic stainless steels for spent fuel dry storage canisters, something that's near and dear to my heart.

The Component Integrity Branch will be presenting a brief overview of the following research topics: Reactor pressure vessel integrity, non-destructive examination, high density polyethylene and environmentally-assisted fatigue, and will provide a highlight on extremely low probability of rupture.

The Subcommittee will gather information, analyze relevant and facts and formulate proposed position and action as appropriate for deliberation by the full Committee. The rules for participation in today's meeting have been announced as part of the notice of this meeting, previously published in the *Federal Register* on December 27th, 2013.

A transcript of the meeting is being kept and will be made available, as stated in the *Federal Register* notice. It is requested that speakers first identify themselves and speak with sufficient clarity

and volume so they can be readily heard. Also, this is a cell phone free zone, so please silence your cell phones.

We have not received any requests from members of the public to make their own statements or written comments. We will now proceed with the meeting called by Michael Case, who's here. I've already asked to give a brief introduction to introduce the speakers.

I might add in advance, I'd like to Thank you folks for tolerating us and coming in and giving us the presentations that we need.

Staff Opening Remarks

MR. CASE: Perfect, not a problem. My name is Mike Case. I'm the Director of the Division of Engineering in the Office of Research, and thanks for the opportunity for bringing us over. We like talking about our products and our activities. Happy New Year. I'm sure it's great to be back.

But before we launch into talking about the work itself, I just wanted to give you some context basically of how we get our work, how we pay for our work and who we work with. As far as how we get our work, when we look at the Office of Research as a whole, about three-quarters of our work is driven by what's called a User Need.

In the materials area, we're probably in excess of that 75 percent. So, you know, if I had to guess, I would say at least 90 percent of our work is generated by User Needs.

We get these User Needs from the regulatory offices. So what that means is typically NRR, NRO or NMSS. So that's how we get our work identified, and our User Need is just they'll -- the user office will write down exactly what the problem is, what the issue is, what the knowledge gap may be, and they write it down and they send it over to us, and we respond to that.

So they describe what the problem is and then describe how we're going to address the problems that they've identified. So it's actually a pretty good process, you know. It helps us, you know, the advantages are -- what we find is that our work is more likely to be used and used.

So they sort of identify the problem from a regulatory perspective, so they have an inkling of how it's going to be used. So it's really helpful for us that a lot of our products are very well used. So they're either used out in the inspection sense, they're either used in connection with 50.55(a) rulemakings, or a lot of times they need up in regulatory guidance.

So that's one of the advantages of the

process. It also helps in budget situations, because they're actually the owners of these business lines. So they actually control our resources, so it's a lot easier for them to understand the work that they've sent us, rather than us conjure up work and then try and sell it back across to them.

The disadvantages of this type of system is that it's a little less flexible from a research perspective. So I don't have seven degrees of freedom to go out and investigate the things that I think are interesting. We're much more tied to the user office.

Conversely, we have a lot of flexibility within a project itself. So you know, especially when we get into situations with the ACRS, we enjoy your comments and observations on the projects, because we have enough wherewithal that we want to fix those, a little less flexibility when you want to propose different projects than what we're working on.

Now as far as how we pay for this work, this is kind of interesting. I wanted to give you at least a sense of the budget in the materials area. The situation, I would say, is generally not good, and so you look back.

If you look back in fiscal year '11, when you look in the Materials area, we were probably close

to a $17 million operation. If you look at the past fiscal year, which was FY '13, we are probably down to about a $10.5 million operation.

Then you look at the underlying budget that supports that, and so the budget is actually lower than that. The budget is more in the $6.5 million range. So you're looking over the course of two to three years an enormous reduction of the resources available to do research in the Materials area.

I'm really proud of both the program offices and my staff, because they've figured out a way to keep a lot of this going. A lot of this was driven by sequestration. Some of it was driven by other agency needs like Fukushima. Even some of the money, you know, we had to keep that crazy Three White Flint North on schedule one year, and so that affected our funds. But there's been a lot of effects on the funds.

But the way that they survived sequestration was they slowed a lot of things down. You know, we didn't really throw that much work over the side. We maybe three one or two projects over the side. We descoped some of the projects. So you know, we tried to focus in in a particular area, and do a few things and not everything.

Then the big one that a lot of people miss

is we didn't really start much new work, in fact probably not too much at all. That particularly worries me, because you know, as I said earlier, we're sort of tied a little bit to the program offices identifying issues.

So what I worry about over a period of time, what may happen is that they're going to stop identifying issues. That, I think, is a problem, because I think there's a lot of good issues that need to be fleshed out in the Materials area, because they need answers so that they can do their job. So I sort of worry about that one a little bit.

Now as far as who we work with, it's -- you pretty well know this. Materials is, I think, one of the best-coordinated research areas in the agency, in that, you know, we work very well with the program offices. We work so well with the program offices that we even supply support for regions.

So when we get into outage session, sometimes the regions need technical support to do operational issues. So a lot of times we work with NRR in this case, and we use our staff to support the regions. That's actually fantastic coordination for this agency.

MEMBER SKILLMAN: Michael, Dick Skillman. Could you give an example of the type of incident you just mentioned, where you're supporting the regions?

MR. CASE: North Anna. They had some problems with their NDE, and a lot of times a lot of the NDE problems, if it gets into, you know, what they can detect, you know, we have experts out in PNNL. So a lot of times it's NDE work that immediately gets us involved with the regions.

Fracture mechanics work, in that we have great people that can do fracture mechanics work. So when the licensee sends in studies, a lot of times NRR will use us as a source of second opinions, so that they can advise the regions.

MEMBER SKILLMAN: Thank you.

MR. CASE: So you know, we have the, you know, the program office staff is actually here. That's how well we're coordinated with them, because they're trying to support us, because they know that we're really talking about their needs. So I really appreciate all the program office folks that are sitting out the audience, because they know that some of this work is important.

We also work really with others. What you'll find, I don't know whether it's highlighted in the presentations or not. A lot of our efforts are done in collaboration with EPRI, and so, you know, we respect each other's roles. So a lot of times we'll do

confirmatory work, but a lot of times we try and use these same data, which is a good thing.

Then some projects like Zorita are enormously expensive. So the only ways that we can get at some of these enormously expensive things is to partner with other areas. We do well internationally as well.

Once again, I'm not sure whether it's highlighted on the slides, but we had a lot of projects that have connections to the international community, so that we get good insights on those projects as well.

So you're probably wondering how you can help. You're always wondering that, and y'all do a great job for us. You know, it is particularly beneficial for us to get comments on the projects themselves, because we want them to be efficient and effective.

So if we're launching anything particularly nowadays, we damn sure want to make sure that it's going to give a good, solid answer. So your insights are always appreciated in that area. I'm interested in whether there's gaps in the program, and we have to be a little bit careful with that one. If you make recommendations on things that aren't there, it's really a recommendation to the program offices, because like we talked about earlier, I get my work for program offices.

So if you say here's an area where we need to work collectively. So it's almost oriented -- those comments are directed at the program offices. What's the last thing -- oh, opportunity. What I don't want to do, especially with the fiscal environment, is miss an opportunity.

So once again, when you see projects that are good, when you all write that down and send that to us, that is enormously helpful, because then I won't miss an opportunity, and Zorita is another good example of that, in that, you know, in order to get higher fluence levels on projects like Zorita, they're very expensive, and it's important that people see value in those.

I don't want to necessarily miss those type of opportunities in the Materials area, because they may never reappear. So that's all that I wanted to do, just get you some context, and we've got a great staff to walk you through some of the projects, and I'm looking forward to it.

MEMBER REMPE: Mike, what I didn't hear explicitly from you when you get these User Needs, do you do everyone? Do you do 90 percent of them? Is there some sort of evaluation reduction or what happens on that?

MR. CASE: NRR prioritizes -- all the

program offices prioritize them when they come over. They're typically pretty long projects. They're typically in the five years. They have a lot of multiple things in them. We've been successful in actually engaging all of them.

Like I said, last year was probably the first year that we've been saying no to people, and that makes me uncomfortable, because there's work that the program offices wanted us to do, and we would say hey, we don't got any money. That's the worry, is that I'm going to train my customers not to care.

So they really should care. There are issues that they need investigation on. But we were successful with engaging them all, and we're not, you know, in today's budget environment we're not.

CHAIR BALLINGER: From my perspective, it's sort of a multi-edged sword. In a constrained budget environment, you want to be sure you're doing exactly what needs to be done and getting a lot of value for that.

That sometimes means that you have to take a hard look at projects that seem to be never-ending, or that maybe need to have sunset kind of thing, so that you can free up resources to be able to respond to a need that comes up quickly.

So it's kind of a balance between what you have, what's been going on and the value that those projects have added to the NRC's way of doing business, as opposed to, you know, just to make sure you're doing the right set of project.

That's why when we started -- asked for this meeting, I was trying to stress that we need to know which projects are the real important ones, have they met their goals, and have those goals resulted in value added to the agency?

MR. CASE: No, that's absolutely true. Really, the way I can, you know, typically they'll keep the budgets flat. So you're right. The way that you can do new work is by completing old work. So once again, I worry when we start stretching things. Are they stretching too long, so that what they're really doing is that they're impeding new work from coming onto the plate?

CHAIR BALLINGER: Thank you.

MEMBER ARMIJO: Mike, I had a question. A few years ago the staff had a -- I forget the title of the activity, but I Think it was something like Anticipated Materials Degradation Program. It was -- the whole idea is for the NRC not to be caught flat-footed by new materials degradation phenomena that

we might have been able to predict.

There was quite a bit of work done, a couple of very good reports on establishing the conditions, either materials, environment, mechanical loading, that might lead to surprises.

But that program has seemed to die on the vine, you know, and so a lot of the materials problems we've addressed in the industry and of course in the NRC have been brought to us by experience, bad experience.

You know, things failed that weren't supposed to fail, or we never anticipated they would fail. So this program was set up, and I was pretty impressed with that. But you know, it was saying we're going to look for problems before they happen, and we're going to try and anticipate them. Then it's just nothing's happened that I can tell.

MR. CASE: Well, that started as what we called the Proactive Material Database.

MEMBER ARMIJO: Yeah, yeah, that's it.

MR. CASE: We've continued that. We've expanded that to 60 to 80 years. That's actually in the CME's portfolio. It is almost done, you know. We did the analysis for 60 to 80 years. It's called the Expanded Materials Degradation Assessment. It should be issued this quarter.

So we have a list of, like you say, the material -- not only for metals, but for concrete and cables. That's sort of the expansion that went on. So we have that insight. We've done that in coordination with DOE and --

MEMBER ARMIJO: EPRI.

MR. CASE: And EPRI.

MEMBER ARMIJO: Yeah, they did --

MR. CASE: So guess what? They have the same list. So we may be wrong, but we're all wrong together. So --

MEMBER ARMIJO: But that was my -- you know, the thinking process and the weight of structure, the approach to identify the most likely areas where we would have problems, that was all fine. But no one ever went out, as far as I could tell, and confirmed, you know, let's say this particular material in this particular environment has all the ingredients for premature failure.

Let's to out and inspect it. Let's work out with some utility or somebody, so we can go out and take a look at something that's been operating for a long time, and see in fact if we can predict a failure, even though they haven't yet happened. It seemed to me that it's just documentation, and it doesn't preempt failures.

MR. CASE: Well, here's my assessment. I don't think anybody right now, neither the industry nor us, DOE a little bit in their light water sustainability program is -- has enough resources to be out in the areas where we might see something.

There's plenty of issues where we do see issues, and those are the ones that are pretty much on the plate. I don't think we're that far out into the future that we're able to do that.

But in some areas, you know, especially for long-term operation, you know, we're trying to stretch where our knowledge is. So that's sort of where we're focusing those sort of forward-looking things.

CHAIR BALLINGER: Okay. In keeping with our time-honored tradition, we're on pace for being an hour behind.

MR. CASE: That's right.

MR. TREGONING: Just to clarify. I just wanted to comment real quickly. Rob Tregoning from NRC Research, on what Dr. Armijo said. Actually, there's been quite a bit of follow-up on that work. Industry developed, in fact, all of their materials research is structured around what's called issue management tables, which derived from this essentially a PMDA exercise.

We did our own, industry did their own. As

Mike said, the findings were almost identical, and then all of their research boils down to these issue management tables, which in one way, in one form or another, all tie back to those gaps that were originally identified, and those have been prioritized, and that's how they actually -- that's largely how their materials research program has been structured.

So I just wanted a quick clarification of that before we went further.

MEMBER ARMIJO: Okay.

CHAIR BALLINGER: Okay. Next up.

Overeview of RES Projects

MR. RUDLAND: Hi. My name's Dave Rudland, and I am the Chief of the Component Integrity Branch in the Division of Engineering, Office of Research. Thanks very much for giving me the opportunity make this presentation, this overview presentation of the current research that's going on in the Component Integrity Branch.

Before I get started, a lot of my staff is out in the audience, and so you'll see their names throughout their presentation, and I may call on them to help me through some of the tough questions you may have, as we move forward.

Again, the purpose of this beginning part

of this presentation is to provide an overview of what we're doing in the research topic areas. I'll touch a lot on what Mike talked about, in terms of how we get our request and how we develop our research plans within the Division of Engineering, and how the work that we have and the work that we're developing supports the program office needs.

We've been doing that by talking about each of the main topic areas, the main focuses of component integrity. That's not just project-based, but is topic-based. I mean we have several projects that are supporting those ongoing topics.

We'll talk about that. We'll talk about how we're meeting our goals and how we're meeting the project, program the office needs, and we do that by going over the major areas, and then I'll be focusing on one of our major programs that are ongoing now, which is the xLPR program.

I've made a brief, a couple of different briefs on xLPR to this group before, but this is mainly to allow our new members to become a little bit more familiar with that program. This is kind of a busy slide. If you look at the handouts, I've given you an enlarged one to keep in front of you.

This is an overview of everything that we

do in the Component Integrity Branch, and I've plotted this thing out larger, so that you can keep that in front of you as I talk for reference. It's kind of a nice little flow chart of what we do in Component Integrity.

The different capabilities and topic areas are highlighted in the different colors in this chart. The top one is piping integrity, which includes things such as the xLPR program, which I'll be talking about in more detail later, residual stress and a lot of our internal efforts and programs, emergent needs support efforts on piping issues.

If you look across the top of this chart, you can see the User Need Requests that were from the program offices, and their titles and how they feed into that particular topic. The MOUs are the agreements that we have with EPRI for cooperative research in those topics.

The updates are some of the major things that are going on within those topics, and the current contracts are the actual job code numbers, the contractors and what the name of the projects are called. So as you can see in each one of these major topics, we have several ongoing projects that are supporting that particular focus area or capability.

So I won't talk that much at the xLPR stuff,

because I'm going to spend a lot of time, the last half of this presentation, talking about that program. But I will be talking about the other four major topics.

The first one is the integrity of reactor pressure vessels, and I'll get into that in a little bit more detail in a little bit and the ongoing efforts there; non-destructive evaluation and our support of looking at whether or not sufficient rigor is being developed by the industry in non-destructive evaluations.

There's been a lot of work currently going on in the industry on high density polyethylene piping. So we have a couple of efforts going on there. They're looking at confirming mechanical behavior as well as non-destructive evaluation processes for detecting flaws in high density polyethylene.

And finally environmental fatigue. We've been working on fatigue for a long time, and we're recently just updating the rules for environmental fatigue, including things like high energy line breaks. So I'll talk some time about that also.

As Mike pointed out, our budgets over the last couple of years have been reduced, and so as I go through this I'll point out the locations of where we've decided at the time to extend or postpone some of the funding in certain technical areas, to help support of

the other areas.

And in a couple of other -- in a couple of these areas, EAF especially, we're nearing the end of that particular work, and so we'll be able to use those funds that we had in the past to help us in the future endeavors. So keep that sheet out on your page, and we can talk about that moving forward.

MEMBER SCHULTZ: Dave, perhaps you can help right at the outset here. What I was hoping for, and this slide, I guess, is probably coming up in your discussions, is information related to what constitutes close out for the projects.

I'm looking at all the 2010 numbers, in terms of User Needs, and I see that for example in the first two, we move from develop a project -- a project in development to "a new User Need associated with implementation."

MR. RUDLAND: That's correct.

MEMBER SCHULTZ: 2013. So what does -- as you go through your discussions, are going to elaborate on what it's going to take to move to closure of, for example, the 2010 or 2006-related project User Needs?

MR. RUDLAND: I can definitely highlight that.

MEMBER SCHULTZ: Okay.

MR. RUDLAND: And as you notice, if you look at the User Need numbers, you can see when they were initiated, and you'll see that a lot of them are around the 2010 time frame. We do have some 2006-2007, which are relatively old User Need requests, and we'll talk a little about that and what our plans are off of that.

In most cases, those are very, very near completion. So there's follow-on things that need to be done, and we'll go into some of that.

MEMBER SCHULTZ: And then came, as Mike indicated, 2011, Fukushima as well as the budget-related impacts that could explain the reasons why we don't have 2011-2012 as much as 2010 and now 2013.

MR. RUDLAND: That's correct, and as Mike also pointed out, these User Needs are usually, you know, four or five year efforts. So there's usually gaps in the years in which they're released, because we're in the middle of ongoing User Needs.

MEMBER SCHULTZ: Thank you.

MR. RUDLAND: Yep. I tried to list as many of the upcoming User Needs as I can, and it's difficult. Usually the way that it works, as Mike pointed out, is that we look very closely with the program offices.

So as they are drafting their User Need, you know, we have a lot of consensus meetings where we talk

about the topics to be done, and we explain to them the level of funding that we have available.

We're able to iterate the work scope within the User Need, to meet their needs. But in some cases, we had to close some User Needs; in some cases, we're responding that we're not going to be able to with the current level of effort, complete the deliverables when they need them, when they have to extend those things out, and I'll talk about those in a little bit more detail.

Okay. Now the first topic that I'm going to talk about is integrity of reactor pressure vessels. This has been an ongoing effort to that we've been working at in Component Integrity for many, many years.

It's focused a lot on doing a lot of assessment of the current technology, the current data relative to embrittlement, and the development of P-T curves and those particular types of topics. So this is one of those particular projects where the User Need is relatively old, in 2007, and we have satisfied good portion of that User Need.

There's still a lot of ongoing questions on whether or not we need to update or revise the current analyses and regulations. So we're using this particular topic to investigate those particular issues. I'll talk about those issues in a second.

CHAIR BALLINGER: I have a question about that. For something that's this -- been going on for this length of time, is there a periodic sort of assessment where you get a chance to reset, if necessary, to change direction in some of these -- in this kind of thing?

MR. RUDLAND: We're constantly doing that. I mean that's something we have ongoing discussions with the program offices on research that we're doing, ongoing discussions on the direction of the development of any analytical tools or analyses that we're doing that needs to meet their needs. So we're in constant development.

CHAIR BALLINGER: But that kind of sort of blends everything together. Has there been occasionally a "let's stop and take an assessment," and then write something up that says "Here's where we are. Here are the gaps remaining. Here's where we need to go."

MR. RUDLAND: I mean in terms of how we have our deliverables, we do that at deliverable time. So as deliverables are being drafted, those correspondence happened with the program office. We do it in terms of, as we're putting forward a regulatory guide, we do it at that particular time.

As the regulatory guides are being reviewed

for whether or not they need to be updated or eliminated, we have those times also. So those kind of things happen on an ongoing basis, especially in this particular category with reactor pressure vessels, those conversations happen a lot.

There's a lot of technical discussions on how, you know, how well -- how much data that we have for embrittlement per se, how will it fits the current trends, the need to modify those trends. Those discussions are constantly ongoing.

MEMBER SKILLMAN: David, how is foreign OE factored into the discussion?

MR. RUDLAND: I think any time foreign OE happens, there are a lot of talking that happens between us and the program office. For instance, the Doel incident that happened. There was a group of folks from RES, as well as from NRR, that talked with the guys at Doel, and understood their problems.

Now we're taking the incident that happened there in regulatory space and determining what needs to be done, if anything, for our plans.

MEMBER SKILLMAN: Is there a formal forum where that type of discussion is --

MR. RUDLAND: I don't there's anything formal. Again, the way that -- the way that we work

through our User Needs is in a lot of cases, since we have such a good relationhship with the program offices, the User Needs usually have some kind of request for technical assistance on emergent need issues.

So we have a formal method to be able to track that interaction. But in terms how we, from the research point of view, deal with the operational experience internationally, it's through the requests from the program offices.

MEMBER SKILLMAN: Thank you.

MR. RUDLAND: As I mentioned, there's a lot of ongoing work that's being done in the reactor pressure vessel integrity area, and this lists some of those particular things that have been published and are under the investigation of whether or not they need to be revised, due to new analyses, increased amount of data and those kinds of things.

As you noticed, looking at the times that these things have been revised, it's been quite a while since they have been revised. For instance, embrittlement data, you know, there's been the surveillance programs that have been going on, and we've been receiving new data from that.

That data needs to be analyzed and determined whether or not the trends that we have in the

embrittlement trend programs need to be modified or not. So a lot of the work in this particular area is focusing on taking a look at what we have published in the past and whether or not it's adequate for the new data that's coming that we have, or the new analyses that we've developed.

So as you can see, we've got a lot of staff involvement in here, not as much contractor involvement at this particular point in time. The contractor involvement is being focused mainly on the two issues of Appendix G, which is the normal operations, and the alternate PTS rule that was developed also.

MEMBER RICCARDELLA: To date, have we seen any surprises in the surveillance data?

MR. RUDLAND: I don't think so. I think the trends are pretty much the same. Again, I think stuff is still being analyzed, but I don't think there's any large surprises.

The main surprises that we have coming is that through studies that have been done at Oak Ridge, looking at what's driving some of the normal operation issues, we're still investigating whether or not small flaws that may occur in the clad may actually be affecting the probability of through-wall crack frequencies.

So this work is ongoing, and right now most

of the staff support is going at looking at whether or not these particular documents need to be revised.

As we talked about, as Mike pointed out, we have a lot of our ongoing support that we're doing for emergent need issues. We've supported Doel, Palisades. Palisades is doing their -- is one of the first plants to use the alternate PTS rule.

So we have a staff member that's going to watch and help through their inspection process, help the regions in their inspection process; developed regulatory issue summaries in extended belt line for Appendix G, demonstrating that you need to develop PT curves for more than just the belt line region for the whole vessel.

So we're constantly working on these emergent need issues as part of these -- as part of the User Need request. And again, if you look at some of the schedules here, we do have plans to do some revisions to the ongoing regulations that we're supporting the program offices on, and one of those is the Appendix H, which is the surveillance program. That needs to be updated, and so we're going to working on that some time in this particular year.

5061(a), which is the alternate PTS rule, we're just in the process of publishing the regulatory

guide and technical basis for that particular regulation. We're under discussions, like I mentioned, for some of the other things like the normal operation regulation, as well as Reg Guide 161 and 199 on embrittlement, whether or not those need to be revised, and those discussions are ongoing and continuing.

One of the other things that Oak Ridge is working on is developing this reactor embrittlement archive project, and basically is keeping a database of all of the embrittlement data, and it's been online since 2012, hosted through Oak Ridge. And again, we're funding those things as the budgets permit.

I didn't point out this at the beginning, but I do want to point out that there's a lot of topics that are going, a lot of discussion and topics that go into each one of these major areas, and you know, if requested, of course, we're willing to go back to give a much more thorough brief on each one of these topics.

On non-destructive evaluation, this is an area that recently has gained a lot of interest, in trying to understand whether or not the industry's NTE methods are sufficient, and sufficient rigor has gone into the development of these particular methodologies.

Also if the qualification process is adequate, and whether or not modeling, UT modeling can

be used to help in the verification of some of these methods. So these projects that we have within NDE are really focused at confirming the industry's approaches, both their new and revised approaches, for trying to detect and size these flaws within the components in the operating plants.

We have several contracts that are currently ongoing with Pacific Northwest National Labs, and most of those are focused on again doing confirmatory studies on NDE-related issues. There's also tasks to help with emergent need issues as Mike pointed out with the North Anna case that happened last year, and understanding how the industry missed those large flaws.

CHAIR BALLINGER: I see the cooperation with EPRI. Is that a really good, solid connection?

MR. RUDLAND: Yeah. In most of our -- in most of our program areas we have ongoing MOUs with EPRI right now, and some of them are stronger than others. Within the NDE region, we have some topics that it's very strong and some we're still working on developing good cooperation with the industry.

So for instance, in visual UT, we have very -- we're doing a very good job of cooperating. In some of the other areas, we're working on the cooperation. It's developing relationship.

MEMBER RICCARDELLA: You said visual testing. You said visual UT.

MR. RUDLAND: Oh yeah, I'm sorry. Yeah, sorry.

CHAIR BALLINGER: And what -- how's the cooperation in the area of cask structures?

MR. RUDLAND: In cask? Well, it's -- we haven't really developed much in terms of cooperation on the cask at this point. I mean it's something that we're trying to work into the -- if you notice here on this slide and the next slide, I talk about the ongoing MOU expires in March of this year, and we're trying to talk about whether or not we need to ask cask to the ongoing MOUs.

Right now, there is nothing cask in the ongoing MOU. We're in discussions with EPRI on that, both from a UT perspective as well as from an integrity perspective.

So the ongoing programs right now, again all of these are with PNNL, and the first one is a large program that is, like I mentioned, based -- looking at mainly the reliability of NDE and the effectiveness. Then there's a lot of different tasks that are going on in this.

And again, how we assess these projects in terms of coming to closure, it's topic-specific. If

there's a particular topic that we're working on, the reports and deliverables will of course dictate that particular closure.

UT in lieu of RT is one that we started working, but because of the level of effort and the amount of funding, it was mainly a confirmatory program that we thought at the time we could probably pull some of the money from. So that particular project is finishing up in '14, because of that little bit less funding.

MEMBER ARMIJO: Dave, on those numbers of reports and NUREGs, are those actually completed or planned?

MR. RUDLAND: Those are planned. Yeah, those are planned right now, right, right. Especially for the first project, because it's not that old. It's only --

MEMBER ARMIJO: That's a lot of reports.

MR. RUDLAND: Yeah, yeah. So that's the planned number of reports that are going to be coming out of that. PNNL is very efficient at publishing these types of documents, so there's no worries with that.

The final one is an international program that is aimed again at looking at the effectiveness of NDE in dissimilar metal welds, and looking at gaining and gathering international experience on NDE. So that's an

ongoing program that actually says ends in '15, and that's an error. It ends in '16, in 2016.

So it's an ongoing effort, international effort to try to bring in the operator experience and any OE that happens, and to discuss that in this international program.

So we talked about the EPRI agreement. Like I mentioned, the ongoing EPRI agreement expires in '14, and we're in the process of trying to figure out how we want to extend that, because there's new topics and some topics are finished, and there's some topics that we're trying to decide whether, what's the best way to work cooperatively with EPRI.

CHAIR BALLINGER: So there's no doubt that it will be extended?

MR. RUDLAND: There's no doubt. Yep, there's no doubt.

MEMBER SCHULTZ: Dave, in this area you have, as compared to the others, you've got listed ASME code support in all the other category areas. But here you don't, although you're referring to an international program associated with standards that seems to be supported by ASME. So could you explain how that works together?

MR. RUDLAND: Yeah. I think that's an

omission on my part. We are heavily involved in NDE and ASME code. That's not on the sheet and I apologize, it should be. We're definitely high and very well-engrossed in the ASME code development effort for NDE.

MEMBER SCHULTZ: And that would be all connected to EPRI IRSN and the other activities related to that?

MR. RUDLAND: That's right, that's right.

MEMBER SCHULTZ: With PDI involved in that.

MR. RUDLAND: PDI, yeah, yeah.

MALE PARTICIPANT: PDI is --

MEMBER SCHULTZ: Performance Demonstration Initiative.

MR. RUDLAND: Performance Demonstration Initiative.

MEMBER SCHULTZ: It's a big program by EPRI to qualify inspectors and procedures on blind samples.

MR. RUDLAND: So one of the tasks in this program is to assess that program.

MEMBER SCHULTZ: Good, thank you.

MR. RUDLAND: And again, the agreement with the IRNS, IRSN, just began here, and it's looking at work that they're doing on flexible probes, and trying to increase the coverage of inspection in areas that it's

typical to inspect with --

MEMBER SCHULTZ: Cask pipe?

MR. RUDLAND: Not necessarily cask pipe, but just pipes that may have areas that -- where the typical probes can be used. So we'll be working with them, and have an agreement to go and use probes and develop data and exchange data on this type of new probe development.

MEMBER SCHULTZ: Where's IRSN? Huh?

MR. RUDLAND: France.

MEMBER SCHULTZ: Huh?

MR. RUDLAND: France.

MEMBER SCHULTZ: Okay.

MR. RUDLAND: So the RPV work and the NDE work and the piping work, which I'll talk about later, are our major topic areas.

We have several other topical areas that we're working on, based on the needs that we got from NRR, and one of those is the high density polyethylene piping, and it's an alternative used in the industry for locations that may have corrosion issues or whatever.

And so our job, we've been asked to do, is to confirm some of the requirements that are used in ASME for safety-related applications, support the program offices and code actions related to HDPE, use the

confirmatory work in some of the mechanical property development as well as the ND

In this particular case, the sequestration and budget issues have forced us to kind of put some of the NDE issues on hold until we're able to have a little bit more funding. We're focusing a little bit more currently on just the material property development, which this last, this slide is focused on.

Our contractor, EMC2, is doing experiments, slow crack growth experiments, and trying to do confirmatory work based on the publications of the industry. We do have an MOU, again with EPRI on that, and we're cooperating with them, and our NRR User Needs.

We actually have two of them. One again is older and we're finishing up, and again, how we rate that or how we determine that is a finishing up type of issues, that we look at how the work is incorporated into the ASME code.

Like I mentioned, a lot of it, the work, is currently being focused on looking at the parent infusion joints for the pipes, and in doing not only specimen tests but also full-scale piping experiments also.

The NDE, as I mentioned, is limited because of some of the funding, and it was mainly limited to look at detection capabilities in the fusion joints.

MEMBER ARMIJO: What kind of NDE techniques do you use?

MR. RUDLAND: It's UT.

MEMBER ARMIJO: It is UT? Will it work?

MR. RUDLAND: Well, that's what we're trying to figure out and confirmed.

MEMBER ARMIJO: It sort of works.

MR. RUDLAND: There's still a lot of development happening.

MEMBER RICCARDELLA: My understanding is the issues aren't classical defects in the joint, but it's chemical.

MR. RUDLAND: It's a lot of different things that can be determined as defects. Dust is also something that actually is considered a defect in the joint, because it can highly degrade the integrity of the fusion joint. So some of those things are not -- you can't detect that with NDE.

MEMBER ARMIJO: Not your classic flaw?

MR. RUDLAND: Right. But like the cold fusion is another one that can be found by NDE techniques.

MEMBER ARMIJO: Sure.

MR. RUDLAND: So we're trying to develop the right procedures for all the different types of defects. So again, NDE right now work is on hold, until

we can free up some funds for that particular effort.

Finally, I'll talk a little bit about environmentally-assisted fatigue. Again, the purpose of this work, which is not a large effort, but it was focused on trying to update the ongoing, existing EAF methodology, and to develop regulatory guide and tech basis for this effort.

And again, it's taking a lot of the data that's been developed by NL and do the analysis and update the trends for environmental assisted fatigue. And we do again have an ongoing MOU with EPRI on that. Actually, it had expired, is now expired. But it was used in the development of this effort, that was co-funded. The money was co-funded by EPRI.

And we have again, similar user needs from NRR and NRO to develop this, to update this technology.

CHAIR BALLINGER: Do you have any interaction with Navy folks, on environmental fatigue in particular?

MR. RUDLAND: I don't know. You might want to ask Gary Stevens on that.

MR. STEVENS: Gary Stevens, Office of Research. Not really. There's a couple --

CHAIR BALLINGER: Because they have a big program.

MR. STEVENS: It's a couple of Bettis folks that attend -- does this work? A couple of Bettis folks that attend code meetings that we have dialogue meetings, but most of their information they're not able to share with us, so the dialogue is limited.

CHAIR BALLINGER: Thanks.

MR. RUDLAND: So the deliverables from that effort as basically in knowledge management, turnover from the contractor. There was, you know, Omesh Chopra from A&L is a wealth of knowledge in this area. So we use this particular tool to also make sure that we understand all that he knows from that.

Then we revised Reg Guide 1207 and the tech basis document for that, based on the new analyses and new data. This is a completed effort. So our metric for the completion of this effort was the development of the tech basis document, the revision to the tech basis document and the regulatory guide.

The drafts are done. It's just at the end, the draft went out at the end of the year. We got them out for comment internally, and we expect it to be issued in early 2015.

We talked about, you asked about how we assess, and again I've mentioned several times that the release of tech basis documents or regulatory are our

basis. Each of the User Need request tasks has a very distinct list of deliverables. So many of our programs are tracked through the metric of those deliverables.

And so as we get to something like a 2007 User Needs request, we've fulfilled, you know, 95 percent of those deliverables. If there's new and emergent needs that are coming up, and we'll roll those over into an update User Need. So in the case of the RPD integrity like we talked about, there's ongoing efforts to revise that particular User Need.

The same thing has happened with xLPR. As you saw there, that we're finishing up the XLPR project, and now we need to go into the implementation and how we're going to use that in LBB. So an updated User Need is being requested also. So that's how we track those in our -- in this particular branch.

CHAIR BALLINGER: So it's really -- if the deliverables are met by definition the program's a success?

MR. RUDLAND: Well, we grade our contractors internally, you know, on technical accuracy.

CHAIR BALLINGER: I'm talking about -- yeah. I'm not talking about deliverables from contractors. I'm more interested in the interaction between the NRR folks that sponsor or do the work, at the

request of the User or User Need, and whether the User deems it successful?

MR. RUDLAND: Right.

CHAIR BALLINGER: In other words, the people you're responsible to here. How do they assess the value of the work? Do you get direct feedback from that?

MR. RUDLAND: Of course. Yeah, I mean we're very -- like Mike mentioned, we work very closely with the program offices.

CHAIR BALLINGER: Okay.

MR. RUDLAND: And so, you know, we're very sensitive to their acceptance or non-acceptance of the work that we're doing, and everything that we publish that is deliverable to User Need goes through their direct concurrence.

So we usually don't publish anything in terms of a NUREG that we don't have consensus on. So we strive as a team to try to come up with a consensus with the program offices, and help them to understand where our recommendations are for their use of that particular information. I don't know if you're looking for a formalized process.

CHAIR BALLINGER: No. I guess I'm new at this, all right, so I'm kind of looking for -- if you put

together a table that says User Needs and Deliverables, that these have been met.

MR. RUDLAND: Yep.

CHAIR BALLINGER: If there was another column there which said "Customer Satisfaction," all right, 1 through 10, all right. If you were to go to the customer, what did the customer put in that column?

MR. RUDLAND: You know, every deliverable, every final deliverable that we make to the program office, we send with it a RES survey of satisfaction. I think that's what it's called or not, and you're asked to fill out the survey.

MR. CASE: Yes, it's a quality survey, but it's really --

CHAIR BALLINGER: Do they fill it out?

MR. CASE: Yes, and we good grades. Sometimes we miss the mark, and so we actually look at those. So Brian, when we do quarterly reviews of the entire research program, Brian looks at the quality reviews, and most of them are green. But every now and then you get a red one.

So you know, Brian says you need to go back and discuss that with the program office, you know, figure out where we came off track. So it's somewhat of a simplistic survey, but it actually works.

CHAIR BALLINGER: Okay, good.

MR. TREGONING: Rob Tregoning, NRC Research. We don't wait until the end.

CHAIR BALLINGER: I would hope not.

(Simultaneous speaking.)

MR. TREGONING: In terms of the planning, the execution, what testing or analysis that's done, I mean that's all done in close consultation.

So it's not just that the User Need comes over, we write a response and then we go to work, and then we hand them a report, you know. It's much more closely collaborated through the entire process. We can't afford to do otherwise, given the budgets that we have.

MR. RUDLAND: Yeah, and we do try, even from the very beginning in our planning, to develop these efforts in a consensus-type process, right, that we have program office's input and understand better what their needs are, so that we can move forward as efficiently as possible, because for us to move forward without their input, you know, we may be chasing our tails.

CHAIR BALLINGER: Okay. Unless we have questions related to this immediately, we probably should continue here, and then save the questions 'til afterwards, 'til the end.

MR. RUDLAND: Okay. So I'm going to give

an overview of the xLPR program. I'll start out with a little bit of background of why we're doing this program.

In 10 C.F.R. 50, Appendix A, there's a General Design Criteria that states that local effects due to pipe ruptures can be eliminated from the design basis of the plants, if it can be demonstrated that pipe ruptures are extremely low, the probability of occurrence is extremely low.

These dynamic effects include things like jet impingement shields and pipe whip restraints that are used there to help satisfy, you know, the safety of postulated defects, postulated breaks that need to be included in the design of Emergency Core Cooling Systems and things like that.

These dynamic effect things, the pipe whip restraints and impingement shields make it difficult for the industry to do inspections and things like that. So it's a bit of an inconvenience for them, and if they're not needed, this part of the regulation allows them, through analyses that are approved by the NRC, to remove these particular devices.

In the 80's, conservative flaw tolerance analyses were developed with sufficient safety factors to ensure that these pipe breaks had extremely low probability of occurrence.

That was incorporated into SRP-363. One of the stipulations, there are several stipulations, things like water hammer can be occurring in the system that are approved for LBB. But also there could be no act of degradation.

So this was used as a criteria to demonstrate that the pipe was sufficiently tough to be able to handle a large flaw that could be found before it would actually rupture in two. It was all kind of qualitative. There was no quantitative procedure available for assessing this probability of occurrence.

The deterministic analyses gave you an answer that wasn't a probability of occurrence. It was safe/not safe, based on this safety factor, on flaw size, safety factor and leak rate.

So in the early 2000's we started getting -- started seeing occurrences of stress corrosion cracking in piping systems that were approved for LBB. So the industry at that time began on an inspection and mitigation program, to try to improve the reliability of these particular flaws, to help gain confidence that these LBB systems were still safe.

So NRR requested us in 2005 and 2006 to take a look at their ongoing systems, ongoing inspection and mitigation programs, to understand if those particular

programs were sufficient.

So in 2005, we took a look at some of the industry's mitigation techniques and did confirmatory work on them in determining whether or not they were effective for changing the conditions that are needed for SCC, and also to help develop a long-term strategy for LBB, understanding that even though we put inspections and mitigation on these pipes, we still don't have a quantitative way of assessing whether or not the probability of rupture of these systems is low or not.

Once you do things like inspections and mitigations, it complicates the deterministic analyses that were done. So in between these two User Need requests that are up there, we went through the process of doing just that, and determining that in the short term what the industry was doing was sufficient for ensuring the safety of those particular lines.

Both of these were closed out, and they're closed out again through a variety of reports and presentations that were made, in concurrence with the program offices, demonstrating that inspections, inspection schedules were acceptable, and that the mitigation programs, if applied properly, were effective in doing their job.

Then in 2010, NRR submitted a User Need

request for the development of a longer term solution, to be able to quantitatively predict the probability of rupture for this. So they asked us to develop a flexible, modular probabilistic fracture mechanics code that could be used.

They wanted to be able to model ACT degradation methods. We wanted to be able to model inspection. We wanted to be able to model mitigation, to be able to properly understand and quantify and propagate the uncertainties on all those inputs in this probabilistic framework.

Their request was to deliver a tech basis and a regulatory guide for LBB at the end of this particular program. We'll talk about the update of this in a little bit, and where we're at on that.

So the core capabilities again of the xLPR and piping integrity are listed above. They include a lot of different things and not just probabilistic code. There's fracture mechanics expertise, expertise in stress corrosion cracking, weld residual stress, both analysis as well as measurements of residual stress, and validating that we can actually predict the residual stresses properly.

Probabilistic modeling, as well as NDE, feeds into the xLPR program, and through that we have

several contractors that are currently working on this program. As you can see the list here, it's many of the ones that we've used in the other efforts that I talked about earlier this morning. Each of them have their own particular scopes and part of the xLPR project team, which is listed here.

So we have, working cooperatively, again through an MOU with EPRI, we've developed a comprehensive team of subject matter experts in developing this code, both from the NRC staff, NRC contractors, EPRI staff and the EPRI contractors, and we've grouped them by expertise.

So there's certain folks that are working on the deterministic model development, and there are certain people that are working on the stochastic code development but together, working as a team, to try to develop this code in a relatively robust manner.

This particular cooperative effort has been highly successful. The information flow has been very successful in both directions. It's not just one-sided, and we've been able to very effectively understand our disagreements and come to a very good consensus within the group.

I'll talk a little bit about the technical flow of the xLPR program. Again, the process includes

the characterization of all of inputs that go into the fracture mechanics code, as well as those uncertainties. We've modeled the entire crack evolution process within xLPR, starting with crack initiation.

This is a topic that we discussed with the ACRS last year in great detail, about how we're modeling not only fatigue initiation but as well by PWSCC initiation also in these pipes, allowing for multiple cracking or actions, multiple crack initiations as they occur.

Crack growth, again both fatigue and SEC crack growth, based on published crack growth laws. These cracks may grow and coalesce, become long surface cracks. In the integrity of these particular pipings, the most severe condition are those where long surface cracks form.

That's what causes these things to rupture before they leak. So we need to in this be able to predict those cases where long surface cracks may form. We've incorporated, like I mentioned, the inspection and mitigations that we can find these cracks, find these flaws or possibly add a mitigation process within the life of the plant, to be able to understand the effects of those mitigations.

If we do have a through-wall leaking

condition, we need to be able to calculate what the leakage rate is, so that we can take credit within the program for leak protection. So we have sophisticated coding in there to be able to calculate the leakage through tight cracks in pipes.

Then of course stability. All of these cracks are certain loads in which these cracks will fail, and causing either severance of the pipe or some large openings. So we have stability routines in there also. It's interesting to point out that each one of these, of course, has its own sets of inputs and its own sets of uncertainties associated with it.

The code is developed, modularized, so each one of these topics is self-contained code that has been developed, QA'd and verified independently of its insertion into the overall code structure.

MEMBER RICCARDELLA: So the crack growth includes the uncertainty on residual stress determination?

MR. RUDLAND: That's right, that's right, that's right. Yeah. It includes not only that, but it includes uncertainty in the crack growth rates and the material properties and all that kind of good stuff.

When we started this program in 2009, it was a very large effort. So wanted to be able to do, to take

a smaller effort first for a couple of reasons. We wanted to be able to understand if we can work well cooperatively, because again, you know, you don't know when you're developing something like this if a cooperative effort will really work.

So we wanted to be able to determine if we could work well together. We wanted to determine what was the best way to code this thing in a modular fashion, so that we could use it generically in the future. And we also wanted to be able to choose the actual software that we could use, that would help us move forward properly in developing this code.

So we ran a pilot study, and that pilot study lasted from 2009 to 2011. We focused on pressurizer surge nozzles, which is possibly one location in LBB lines. We only considered one particular cracking mechanism in the pilot study, PWSCC.

We developed a code. We actually developed two codes, and we did that within a configuration, pretty strict configuration management system, and we developed a program plan that had objectives, schedules and deliverables and all that for Version 1.

We developed these two codes, and we developed two codes because we were still unsure exactly what type of probabilistic framework to use, whether we

wanted to write from scratch or whether we wanted to buy an off the shelf software that would allow us to do things like select random numbers from different types of distributions and things like that.

The two codes gave us the exact same results, and we were able to, with a limited number of samples, come to relatively low probabilities of occurrence, using important sampling techniques and adaptive techniques that we've been developing.

So this is a plot from one of the -- from the pilot study final report, that demonstrates that for this particular case, the decrease in the mean probability of rupture, with the increase of either mitigation or inspection or leak detection, and demonstrates that the code's able to do that.

This particular case was run with about 50,000 Monte Carlo realizations. So we're able to sample out the important aspects that drive this failure, and get that down. So we were able to calculate down to 10 to the minus 8 probability of occurrence, with a limited number of samples.

There's still some work that needs to be done and convergence, this bottom plot, demonstrates that for that particular case, more realizations are probably needed, so that we can increase our confidence

in the mean values.

MEMBER RICCARDELLA: These are mean values?

MR. RUDLAND: Mean values, yeah. The code was also -- the code's also able to develop the uncertainty on the mean values also. It's not demonstrated in here, but we did that within the reports that we wrote.

MEMBER RICCARDELLA: What was the form of mitigation?

MR. RUDLAND: This one was MSIP.

MEMBER SKILLMAN: Talk to us about validation of the code.

MR. RUDLAND: Oh boy. Okay. So two parts to that. There's verification and validation. So the verification is done through the robust QA program. We have detailed plans that we write for the verification. We look at testing and all that kind of stuff to do the verification, make sure we have coded what we think is coded.

MEMBER SKILLMAN: Gotcha.

MR. RUDLAND: Okay. So validation is a couple of different parts. The fracture mechanics modules need to be validated, to demonstrate that they are predicting what we think they're predicting.

So if I have the stability of a cracked pipe, and I have a model that I've developed that will give me what the maximum load is for that particular crack and that particular pipe, experiments can be run to demonstrate that my model predicts the maximum load in those experiments.

MEMBER SKILLMAN: So experiments have been performed?

MR. RUDLAND: Experiments have been performed.

MEMBER SKILLMAN: Many, many experiments.

MR. RUDLAND: Yeah, and not particularly it's many, many. In some of the other models, not so many, you know. So we have to make some engineering judgment on that. But what that tells us is that tells us it can predict the experiments really well. It doesn't tell us it can predict the behavior inside the plant very well, which may not have the exact same conditions as the experiment, in terms of constraint and things like that.

For instance, in the stability example, you know, the pipe is bent with the ends free to rotate. In a plant, that's not the case. Things are constrained by vessels and by steam generators and things like that.

So you have to be able to qualitatively

understand the output of your model relative to the true behavior in the plant. So we're trying to rank our models based on how we think the behavior in the plant will be, whether it's a conservative prediction or non-conservative prediction, in terms of that.

So there's two realms of validation when it comes to the models. Now when it comes to the full code output, that's a little bit more difficult, because there's no ruptures, right? So I can't validate against operating experience on large bore piping ruptures in nuclear power plants, because there isn't any.

So what we can do is we can take a step back and we can validate some of the preliminary results, the number of cracks, the number of leaks, and we can validate to the operating experience that we have for that, to give us -- to increase our confidence in that particular output.

So that's the kind of process that we plan to take in validating our Version 2.

MEMBER SKILLMAN: Okay, thank you. Have we picked a target yet as to what we consider low?

MR. RUDLAND: Yeah. Let me get to that, okay. I'll get to that in a few minutes. So the pilot study, again which was that two and a half year effort that you saw, we demonstrated that it was feasible.

We wrote several reports that published all of the findings that we found. We did a great job, I think, in terms of working within the cooperative environment.

We did find some potential gains. We identified potential gains in the program that we're currently in the process of incorporating into the Version 2 structure that we have, and we selected a commercial software framework to help us, and we did that through independent review, cost analysis, long-term prospects of maintenance for the code and things like that.

MEMBER ARMIJO: What is that?

MR. RUDLAND: It's called GoldSim.

MEMBER ARMIJO: I know what you're talking about.

MR. RUDLAND: Okay. So from the lessons learned in Version 1 in the pilot study, we moved forward in Version 2, because the User Need really wants a code that is -- wants a code that can be used for LBB. Remember the pilot studies focused on one location, one mechanism.

So we needed to expand what we did in Version 1 for materials loads, mechanisms, mitigations, everything associated with those lines of proof of LBB, and we expanded our quality assurance program that was

fashioned after NQA-1. That includes the verification or validation processes that I talked about just a second ago.

MEMBER SCHULTZ: So all of the code developers have been qualified with regard to the --

MR. RUDLAND: Trained.

MEMBER SCHULTZ: Trained and qualified with regard to their verifications?

MR. RUDLAND: Yes. All of the members that are on the team have to go through some training.

MEMBER SCHULTZ: Right.

MR. RUDLAND: Okay, and those people that are doing verifications are subject matter experts in those particular areas, right.

MEMBER SCHULTZ: Sure.

MR. RUDLAND: And they have been or will be trained in the verification process, which is very well dictated through the QA documents that we have.

MEMBER SCHULTZ: Right. The developers and the verifiers have been qualified?

MR. RUDLAND: That's right. Everybody's been trained in the QA procedures. The developers and verifiers, which aren't the same people, and they may not be in the same organizations.

MEMBER SCHULTZ: Right.

MR. RUDLAND: But they're all part of the xLPR team.

MEMBER SCHULTZ: In the terminology here, you keep saying qualified. You keep saying "trained." Is there something I'm missing in that?

MR. RUDLAND: Well, I'm not sure what you mean by "qualified." There's no regulated test that needs to be taken, right. So there's a set of training -- a set of training that's a requirement within our QA program. We've had our QA program audited by EPRI and an independent contractor through EPRI, to justify its ability to be able to do this program within the process.

MEMBER SCHULTZ: Generally -- when I say qualified, it's generally so a person is trained?

MR. RUDLAND: Right.

MEMBER SCHULTZ: But then the quality assurance program requires that person who is trained to be, if you will, administered through the process associated with doing the work and demonstrating, demonstrating that they understand the training they have received?

MR. RUDLAND: Right.

MEMBER SCHULTZ: So that would be my take on qualification of an individual and organization.

MR. RUDLAND: Yeah.

MEMBER SCHULTZ: And an organization for maintaining that oversight, and I noticed you've got another portion in this project that isn't an individual or an organization, that says quality assurance. But it's like programmatic quality assurance.

MR. RUDLAND: So we have team members from both EPRI and NRC that are on the quality assurance group, and their job is to make sure that we're training, and that we're following the processes properly. That's their entire job.

MEMBER SCHULTZ: Thank you.

MR. RUDLAND: The important part about this is even though we're working this in a cooperative manner, and developing this both from the NRC and from EPRI's side, when a licensee is going to be wanting to use xLPR in the future, it still needs to go through the normal channels of regulatory approval.

So we're striving, in the Office of Research, to try to keep communication with the program offices as fluid as possible, so that they understand in detail the models and the assumptions that are being made in the development of this particular code.

So their review would not be as difficult when the time comes. So we're having workshops and discussions with them, to keep them informed through this

Version 2 developmental process.

MEMBER RICCARDELLA: So the intent of this code is it's for licensee use?

MR. RUDLAND: The intent of this code is for whoever wants to use it. We're going to distribute it. It's going to probably be publicly available for distribution.

MEMBER RICCARDELLA: At a cost?

MR. RUDLAND: I'm not charging anything.

MEMBER ARMIJO: Done when?

MR. RUDLAND: We hope to have it done by the end of the fiscal year, this fiscal year.

MEMBER SCHULTZ: In that regard, so there's quality assurance of the coding itself, and there's manuals that have been developed for --

MR. RUDLAND: Will be.

MEMBER SCHULTZ: Will be developed. I guess the next step is, of course, quality assurance, or training associated with use of the code.

MR. RUDLAND: Right, right.

MEMBER SCHULTZ: We've seen many presentations on this, and it's a complex tool to use.

MR. RUDLAND: Yeah.

MEMBER SCHULTZ: So I would presume that qualification of individuals using the code would be

important also?

MR. RUDLAND: Yes. There will be training set up, and right now we're still in the developmental process, because we're focusing on that. But you know that kind of stuff is always in the back of our mind. Any licensee that wants to use this code, the QA program that we've developed is not sufficient probably for them just to say to our regulators, hey, here's the QA program.

They're going to have to qualify it within their Appendix B program, to demonstrate that it meets the Appendix B program. So it's going to take some work for them to be able to do that.

So we've tried to at least cover the developmental and verification processes enough within this QA program, to be able to be beneficial to anybody that wants to use an Appendix B program.

MEMBER RICCARDELLA: Is there any concern with the fact that both industry and NRR will be using the same code to evaluate a given location?

MR. RUDLAND: Well, I don't think so, because the use and the interpretation will be separate, right? So we're going to write a regulatory guide on how to use this code, and that's going to be at our own discretion, and the inputs and whatever that's developed for use, and the interpretation of the results are

independent.

MEMBER RICCARDELLA: It would be like ANSYS or something? I mean both sides can use ANSYS too for the same problem?

MR. RUDLAND: That's right, that's right.

MEMBER SKILLMAN: David, as I interpret the first bullet, a licensee that would want to use this version would need to have its own expertise to do the structural mechanics for the location of interest, or go out and find a contractor.

MR. RUDLAND: To develop the inputs.

MEMBER SKILLMAN: To develop the inputs, because there are the issues of pinning, mass, bending, thermal.

MR. RUDLAND: That's correct.

MEMBER SKILLMAN: All of those characteristics that are associated with the structural mechanics analysis. Is that how you're seeing it too?

MR. RUDLAND: Yes, that's correct.

MEMBER SKILLMAN: Thank you.

MR. RUDLAND: That's pretty typical of most of the complex analyses that are done, right, is that they need to have contractors or some other experts to use them.

MEMBER SKILLMAN: I think some licensees

have developed a very high level of expertise, but most have not, and need to use a contractor that is highly skilled in this particular discipline.

MR. RUDLAND: Yes, that's right.

MEMBER SKILLMAN: Okay, thank you.

MEMBER RICCARDELLA: Just to nitpick, the continued use of LBB on the slides concerns me a little bit. I mean I hope they're going to cease to be LBB lines and start being xLPR lines or xLPR locations, you know, because to a large extent, LBB is a misnomer, right?

MR. RUDLAND: Yeah.

MEMBER RICCARDELLA: I mean one of the mitigation approaches we use is to put weld overlays on these pipes.

(Simultaneous speaking.)

MEMBER RICCARDELLA: That pretty much guarantees you're not going to have a leak.

MR. RUDLAND: Right.

MEMBER RICCARDELLA: But you know, we need to kind of change that terminology, and even the original LBB analysis doesn't really prove that it's going to leak before a break. All you say is I'm going to assume a through-wall flaw, and show that I have adequate toughness to sustain that through-wall flaw.

MR. RUDLAND: Right, you know, and the

reason why we keep saying LBB is because there's certain lines that have been approved to remove those particular things, right.

MEMBER SKILLMAN: I understand, yeah.

MR. RUDLAND: So it's --

MEMBER SKILLMAN: Sep lines or something.

MR. RUDLAND: So those lines may or may not need to do an analysis to demonstrate that they're still within that particular -- right.

So that's why -- and we've been focusing the development of -- you know, we've been developing some inputs cooperatively, and those inputs have been focused on particular locations within those lines that have been improved for LBB.

But you're right. Not only in the point of calling it xLPR or whatever, but the code that we're developing hopefully is going to be generic enough that it's not going to be associated only with those particular locations, but can be used in reactor coolant piping systems in general.

MEMBER SCHULTZ: David, could you just go over the third bullet one more time, in terms of "must stay within available cost and schedule limitations"?

MR. RUDLAND: So you know again, this is my disclaimer about funding. You know we --

MEMBER SCHULTZ: So there is a -- you're just saying there is a constraint in terms of what will be accomplished?

MR. RUDLAND: Well, if you take a combination of what and how much, that's where the constraint is, right. So we've been saying I'm going to get this code done by the end of the calendar year or the end of the fiscal year this year, that's of course tied to the amount of money that I'm able to spend in that particular area. So in order to get those done, I've got to keep those two constraints.

MEMBER RICCARDELLA: Software development is always a factor, two or three times what you estimated.

MEMBER SCHULTZ: Sure. I understand that bullet.

MEMBER RICCARDELLA: If you're lucky.

MEMBER SCHULTZ: And the last bullet is talking about the models within the tool does not guarantee regulatory approval?

MR. RUDLAND: That's right.

MEMBER SCHULTZ: And certainly the applicant will need to justify the models chosen, as well as the demonstration that the code has been used properly for the particular application?

MR. RUDLAND: Exactly, that's right.

We're developing this thing modular-based so that if Pete wants to do an analysis and he has a different crack growth model than what we've decided in the xLPR program, he can put in his crack growth model. But that doesn't -- just because it's in XLPR doesn't mean that it has automatic approval anyplace, and he still has to go through the process.

MEMBER RICCARDELLA: Even what is in it.

MR. RUDLAND: That's right.

MEMBER RICCARDELLA: If one brings their own model, that's probably another level of oversight or review.

MR. RUDLAND: Yeah. There's many paths that we can go with that. I mean we can -- when we finish this particular effort, we can have the review by NRR done on all of the technology that's in this, to form a baseline of approval, right, so they can reference that.

If there's changes made, they'd have to justify the changes made based on the baseline that we set, and we haven't decided exactly how we're going to move forward with that.

MEMBER RICCARDELLA: Okay, thank you.

MR. RUDLAND: So the benefits of xLPR, and Pete kind of pointed on it a little bit. But you know, for the LBB issue, you know, the really benefit is to

develop this regulatory guide, as to how we're going to deal with xLPR, and possibly update 363 or not. Those kind of decisions haven't been made at this particular point. But we'll have a quantified solution for the LBB issue.

But there's a lot of other things that can be -- we can use, we can apply xLPR to, and it's just some examples. A good one is research tools, you know. So if we have an issue and we need to try to prioritize our research, we can use xLPR to do that, to determine what are the drivers for a particular failure, and where we need to prioritize our research, to help us get a better understanding, or to decrease the uncertainty in the results that are given.

I can use for some of the other piping issues like risk-informed ISI or transition break size development. So there's a lot of different applications, and we've tried to keep this code -- tried to develop this code in a modular type of fashion, so that it can be easily adjusted and modified for other applications.

Realizing that when we do move to something other than xLPR, we have to develop a technical basis for it, just like we're doing for the LBB lines. So it's not as simple as flipping a switch. We'd have to go through

the process of developing that particular basis for whatever problem it is that we're trying to solve with this code.

So acceptance. Pete asked about this earlier. Right now, NRR is leading the effort on the development of an acceptance criteria. And what does that mean?

Well, there's a lot of different levels of acceptance, you know. What are the acceptable inputs? What constitutes acceptable results? How do we -- what's the acceptable way of delivering this information, and then who conducts the analysis.

If we determine that every system that's been approved for LBB has to run xLPR, who runs that? Is it the NRC? Is it the industry? Who does that? Is it plant-specific? Is it generic? So these are the kind of questions that the acceptance group are tackling, and they're not -- they're not easy.

So the group is spending a lot of time talking about these issues, and it's focusing right now basically on what constitutes acceptable results. So we're looking at risk, and we're looking at how we're going to evaluate changes in risks, looking at a case that has been approved for LBB, and now the have PWSCC. They have augmented inspections and they have mitigation.

What's the change in risk, going from the way it was when there was no PWSCC, to the way it was after with mitigation and with an augmented inspection program?

So looking at that delta, you know, so we can graphically talk about that. If you look at baseline conditions, basically like the inputs to SRP-363, you know, in terms of the mechanisms and things like that.

You can develop with xLPR a probability distribution that's a frequency per year, that's got spread to it, that can be used to understand the conditions that was before PWSCC, let's say.

Then we end up conducting analyses in a modified condition, and the risks will increase. But is that acceptable? If we have an increase in risk, is it acceptable? We then say okay, well we put an overlay on it or produce some inspections, and now the risks decrease.

That's good, right. Decrease in risk is good. But what are those levels that are acceptable, and is there guidance that's already developed that we can use to quantify acceptable risks?

MEMBER RICCARDELLA: So the middle one would be an LBB-acceptable pipe that doesn't have susceptibility?

MR. RUDLAND: Yeah. So we'd run it, you

know, with typical properties and fatigue issues and things like that, to develop what that is, or we'd baseline at a zero maybe, or something like that, you know. I mean again, these are the things that are still up for discussion.

(Simultaneous speaking.)

MR. RUDLAND: Right. So now what we're looking for is deltas.

MEMBER RICCARDELLA: Yeah.

MR. RUDLAND: Maybe this doesn't go down either. Maybe this goes up a little bit. I don't know, you know. This is just an illustration of how the risks may change.

MEMBER RICCARDELLA: So in your slide on the team, I didn't see an acceptance group. There is an acceptance group?

MR. RUDLAND: Right.

MEMBER RICCARDELLA: Or is that the Program Integration Group?

MR. RUDLAND: No, no. The acceptance group is a group that's being run xLPR -- or I'm sorry, being run by NRR, that's separate of the program development team.

MEMBER RICCARDELLA: And are there involvement in that group?

MR. RUDLAND: Yes. Yeah, EPRI's involved in that. Bob Hardies leads that effort. And so one of the thoughts is to use Reg Guide 1.174, that's already published and provides guidance on acceptable levels of increase in risk, in terms of damage frequency or large early release.

So we had a lot of experience with this particular Reg Guide, and we're currently evaluating whether or not we can take the xLPR output and put them in terms that we can use within this Reg Guide. So that kind of work is still continuing and how we're going to do that.

But this seems like a pretty reasonable approach, because that way we can take a look at the impacts of small, medium and large break locas on the overall risk, and the change in risk due to this. So this is one of the areas I think is moving forward, in how we're going to understand the acceptable for LBB.

So our status and schedule. I think we've talked about this a little bit throughout the last 15 slides. The Version 2 is currently underway. We finished Version 1 in March. That was when actually the NUREG was published. Version 2 is currently under development. Our beta version will be finished in March, and it's currently on schedule to be finished in

March.

We'll then spend between March and September going through the full V&V effort for the code, in hopes to publish and release the code in September of 2014 or thereabouts.

Originally, we had planned to have it delivered at the end of this past calendar year, at the end of 2013. We had to delay things due to some of the sequestration issues. Some of the contractors had limited budgets because of that. So it pushed us back about seven or eight months.

And again, the hope then is to take that, and once we finish the development or as we are in the V&V process, we're going to begin implementation discussions on how we're going to take what we've done in a developmental process and couch it into a regulatory guide.

So we're going to begin those processes and discussions of this this spring, in hopes to have a regulatory guide ready for publication in the 2015 or late 2015 or 2016 time frame.

And as I mentioned at the very beginning, we've briefed the ACRS in the past on xLPR, both this committee and the full committee, on weld residual stress, our validation programs, and on how we're

incorporating PWSCC cracking issues, the crack initiation into xLPR. All of those happened within the last two years, those briefings. I think that's my last slide.

CHAIR BALLINGER: Good. Are there any -- well, remarkably we're almost on time, if you consider the fact that we've been asking questions all along. Are there any other questions?

(No response.)

CHAIR BALLINGER: Okay. Well very good. Thank you very much.

MR. RUDLAND: I appreciate the time, and if there are topics that you've seen besides xLPR where you'd like a more formal presentation, please let us know, and we'd be happy --

CHAIR BALLINGER: I think what I'm going to do is ask the members here, plus the rest of the members, if they have any questions related to the Materials. I'll compile a list of questions, get them off to whoever -- to Chris probably, and we'll go through that, because we have to write this thing up pretty soon.

MR. RUDLAND: Okay, all right. Thank you very much.

CHAIR BALLINGER: Thank you very much. We have a break until 10:17. Thank you, again.

MEMBER ARMIJO: 10:17?

CHAIR BALLINGER: 10:17. What did I say?

MALE PARTICIPANT: That's what you said.

(Whereupon, the above-entitled matter briefly went off the record.)

CHAIR BALLINGER: Okay. It's 10:17. Hopefully, we can get going here. I don't know where Sam is.

MR. BROWN: He'll probably be back. We can go without him.

CHAIR BALLINGER: Think we can go without him?

MR. BROWN: Just hit the gavel.

MALE PARTICIPANT: You've got a quorum.

CHAIR BALLINGER: Okay. Can we pipe it down out there?

MEMBER REMPE: Use the gavel.

CHAIR BALLINGER: Oh, oh, oh.

(Laughter.)

MR. BROWN: Power and authority.

CHAIR BALLINGER: I'll need counseling after that. Okay. So we now have the second half, and I guess who's doing the -- John Burke is doing the --

MR. BURKS: I'm just controlling the computer.

CHAIR BALLINGER: You're controlling the computer?

MALE PARTICIPANT: Resistance is futile.

(Simultaneous speaking.)

Overview of RES Projects-CM Branch

MR. FRANKL: This is Steve Frankl. I'm the acting branch chief for the Corrosion and Metallurgy Branch in the Division of Engineering, Office of Research. Mirela asked -- Mirela Gavrilas, the current branch chief, asked me to step in in her big shoes, and give you this overview on the CMV research activities.

I've been with the branch only for a couple of months, so please have understanding when, you know, when I ask some of the leads of these projects to answer some of the more detailed questions that we may get from you.

CMV has quite a vindicated staff. I'm really proud of them. They are Materials engineers and scientists, metallurgists and physical chemists. Next please.

CHAIR BALLINGER: I thought you had control of that?

MR. BURKS: No, I do.

MR. FRANKL: Yes. Those mice don't want to cooperate. What I'm going to do is I will try to provide

an overview of research topics for the branch, as they support the program office needs, and hopefully we'll achieve common understanding of the project areas and capabilities, and we'll also demonstrate, you know, the value-added to the NRC and its mission.

We will overview and hopefully what this will -- what we are going to be doing is overview the major projects, and Darell Dunn sitting next to me will provide a detailed review of one of the projects on stress corrosion cracking of dry cask. Next please.

Okay. The first project that I will try to summarize for you is on aging of neutron absorbers in spent fuel pools. The objective here was to develop the technical basis for the aging management of neutron absorber materials.

This was initiated, if you will, with two User Needs from NRR, and in order to support the review of license amendment requests and determine what future regulatory actions may be warranted. We did a lot of work in-house and are doing a lot of work in-house in this area, but of course need to also rely on contract support.

With this activity, we had contracting support from consultants, as well as Oak Ridge National Lab. We have produced three -- what I would like to just call our three technical reports that were published in

2012 and 2013, and the focus here was on measurement uncertainty, as well as the monitoring degradation of neutron absorbers. Next page please.

The key results that came out of this project so far was that methodology uncertainties, and we are calling out one of the, I guess, tools, BADGER, can have significant impact on measurement results, and the next major key result is that when we were looking at, you know, materials, the predicted degradation for Boraflex as well as phenolic resin neutron absorbers the -- when you look at predicted degradation, those were consistent with operating experience.

And in particular, if we look at Boraflex degradation, that can be related to the gamma doses that Boraflex was exposed to in spent fuel pools, and when we look at phenolic resin neutron absorbers, so far we have not identified straight correlation, if you will, between gamma doses and the degradation of this particular absorbers.

In terms of the status as I mentioned, this is not on the slide, but I was requested to provide you, I guess, a snapshot as to where we are in these programs. The work is continuing, and we are planning on investigating the aging behavior of Boral this year. Next slide please.

The next topic is on -- project is on stress corrosion, cracking of dry storage canisters. This is the project that Darell will cover in more detail. But the objective here was to evaluate the stress corrosion cracking susceptibility of spent fuel dry storage canisters exposed to atmospheric chloride salts.

The work was -- research was requested by NMSS, with a User Need in 2011, which basically continued work from a prior User Need. Ultimately, the results of this research will inform safety evaluations and licensing actions for storage facilities.

As I mentioned, we do a lot of work in-house, but we also needed contracting support from the Center. We expect to publish the draft NUREG CR in March of this year, and we also published a NUREG CR back in 2010. Next page, please.

MEMBER ARMIJO: I can't help myself, but why in the world did the NRC permit the use of austenitic stainless steels for this application in salt, in marine or near-marine environments? I mean this is a -- you know, this is well-known.

There's a big problem with chloride stress corrosion cracking, and the industry should never have been proposing the use of such materials, unless they had some special preventive or maintenance program or

something to protect those materials. What was in our permitting process that let that get past us?

MR. DUNN: First of all, I don't think any of us here sitting at this stable were involved in that process. But I'll also point out that, you know, stainless steels are also used in reactor designs. They're also exposed to atmospheric chlorides, and they've also been subjected to stress corrosion cracking events.

So it's not a unique problem for the dry cask storage system. It's something that affects other reactor components as well.

MEMBER ARMIJO: But not internal. I mean the inside. Where in the reactor system do you have chloride cracking?

MR. DUNN: There have been a number of cases. There's an information notice that was put out in 2012, where piping systems have been discovered to have cracking. One of the most probably significant cases that's well-documented is a foreign case. But it was Koeberg, which is essentially a plant in South Africa, where they had a refueling water storage tank or a refueling water storage line that had extensive cracking, based on the atmospheric exposure to chloride environments. I think Bob Einziger would like to make

a comment.

MEMBER ARMIJO: Shame on their metallurgist too. Where is Bob?

MR. EINZIGER: Bob Einziger, the NRC. You have to remember when these were first put in service, there was the plans that DOE was going to have a repository in 1996, and these things were only going to be in service for about 20 years, before they went into a repository atmosphere, where everything changed.

It was shortly recognized after that that this could be a problem, and research was started on it, and that's the short answer, Sam.

CHAIR BALLINGER: So you said -- you're saying that the stupidity was uniformly spread?

MEMBER ARMIJO: No. It was temporary, temporary, short term.

MEMBER SCHULTZ: There was a rationale.

MR. EINZIGER: I don't want to say it was stupidity. It was lack of foresight.

MEMBER ARMIJO: Yeah. Okay. So we know what we knew before, to leave these things out there long enough, you're going to have some residual stress, and if you have enough chlorides, they're going to crack. Whether they actually penetrate and do any -- cause leakage, that's another question. But you're going to

have cracking issues at least.

MR. EINZIGER: It's possible.

MEMBER ARMIJO: I think that's a true statement.

MR. DUNN: Darell's going to explain a lot more details when we get around to it.

MR. FRANKL: So as you can see on this page, on the key results, I mean it just confirms your concerns, I mean, that austenitic stainless steels are susceptible to chloride stress corrosion cracking, that accumulated salts can absorb moisture from the environment, and that SEC initiation was observed at the lower surface concentrations tested. This was at 0.1 grams per square meter, which is I guess lower than reported in some previous studies, and also SEC initiation was observed at low strains, where the stresses are close to the yield strength of the steels.

However, I mean the only piece of good news is that no SCC was observed in non-chloride salt. But Darell will be giving a detailed presentation on this topic. Next page.

The next one topic is on vacuum drying of spent fuel canisters. The objective here was to develop a test plan for measuring the quantity of residual water in spent fuel canisters after vacuum drying.

The User Need from NMSS initiated the research. This is a big User Need, this extended storage transportation regulatory program. You will see the same User Need called out in various -- under various projects, and this particular project was just one of the soft tasks under this user need.

The outcome of this work, the regulatory use would be the determination of -- to determine if experimental testing could be used to confirm the adequacy of current regulatory guidance for vacuum drying. Two TLRs were generated in 2013 on this subject. Next page, please.

The key results of the work were that testing can be conducted using special instrumented fuel assemblies, and that a test plan to measure -- a test plan was to measure the residue of water was developed, and that currently no testing is planned by the NRC because a similar project is being sponsored by DOE.

MEMBER REMPE: Could you elaborate? Is this the high burnup demonstration when you say it's a different project?

MR. DUNN: This is funded by a DOE Nuclear Engineering University program, DOE NEUP program. They actually have the TLRs that were produced as part of this work. There was a -- DOE had a call for --

MEMBER REMPE: This is the Sean McDevitt (phonetic) work?

MR. DUNN: I do not remember --

CHAIR BALLINGER: The IRP Texas A&M?

MR. DUNN: Hey, I don't know who's doing the work. Bob, I think, knows who's doing the work on this one.

MR. EINZIGER: Bob Einziger from the NRC. No one's doing the work on this one. There's currently a DOE call out for proposals to do this work. It's a $3 million project over three years, and I think the call closes in a couple of months, to see whether somebody is going to do it.

There's two pieces to the drawing effort. One is to see how well you can remove the free water, and the second part is to see if there's going to be a problem with the bound water. The bound water would be looked at in the high burnup demonstration test, if they monitor the moisture levels over time.

MEMBER REMPE: Okay. So what I'm hearing is that you're going to rely on a IRP to satisfy that User Need with a university, and if you do, where is the guarantee that some university that is really responding to DOE funding is going to meet your User Needs?

MR. EINZIGER: Well obviously if no one

responds, then we have to go back and reevaluate where this stands in our priority of work that has to be done.

MEMBER REMPE: But even if a university does it, sometimes with those NEUP projects, I end up having to monitor their progress, and there's not really a -- does the university know that they need to respond to NRC? Where's the mechanism to ensure that you get what you need?

MR. EINZIGER: Well, we don't have a direct say in what the university does. But most of these large programs like the one at Texas A&M has an advisory board for it, and like on that one, I'm on the advisory board for the Texas A&M project, and I'm on the review board for the DOE NEUP proposal.

So we do have some inroads into what they're doing, and at least while we can't command them to do anything, we can allow them at least to know what we feel about what they're doing.

CHAIR BALLINGER: I know there's a lot of history to this, and you are part of that history. It's a different kind of fuel, but nonetheless a lot of drying work done, can we spell "end reactor fuel"?

MR. EINZIGER: Can we what?

CHAIR BALLINGER: The end reactor fuel program.

MR. EINZIGER: Yes, what about it?

CHAIR BALLINGER: You know well about that. There's a lot of data out there on drying. Is that being mined?

MR. EINZIGER: To the extent possible -- we know there are some drying issues. The French are seeing or have seen a large buildup of hydrogen in their transportation casks, and the only way that could possibly be happening is because of inadequate drying.

The end reactor fuel is a little bit different. There's a lot more failed fuel, but we're looking at -- I mean the purpose of this project, if it goes through, is to see whether the criteria, that's probably a bad word, whether the recipe for knowing whether you're dry is really getting it dry, and whether the variations on that recipe are getting it dry.

CHAIR BALLINGER: Do you know if they still have the canisters monitoring out there in Richland? I know they had several storage canister systems that were buttoned up and then instrumented, and they recorded basically -- recorded pressure versus time, maybe hydrogen as well. Is that still ongoing or did they just --

MR. EINZIGER: I haven't looked into it for a while.

MS. GAVRILAS: This is Mirela Gavrilas of the staff. Just a bit of clarification. We were only tasked to check the feasibility of conducting an experiment. That was -- those are the two reports that we produced. The User Need did not go any further. So it's still up to NMSS to define further work if needed.

CHAIR BALLINGER: Because there may be an ongoing experiment out at Hanford.

MR. FRANKL: Yeah. What I was going to mention is that as far as research goes, the work is completed. So I guess we definitely would appreciate a new User Need in the future if --

MEMBER ARMIJO: Now if people are loading and drying casks all the time in the industry, now don't they have to meet some sort of drying criterion that says after you've done this process, show that you've removed 99.9 percent of the water or something? Don't they have some sort of a regulatory requirement that they have to meet?

CHAIR BALLINGER: I think there's a pressure rise criteria.

MEMBER REMPE: I think this --

MR. DUNN: It depends on how the drying's done, but --

MR. FRANKL: Yeah. We will --

MR. EINZIGER: There's no mandatory requirement, but there is a procedure that was built, developed by PNNL, that was blessed by the NRC, that basically says you have to pump it down to 3 torr and can't let it pressurize of more than 3 torr in 30 minutes, and it's considered dry.

The problem is we have had canisters that had that technique, that did appear to have water in them after they were delivered, and also of course the French are having the problems, and this technique has really never been --

MEMBER ARMIJO: So it was never really qualified is what you're saying?

MR. EINZIGER: Well, the thing Sam is that you've got a tube that's 14 feet long, that's -- you're measuring the pressure on top of it, and you're making the assumption that the pressure on the top of the tube is the same as the pressure inside the cask 14 foot below. It's a small bore tool, and so there's some questions about whether you're really getting it -- getting it dry.

MEMBER ARMIJO: Well, it would seem that that's -- if you wanted to do research or verify, you'd work with those guys that are actually drying things on a large scale, and have them run variations of their drying procedure, rather than go to a university to do

a bunch of experiments that may not have anything to do with reality, either reflushing them with helium or some inert gas, giving it time for the heat to vaporize what residual water is in there.

You know, that's where you -- a practical place to do the experiments, rather than --

MR. DUNN: In the course of doing this work, we did go to both Holtec and Tien. They both have training facilities that have this type of equipment, and they can do this type of simulated drying work. So we did interact with the vendors that developed these processes.

MEMBER ARMIJO: Yeah. If anybody would know how to improve, it should be those guys, and I'd go to them and encourage them to be -- if you do go and a research program, go with the guys that are actually running these big things, instead of let a university fool around, which is what they'll do.

MR. EINZIGER: The integrated programs require that the universities have an industrial partner, and they know who those industrial partners are.

Also, in the process of their research, doing the survey of the people who are doing drying, the found out, for instance, a lot of them don't use a full length canister. They'll test their methods out on a

partial then, so they don't have the pressure differential.

So there's issues with that, and of course there's all sorts of nooks and crannies in fuel systems that can trap moisture that aren't in their test. So yes, it has to be considered, and yes, they should be part of it.

MEMBER REMPE: And also wouldn't there be -- I mean okay. You can test to see if you even dried to a certain level near the spent fuel pool. But then you take it out, put it on a pad and after so many years of climate changes and things like that, don't you see -- wouldn't moisture accumulation vary with experiencing it out in the actual environment?

MR. EINZIGER: That's the corpus of dealing with moisture monitoring in the demonstration.

MEMBER REMPE: The high burnup demonstration.

MR. EINZIGER: The high burnup test that sat on the pad over time, to see whether you get that. There are two reports here, but there was a third report done by the Center in San Antonio, that looked at what would be the issues if you didn't get the water out, and one of them indicated that over time, a few years down the road, that you might have a problem with the bound

moisture that's tied up in the crud and the oxide. So that might start evolving down the road.

CHAIR BALLINGER: We'd better get going here.

MR. FRANKL: The next project is on function and monitoring of dry cask storage systems. The objective here was to review available monitoring technologies for temperature humidity corrosion, etcetera, for spent fuel dry storage cask, and to identify where improved technologies may enhance future monitoring capabilities.

The work was initiated with the same User Need request from NMSS, and ultimately this is -- will be used to develop regulatory guidance for monitoring an evaluation of proposed actions, industry actions to mitigate degradation. The draft TLR on this subject will be published hopefully next month. Next page.

The key results are that monitoring the temperature and relative humidity on external surfaces is feasible. However, monitoring corrosion and cracking on canisters requires advances in the state of the art. On internal structures, systems and components however, monitoring does not appear to be possible with existing dry cask storage system designs.

The work is -- the research is continuing,

it's ongoing, and we will be doing more work in the area, and of course we'll be reporting from time to time on progress.

The next topic is containment liner corrosion. There were multiple objectives here. First --

MEMBER REMPE: I'm sorry to interrupt, but before you switch topics, we've talked a little bit about the high burnup demo indirectly here, and it's hard to backfit storage systems obviously, to put in instrumentation. But I guess my understanding, and this is a little off topic, and maybe we'll discuss it more this afternoon, is that there will be -- there's a need associated with that demo to validate models.

I just was wondering how one decides what's sufficient and adequate instrumentation? Is there guidance that the NRC uses? This comes up with other things too, even when we're trying to irradiate fuel, for example, and what NRC needs, and how does NRC decide what's adequate instrumentation for something like that?

MR. DUNN: Okay. For the high burnup stuff, that's probably a better discussion for this afternoon. So for the other parts of the systems that we were looking at, there really isn't a whole lot of monitoring that takes place with these dry cask storage

systems right now.

So there's not a regular temperature or a relative humidity monitoring that occurs on these things. About the only monitoring that really takes place is pressure monitoring of the bolted casks, where you're looking at the pressure between the overring seals to determine whether or not you have a seal that might be leaking.

But for the welded systems, which are 90 percent of the casks that are in service, there's no internal or external monitoring that takes place during license renewal. There's a lead cask inspection that can take place, or that's done, but there's no monitoring of temperature or atmospheric condition, or inspection of the cask to determine whether or not degradation is occurring.

So this report looked at possibilities of doing those types of monitoring. Inspection was done really with a separate effort. But the monitoring of environmental conditions and degradation that could happen, how could this be basically retrofit into these existing cask designs, and it's a challenging thing to do.

MEMBER REMPE: Yeah, and how much to do. You mean what's considered adequate, what's, you know,

not enough --

MR. DUNN: We didn't -- we didn't --

MEMBER REMPE: Talk about the existing parameters, humidity --

(Simultaneous speaking.)

MR. DUNN: Right, right, and agree with this --

MEMBER REMPE: Not a temperature, not every temperature every ten inches, but just temperature.

MR. DUNN: Right. This certainly is something that would have to be addressed, what is adequate. But at this point, the idea was to take an exploratory look at what type of instrumentation is available, has been used in existing reactor systems or other industries that might be useable in this type of system. That's as far as we went.

MEMBER REMPE: Okay.

MR. FRANKL: The next topic. The next topic is on containment liner corrosion. The objective was to develop models to calculate corrosion rates for a liner plate, by the embedded in the concrete and to develop a model to estimate the leakage from containment during a design basis loca event.

The research was initiated with a User Need from NRR for containment liner corrosion, and ultimately

will determine -- the results will be helpful in determining additional inspections of the containment liner or the need for additional inspection of the containment liner, beyond that currently implemented in accordance with the ASME code. It's Section 11, subsection IWE of the ASME code.

We had contractor support from the Center for this activity. We published two TLRs on the subject, and also had workshop backing in 2011. The key results of the research were that the corrosion cell and the liner is not likely to support both a high corrosion rate and a large corroded area in the liner.

The through-wall corrosion is -- we found that the through-wall corrosion is initiated from foreign objects left in the concrete during initial construction, you know, such as wood. The leak rate is controlled by the size of the hole, when the hole is small inside, and that the radioisotope releases would largely be restricted by the narrow gap between the liner and the containment wall, and by the permeability of the concrete.

The work, the research is complete and so the next subject is on the leak path assessment of the North Anna CRDM nozzle.

MEMBER SKILLMAN: Before you change topics

please.

MR. FRANKL: Okay.

MEMBER SKILLMAN: To what extent is the conclusion supported or not supported by a containment --. We know that the one plant had the 2 by 4 that was adjacent to the liner. There were probably others that we don't know about, and it could be that there are other locations in that same containment that had wood adjacent to the liner. But this containment and others have the ILRTs.

MR. DUNN: The ILRT data was used, or the modeling was compared to the ILRT data for that one particular incident.

MEMBER SKILLMAN: And a ten millimeter square hole is a pretty big hole. That's 3 by 3 millimeters. That's a good-sized hole.

MR. DUNN: Yeah. There have been, don't remember what the largest hole in containment has been, but that's -- we've seen holes. I think --

MEMBER ARMIJO: Beaver Valley was bigger than that.

MR. DUNN: Beaver Valley was much --

CHAIR BALLINGER: Much more. More like three inches.

MR. DUNN: Yeah. It was -- I think it was

three quarters an inch by an inch.

MEMBER ARMIJO: About the size of a 2 by 4 cross section.

MALE PARTICIPANT: Upper side of a 2 by 4.

MR. DUNN: It had a decent-sized hole. Now that hole was likely plugged up by corrosion products and other things too but -- and a paint blister over it as well, but --

MEMBER SKILLMAN: But you're saying hey, ILRT information was factored into this document.

MR. DUNN: ILRT information was used in the modeling report.

MEMBER SKILLMAN: Thank you.

MEMBER ARMIJO: But at least in Beaver Valley, I thought it was detected by blistering --

MR. DUNN: Of the paint.

MEMBER ARMIJO: Of the paint, but not by the ILRT.

MR. DUNN: Not by the ILRT.

MEMBER ARMIJO: Yeah.

MR. FRANKL: The next project was on leak path assessment of the North Anna CDM Nozzle 63. The purpose was to evaluate the ultrasonic testing UT, to detect a primary leakage path between the reactor operator head penetration and the reactor pressure

vessel head.

The work was initiated with a User Need from NRR, and the results are expected to have the staff interpret and evaluation licensees' ultrasonic leak path assessment. We had published a NUREG CR back in 2012 on this subject, and we used contracting support from PNNL.

The key results of the work were that leakage path detected by the UT was confirmed by destructive examination. So we are confirming that the UT examination was successful. The pattern of boric acid deposits observed was in agreement with the destructive examination, and that minimal corrosion of the low alloy steel reactor pressure vessel had -- was observed.

MEMBER RICCARDELLA: This was a replaced head, so you were able to --

MR. FRANKL: This was the original head.

MEMBER RICCARDELLA: The head that was replaced?

MR. FRANKL: Yes. This was the original head, with alloy 600 nozzles. The next topic is on irradiation-assisted degradation, and here the objective was to develop the technical bases for assessing irradiation-assisted degradation of core internals, and potential synergistic effects between

thermal and neutron embrittlement in cask austenitic stainless steels.

The User Need for this activity came from NRR, and ultimately this will help evaluate effectiveness of the aging management programs, as required by NRP-227A. This is a very large -- has been a very large undertaking.

So we've -- we had a contracting support and cooperation MOU with EPRI, and contracting support from ANL as well as INL. There's a typo on that page. PNNL was not involved in this activity.

Three TLRs and one NUREG CR were produced, and the key results so far are that under PWR conditions with, I guess, low corrosion environments, both code work and non-code work, non-code work stainless steels exhibited increasing stress corrosion crack growth rates with increasing fluence levels from 5 to 25 displacements per atom.

The fracture toughness of the same stainless steels decreased with increasing fluence, up to 8 dpa, and the thermally aged. When we took thermally aged stainless steel samples, and exposed them to relatively low dose neutron dose irradiations up to 0.08 dpa, the fracture toughness decreased, in addition to the decrease that happened due to the thermal aging.

The work is ongoing and our goals is to further irradiate samples that will be coming out -- that are coming out of the Zorita reactor, and do additional hot sell -- we are continuation the hot sell exams at ANL, and we are also working on benchmarking, if you will, the ATR reactor at INL for the -- for accelerated irradiation, over and beyond what was accumulated in reactor, in commercial reactor.

CHAIR BALLINGER: This is not in your slides, but it was in some of the materials provided, where if you looked at the effect of just plain water exposure on toughness reduction at temperature, in other words, this so-called environmental toughness issue, because that's a baseline unirradiated completely, there's some indication that just exposure to water for over a few thousand hours results in a reduction in toughness. So that's mentioned as a topic in some of the write-ups that we have, but it's not here.

MR. FRANKL: Yeah, water effect on toughness. Sri, do you have any -- could you add anything on did we look at water. Would you come to the microphone?

(Off mic comments.)

MR. RAO: I want to hear his question.

CHAIR BALLINGER: Okay. This is an effect

-- this is dealing with the effect of radiation on toughness reduction, but for stainless steels, welds in particular that I have experience with, just exposure to water itself, just no radiation damage at all, after a certain period of time when you measure the in situ toughness or resistance to tearing, however you want to define it, there's a reduction in some cases. So is this factored into this?

MR. RAO: Yes. In fact, you know, talking about --

MALE PARTICIPANT: Microphone.

MR. RAO: This is C. Rao from NRC. Yes. In the modeling itself, when you compare to air measurement, there is a decrease. And also thermal aging also decrease. There is no radiation. But this is basically what we're looking at is in a realistic sense, if you have a cask material subjected to radiation in the reactor, you have concurrently both thermal as well as radiation effects are happening.

So for that form, what we did was we thermally aged them to such a -- definitely we're sure that that it reached the saturation, like 10,000 hours. As you mentioned, roughly about 2,000 hours almost it reaches the plateau.

So we wanted to make sure it went to 10,000

hours. Then we put those samples in the reactor and right now we are trying to do water -- we already got the samples out and test it at 0.08 dpa, which is actually a beginning to where we can see whether there is really effect of radiation, and another set of samples at 3 dpa, which are already thermally aged samples.

We found even the small dpa, it is not the same degree of thermal aging, but some extent it does.

CHAIR BALLINGER: I want to make clear, it's not even thermal aging that's an issue. It's just water exposure and high temperature.

MR. RAO: Yes. We are -- actually, we have done that testing in both PWR conditions and also deoxy water, D water. It's control. That's how we're testing --.

CHAIR BALLINGER: And that's part of this program?

MR. RAO: That's right, of course.

CHAIR BALLINGER: Okay.

MEMBER ARMIJO: Just for curiosity, what are the cast stainless steel components that are used in the core internals of PWR?

MR. DUNN: Cast?

MEMBER ARMIJO: Yeah. Apparently, this is a program on cast austenitic stainless steels. So what

are the particular components of concern?

MR. CHERUVENKI: So this is Ganesh Cheruvenki. I work at DE and RR. We deal with the internals. The lower support columns for Westinghouse are made of cast austenitic stainless steel CF-8. The delta for light content could go up to 18 percent reported.

So there is a potential on these lower support columns, which is designed by Westinghouse, is not only prone to the neutron environment, it's also subject to IACC.

So we have a multiple aging degradation attacking the lower support column.

MEMBER ARMIJO: Are those materials susceptible to formation of sigma phases as well?

MR. CHERUVENKI: Sri can answer that, sir. I don't think so. Thermal I'm recommending is only formation of the spinodal decomposition. But Sri can elaborate on that.

MR. RAO: Well there are several mechanisms actually. You can have the chromium depletion coming at the grain boundaries.

However, if you look at the microstructure, very high resolution microstructure, you have many different components, I mean different types of

precipitants form, and they degrade, depending upon the situation.

So it's a complex process. So basically the handling the spinodal decomposition of that alloy in the precipitation, and in fact another thing is we have actually three type of austenitics: cast steel, particularly low-moly and high-moly, CF-8M. Once you introduce moly, it's a different ball game.

MEMBER ARMIJO: Yeah, I know. All of these -- all the sigma phase forming the molybdenum, chromium. If you have enough of that, you can start getting very complicated.

MR. RAO: That's right. I mean all those things -- in fact, actually, originally I thought I would have more slides, but it's much more basic fundamental research point of view.

MEMBER ARMIJO: Okay, thank you.

MR. FRANKL: The next topic is on primary weld stress corrosion cracking. The objective was to evaluate the use of high chromium alloys and weld methods, using replacement components and repairs for PWSCC mitigation.

An NRR User Need initiated the activity, which was an extension of a prior User Need also from NRR. The regulatory -- excuse me.

MR. BURKS: I think those are backwards.

MR. FRANKL: Oh, those are backwards. Sorry, yes, sorry. The objective was to -- the regulatory use will be to develop safety evaluation criteria on nickel-based primary system pressure boundary component, subject to PWSCC degradation.

We produced two NUREG CRs, as well as a TLR in 2012 and '13. The key results of the work are that Alloy 690 is strongly resistant to PWSCC and less subjected to code work. Alloy 690, weld heat affected zone, also appears to be resistant to PWSCC.

The Alloys 52 and 152 were weld metals are more resistant to PWSCC, compared to Alloys 82 and 182, and that this similar method of dilution zones may be susceptible to PWSCC. The work is ongoing.

MEMBER ARMIJO: Could I just go back to that last presentation. Aren't the tie plates, at least in BWRs they're called tie plates, where the fuel assembly upper and lower tie plates in PWR. Are those castings or forgings?

MR. DUNN: I don't know the answer to that. Somebody else would have to answer that.

MEMBER ARMIJO: In the BWRs, they're castings. So if I was going to look for thermal degradation and aging of cast austenitic stainless

steels in castings --

MR. DUNN: You're talking about the irradiated-assisted degradation?

MEMBER ARMIJO: Yeah, okay.

MR. DUNN: Okay.

MEMBER ARMIJO: I just wanted to say, if you're looking for thermal or irradiation or environmental degradation of cast stainless steel components, if the tie plates of the PWR assembly are castings, that would be very convenient to have a lot of data available.

MR. FRANKL: Yeah. We will get back to you on that.

MEMBER ARMIJO: Yeah, okay.

MR. FRANKL: The next topic is subsequent license renewal. This was -- the objective was to support the development of regulatory framework for licensing a second period of extended operation from 60 to 80 years, with -- this was with a User Need from NRR, and ultimately the results, we'll have the User office to develop subsequent license renewal guidance-based documents.

The work was -- we needed contracting support from Oak Ridge and ANL, and also had MOUs with EPRI and DOE for sharing the information. We produced

two TLRs, one on aging management program effectiveness audits and the evaluation of the International Periodic Safety Assessment's PSRs.

The key results of the work are that licensing review guidance documents will be revised, because of the audit results at three plants. However, no generic conclusions can be drawn from only three of these -- only three audits.

The review of the PSR lessons learned show no deficiencies or shortcomings in the reactor oversight program or licensing renewal process. We are continuing the work, and we are expecting new User Need from the User office.

The next topic is on expanded material degradation assessment. This is to identify knowledge gaps and research needs to materials degradation for plant operation up to 80 years. The work is supported with a User Need from NRR, which expands on a prior User Need from the same office.

This work will help the User office develop technical input for regulatory reviews or potential subsequent license renewal applications and prioritize NRC research needs. We have contracting support from Oak Ridge. This was an extended undertaking, in terms of level of effort. So the work co-funded by the DOE

Light Water Reactor Sustainability program.

We produced five, so far five draft NUREG CR reports, which we expect to publish in June 2014, and these would be on core internals, aging of core internals, reactor pressure vessels, concrete civil structures, as well as cables and cable systems. Next slide.

The key results of this work are that we have -- we have -- there are no surprises or new mechanisms identified by expert panels, and that additional information is needed to address the knowledge gaps for subsequent license renewal, such as in the areas of irradiation-assisted degradation, which we talked about earlier.

The experts are in good agreement about what issues should be addressed further, and there is general consensus regarding long-term degradation mechanisms. The work is nearly complete and as I said, will be published by the middle of the year.

CHAIR BALLINGER: I would question the words "no surprises." Surprise is by definition something we don't know about.

MR. FRANKL: Yeah.

CHAIR BALLINGER: So to say that there are not going to be any surprises, you may postulate that

there won't be any surprises, but I don't think we can say there won't be any surprises.

MEMBER ARMIJO: In this assessment, do you include the use of new materials in the new reactors as part of your assessment?

MR. FRANKL: I believe Srini, would you please come to the microphone.

MS. GAVRILAS: This is Mirela Gavrilas from the staff, and I can take that. Now this was limited to the current fleet. There might have been some discussions, but ancillary to the main topic.

MEMBER ARMIJO: Well, I believe it should address all the licensed reactors, whether they're operating yet or not. We have four PWRs, APWRs.

MS. GAVRILAS: That's a very good suggestion, but this effort was to support subsequent license renewals. So the target was 60 to 80 years of operation in the current fleet, and if I may also address Professor Ballinger's surprises question, that slide --

That bullet meant to say that the expert panels did not surprise the staff. That's all that that said. There were nothing that they -- that rose to their attention or they brought to our attention that surprised us. They were things that we knew about.

MEMBER ARMIJO: You know, my problem is

that we're building eight PWRs in the United States. They're using new materials in the pump, high manganese stainless steels, which we don't know a lot about. They're used in a situation where they're not inspectible, and they're in retaining the flywheels, very heavy, high rotational speed.

And that -- that is a concern and the ACRS has written a couple of letters and exchanged information with the staff. I believe there is certainly a research information gap on those materials, and I would expect that the expanded materials degradation program wouldn't limit itself entirely only to what is currently operating, but also what is being built.

So I think you may want to consider adding an addendum or something for anything that's new, that you have no experience with or experimental work, to confirm the suitability of the material.

CHAIR BALLINGER: At least to define a gap.

MS. GAVRILAS: We'll take -- we'll engage NRO in discussions. So far we haven't heard from them. So this was an NRR User Need, came up as NRR several years ago. I think it was in 2010, and since then nobody added anything to what research had to do.

But we'll engage NRO in discussion and see if we can follow up, if there's anything that they want

us to follow up on.

MEMBER ARMIJO: Yeah, because I think the problem there is if it was an inspectible component, just okay, it's another material. We'll be able to see if something's starting to happen. But something that's designed for the life of the plant, you should have a good database that says it's capable of achieving that life without flying apart, and causing a high energy accident.

MR. THOMAS: Brian Thomas, deputy director of the Division of Engineering Research. Just a quick question. You mentioned that an ACRS letter was written to that effect. Was that specific to the EMVA (phonetic) program?

MEMBER ARMIJO: No. It was related to a part -- I think it was related to the APWR review.

CHAIR BALLINGER: Right.

MEMBER ARMIJO: And it was the retaining ring on the flywheel. It's very complex. It's a brand new component, and we have concerns about the lack of inspectability of those components, and the assumption that they could be protected from the operating environment by a thin 36 -- Alloy 625 thin can around them for 60 years.

The limited amount of testing done by Westinghouse indicated the material was susceptibility

to stress corrosion cracking if that 625 can leaked. But and that's all the data we have. So ACRS was concerned about that, and the staff said well, we don't think it's going to crack.

So they basically told us to pound sand. But I'm telling you you guys in research ought to take a separate look at that.

MR. THOMAS: Thank you. We'll definitely look into that. You also mentioned plumbing-related components that might be used in new reactor applications. I thought I heard you mention that. Is that also addressed in that letter?

MEMBER ARMIJO: No, no. Plumbing? I don't think -- I didn't mean to mention that. But if I did --

MR. THOMAS: Oh, I thought I heard it mentioned.

MEMBER ARMIJO: No. It was really focused on new materials. Anybody using new materials and they don't have a really solid database or experience base, either for foreign plants that have used it experimentally, that's where you get into trouble, that you don't know.

These are complicated environments that they have to work in, and there's no substitute for

testing.

CHAIR BALLINGER: Okay. I'm operating on the assumption that we can probably stay until noon. We're probably going to get shot for doing that, but we do need to get moving here.

MEMBER ARMIJO: Yes.

CHAIR BALLINGER: Yeah.

MR. MAKUTESWARA: Quick response to both things. One, with respect to the new materials, the NRC staff is also cooperating with the Department of Energy Light Water Sustainability research, and there they are looking at new materials degradation.

So we will keep our eyes tuned to the program as a part of that, and then let the staff be aware of it as we go along for the new materials. My second comment is with respect to the no surprises thing, and what Mirela said is correct.

An example is the radiation late-blooming phases that could cause potential effects and so forth. So we are being -- the MDA also brought that forth, and that is the subject of the second bullet, in the sense that we need additional information and things.

For that also, DOE LWRS program is continuing to do research and the staff will keep our ears and eyes open for the ongoing results, and also

participate in the direction of the program as much as we can.

CHAIR BALLINGER: Okay, thank you.

MR. FRANKL: The last project, and last but not least is the project on steam generator research. The objective was to bolster the technical bases for steam generator non-destructive evaluations to the integrity, and consequential steam generator tube rupture.

The work was initiated with a User Need. In 2012, on steam generator inspection and integrity issues, which builds upon research conducted with previous User Need, including the ones on consequential steam generator tube rupture. This research will support the technical evaluations of the licensee submissions and inspections of steam generator tubes.

We have used ANL for many years, and we'll continue to use ANL. Have seven draft NUREG CR reports, and one draft TLR under staff review now, and we listed all of these reports here, as well as on the next page.

The preliminary key results of this research is that industry inspection and integrity models are often confirmed by NRC-sponsored research, and periodically research results in changes to industry guidelines or practices, and we provided here three

examples, one on leakage models.

The research found possible issues and the industry changed the guidelines. On pressurization rate, it was observed that the rate can affect the burst pressure. This led the industry imposing limits on pressurization rates for in situ as well as laboratory tube pressure testing.

In the area of non-destructive examination, the analyses under this program led the industry to new work on in-service inspection and data acquisition. As I mentioned, the work is ongoing, and we plan to continue this activity. So that basically concludes the overview of the branch projects, and Darell Dunn will be presenting details on stress corrosion cracking in the storage casks.

Stress Corrosion Cracking

MR. DUNN: Okay, all right. So my name is Darell Dunn. I was -- I'm with the Corrosion and Metallurgy Branch in the Division of Engineering and Research, now moved over to Structural, Mechanical and Materials Branch in the Spent Fuel Storage and Transportation Division in NMSS.

So what I'm going to talk about is something that's still near and dear to me. So a little bit of background material. Austenitic stainless steel is

susceptible to stress corrosion cracking in chloride-rich environments and in marine atmosphere. There's plenty of information that's out there to support that.

We are aware of some -- of the work done by the Japanese Central Research Institute for the electrical power industry, CRIEPI. This slide says since the early 2000's, a big chunk of that work was done in that time frame. But they have work actually going back into probably about the mid-1980's.

EPRI also produced some topical reports in the mid-2000's that identified the potential for atmospherics stress corrosion cracking of austenitic stainless steels, and I mentioned in one of the earlier comments the plant operational experience with SEC for outdoor stainless steel tanks and piping systems located in near-coastal environments that occurred in the U.S. and internationally since the 1990's. That information notice is actually listed in the back of this presentation. I think it's 2012-20.

MEMBER ARMIJO: Darell, do you know what the Japanese, if they use the austenitic stainless steels for their dry casks as well? I believe they do, but I'm not sure.

MR. DUNN: Yes, they do.

MEMBER ARMIJO: But they also put them in buildings.

MR. DUNN: That's correct.

MEMBER ARMIJO: So they're not really completely exposed. They're not airtight --

MR. DUNN: They have a different exposure condition than what our systems have.

MEMBER ARMIJO: Yeah.

MR. DUNN: Okay. So previous to NRC research, there was a NUREG CR published in 2010 that had some of the initial work that was done in this effort, and in that work, testing was performed using 304, 304-L, 316-L, U-bend specimens. There was a technique developed to deposit simulated sea salt on the surface of these specimens, without inducing cracking.

During the deposition process, we did a lot of testing to verify that was in fact the case, and then we did exposures at different temperatures, simulating a long period of time out on the ISFSI pad. So the temperatures of exposure were 43, 85 and 120 degrees C.

Cracking was only observed on specimens that were exposed at 43 degrees C. At the elevated temperatures, the relative humidity was low enough that we did not get deliquescence of the deposited sea salt. But at 43 degrees C, the relative humidity was high

enough. Deliquescence occurred. We had the formation of a near-saturated chloride solution, and cracking was observed on the U-bend specimens. Next slide.

So the motivation for the current research is there were some differences. When we started talking to CRIEPI in more detail, there were some differences that were identified in the previous work and the NUREG CR 7030, and some of the CRIEPI work. CRIEPI did some work with some very low chloride concentrations, and still was observing cracking.

They also observed cracking at lower relative humidities than was previously tested in some of the NRC-sponsored work, and even lower stress values. Specimens which were stressed to even values below the yield strength of the material, they were still getting cracking.

Some of the other motivation was this was an important degradation scenario that was identified in the NRC identification and prioritization of technical information needs, with affecting potential regulation of extended storage and transportation of nuclear fuel. That's the 10 report (phonetic), which was made available for public comment in May of 2012, and of course this was driven by a User Need from NMSS on extended storage and transportation Regulatory program review.

So the scope of this revised program, we used contractor support for the Center for Nuclear Waste Regulatory Analysis. This testing was done over a period of two years, from October 2011 to October 2013. I don't know that I'm going to go into detail on all the testing that was done here, but this slide identifies the type of work that was done.

With chloride salts, and again, focusing primarily on simulated sea salt. We did deliquescence measurements to determine at what relative humidity we'd get enough water absorbed in the salt to form a chloride solution, that would potentially make the material susceptible to stress corrosion cracking.

We did test under conditions with cyclic humidity, but in this particular revised work, we used humidity values that would be easily obtainable in the natural environment. Some of the previous testing that we had done, our absolute humidity values were very high, in order to get the relative humidity values up to where we could get deliquescence to occur.

In this particular, we used absolutely humidity values that were at maximum what you would observe in a natural system. So about 30 grams of water per meter cubed of air is typically about the maximum absolute humidity that you see.

Now the relative humidity, of course, depends on temperature. But that's the maximum absolute humidity.

MEMBER SKILLMAN: Is that a marine fog? Is that what that is?

MR. DUNN: No, and that's not a physical limitation either. That's just an observation that when we look at weather. NOAA had published weather station data for multiple stations, and that happens to be about the maximum absolute humidity that you observe in a natural system.

But it's not a physical limitation. You could actually potentially get much higher absolute humidity values that would be rough environments for people to survive in. But it is physically possible to achieve those.

MEMBER SKILLMAN: Thank you.

MR. DUNN: We did do some tests with elevated temperatures. Again, I mentioned that we didn't get tests, cracking at 85 degrees C in some of the previous tests. So we actually looked at temperatures sort of in between 30 and 80 degrees C in this work.

We did do some work with high humidity, because at high humidities we could potentially have deliquescence and even dilution of the salt that's

deposited on the surface.

So we wanted to look at the effect of that, and of course I mentioned the strain values. The original tests were done with U-bend specimens, where we had 14 to 15 percent strain.

We did use U-bend specimens in this test as well, but we also used some C-ring specimens, where we had strain values as low as 0.4 percent. So just above the yield strength of the material.

We did look at some non-chloride species that you might expect to occur from other processes, other industrial processes or agricultural processes or atmospheric deposits.

We also performed some deliquescence measurements, and we did exposures with specimens that were only salts with no chloride, and then other exposures with mixtures of non-chloride and chloride-based salts that might occur under some situations, and we have drafted a NUREG CR, 7170, and this is currently in review, and we expect it to be published early this year.

Okay. So the cyclic humidity testing. Again, we limited the absolute humidity values to something that we would actually expect to observe in a natural system. We did vary the test temperature of the

specimens, and we also looked at variations in surface chloride concentration and material condition.

By "material condition," I mean we had some specimens that were as-received. We had some specimens that were sensitized to simulate a weld heat-affected zone, and then we actually had some specimens that were in the as-welded condition.

So the methodology here was to deposit difference, three different concentrations of salt onto the specimens, and we picked these concentrations because some of the CRIEPI work had indicated that a critical chloride concentration was about 0.08 grams per meter squared. So that would -- if we're looking at the sea salt concentration, that's about the middle value, about one gram per meter squared of salt.

That's what CRIEPI had indicated was sort of a threshold concentration, where they, you know, above which they would take backing and below which they weren't. At 0.1, it's very difficult to put less than 0.1 grams per meter squared of salt on a specimen repeatedly, and in fact the specimens in those cases don't really look like they have too much on them.

But you still see quite a bit of metallic luster, and of course at ten grams per meter squared, they got ten times the amount of salt that CRIEPI had indicated

was a threshold. So in that case, we should easily see cracking.

We did this by exposing the specimens that were heated to short cycles of salt fog, so that the fog would descend upon the specimens, evaporate and deposit as a solid salt, and not form a liquid and initiate cracking during the deposition process. We determined, you know, the amount of salt that was deposited using specimens that were weighed before and after the deposition process.

The sensitized specimens were done for two hours at 650 C, and our test chamber was operated at absolute humidity conditions between 15 and 30 grams per meter cubed. So given the temperature, that later -- the relative humidity under those conditions depends on temperature, and that's shown in the following slide in the table.

So when the -- at low temperatures, at 27 degrees C, when we're at the low absolute humidity value, our relative humidity is still 56 percent, and then when we're at the high absolute humidity value, we're at a relative humidity of 100 percent. So this shows the test results for these -- this cyclic humidity exposures.

At the low temperature we didn't see stress corrosion cracking, but at the higher temperatures and

in relative humidity ranges that are listed here, we observed stress corrosion cracking.

The last column here shows the lowest salt concentration where stress corrosion cracking was observed, and for the specimens tested at 35 and 45 degrees C, we got cracking observed on specimens that had very low salt concentrations, about ten times less than what was previously reported in some of the Japanese studies.

So the pictures at the bottom show the actual appearance of the specimens. These are U-band specimens that are mounted in a chamber. They're actually sitting on a cylindrical heater that's been isolated with Teflon, and the top picture here, with lots of rusty spots on it, shows the ten gram per meter squared of salt; middle is the one gram per meter squared; and the bottom, which you can almost see of the metallic lustre of the specimen, still has 0.1 grams per meter squared of salt.

The middle picture shows a cross-section of this, one of the specimens with the lowest salt concentration, clearly indicating that we've got stress corrosion cracking propagating from the surface, going through the specimen. You see the branching of the crack as it propagates through the microstructure.

Then at the high salt concentration, as you might expect from the first picture there, we got a combination of cracking and pitting, and that's why you see these large rusty spots on those specimens. Next slide.

We did do some tests with elevated temperature exposure, up to about 80 degrees C. CRIEPI had indicated that they had -- were able to get stress corrosion cracking at that temperature, and in order for that to occur, the only component of sea salt that would have deliquesced at that temperature in a realistic absolute humidity value would have been calcium chloride.

There's very little calcium chloride in sea salt. There is some, but it's a very small component of sea salt. There's much more magnesium chloride, but at these relative humidities, magnesium chloride would not have been expected to undergo deliquesce.

So the results here are shown in the table. In this case, we used ten grams per meter square of sea salt, using again, U-band specimens and different humidity values at 60 and 80 degrees C. And we kind of took the approach here that we would do some accelerated testing and see if we could get stress corrosion cracking to occur, even if we had to use some non-realistic

conditions.

So you'll see here in this absolute humidity column that we've got absolute humidity values that are way above, in some cases, way above 30 grams per meter cubed of water and air.

In those cases, we certainly get cracking. But the first case here for the 60 degree C, 22 percent relative humidity and 29 grams per meter cubed of absolute humidity, we observed no stress corrosion cracking in that case.

MEMBER SKILLMAN: Darell, let me ask you back up and compare two slides. The slide that shows the test results with the -- that slide, 62 please.

MR. DUNN: Yes.

MEMBER SKILLMAN: And back up please to 58, I think it is. Back one more.

MR. DUNN: Yes.

MEMBER SKILLMAN: It seems as though the data that is presented in this slide is contrary to the one where you showed the specimens. For example, in this slide, 43 degrees Centigrade samples all show stress corrosion cracking, whereas in the test results on the later slide, the results are just the opposite.

I don't understand it. Here you show no stress corrosion cracking 120 C and 85 C, but you do show

stress corrosion cracking at 43 C.

MR. DUNN: Right.

MEMBER SKILLMAN: So if you move ahead several slides --

MR. DUNN: To 62?

MEMBER SKILLMAN: Yes please. One more. In that particular case, in the top column, in the top matrix you show the cooler temperatures with no stress corrosion cracking, and at the higher temperatures, stress corrosion cracking.

MR. DUNN: Right.

MEMBER SKILLMAN: I'm confused.

MR. DUNN: Okay. First of all, all of these temperatures are less than 85. At 85, our relative humidity value is just too low to get stress corrosion cracking to occur. You can't get deliquescence of the salt at that temperature, unless we really drive the absolute humidity to just completely unrealistic values, okay.

So all of these temperatures here are really well below 85 C, and in the first slide here, the results are consistent, with the exception of the first slide. What we think happened there in that first row or 27, is that you're getting deliquescence of the salt, but you're always at a very high relative humidity.

Basically what's happening is the salt is draining off the specimen. There's nothing to contain -- this salt is deposited on the specimen as a dry deposit, a very thin dry deposit, and so if we get deliquescence and we're always at a high relative humidity, the salt deliquesces, it forms liquid and it can drain off the specimen, and then, you know, we basically don't have the exposure to the chloride solution anymore, because it's all drained off.

That's what we believe occurred on this particular specimen. Now if you go to higher temperatures, 35, 45, 52, we're getting stress corrosion cracking to occur. So in that case, it's at least consistent with the previous observations.

MEMBER RICCARDELLA: And the higher the temperature, the more -- the higher concentration you need to get the cracking right?

MR. DUNN: That appears to be the case.

MEMBER RICCARDELLA: Which would be consistent with your earlier slide.

MR. DUNN: Probably because we're -- when we go to the higher temperatures, at lower temperatures, when you get at 35 degrees, for example, the deliquesce relative humidity of sodium chloride's about 75 percent. So at 35 degrees, we've gotten deliquesce of pretty much

everything, when we're at the high relative humidity value there.

All the components of sea salt, all the chloride components of sea salt, calcium chloride, magnesium chloride, sodium chloride, we've got deliquesce. We've got a lot of chloride available there. So 0.1 grams per meter squared may be all we need.

When we go to the higher temperatures, 60, the only thing at that -- the only chloride species in sea salt that's going to deliquesce at 23 percent relative humidity is going to be calcium chloride, and that's a very -- again, a very small component of sea salt, a small fraction of the amount of chloride in sea salt.

So you've got to have a lot of sea salt present, have enough calcium chloride to get stress corrosion cracking to occur.

MEMBER RICCARDELLA: Thank you.

MR. DUNN: Okay. So I think we're at 64. Okay, so this shows the results of the high temperature test, some of the specimens and some of the cross-sections. Again, sensitized specimens at 60 degrees C, at 30 percent relative humidity.

You can see the appearance of the specimen and the cross-section showing the cracking that are

actually circled with the red circles here, and at the highest temperature here on the far right, the sensitized 80 degrees C specimen with 28 percent relative humidity, we also observed cracking in that case.

Okay. So one of the -- again, one of the key differences between the original work and the Japanese work was the amount of strain on the specimens. So in order to evaluate that, we used C ring specimens, where we could strain the specimens.

We could actually equip those specimens with strain gauges and then systematically strain them, so that we had a controlled amount of strain in the specimens without plastically deforming them.

It turns out that we can, you know, we tried to vary the strain to get a higher value than 0.4 percent. We originally had an idea that we could go higher, but if we strained the specimens too much, then actually the legs of the specimens start touching and that's the end of that. So that's the maximum you can do.

So we did testing at 0.4 percent and 1-1/2 percent, again measured with a strain gauge, and the specimens were exposed to different temperatures. We used a fixed, absolute humidity of 30 grams per meter cubed. So that gave us relative humidity values of 72 percent at 35 degrees C, and 32 percent at 52 degrees C.

So the next slide has the test results. It shows the test temperature, relative humidity values and salt concentrations and strains, and again, we observed cracking in some cases with low strains and generally, at the lower temperatures, we took a little more salt to get this to occur, and of course the sensitized materials were more susceptible to cracking than the as-received materials.

But if we go to high enough temperature and we have, you know, a decent amount of salt present, we can still get the as-received material to undergo cracking in that case. Okay. So got a few more slides.

We looked at non-chloride bearing species. These would be species from industrial, agricultural or commercial activities, where we did a literature review and looked at the possible species.

Most of these are ammonium salts, ammonium sulfate, ammonium bisulfate, ammonium nitrate. You can see the representative set of species that were selected for testing.

We also included fly ash, which has actually a much different composition than any of these other deposits, and here we did testing with 304 stainless steel U-band specimens. Test results are shown on 68. Basically, the sum of this is if we don't have chloride

present on the specimens, we don't get cracking. That's probably a good result.

The only thing that was really kind of interesting is with the ammonium bisulfate. When you get deliquesce of that particular salt, it's very acidic. pH is probably less than 1, or close -- well, it's listed here as being even negative values.

You see that specimen here at the bottom right of the slide. It's black. It's got a lot of oxide on the specimen, and it has undergone a fair amount of corrosion, but no cracking in that particular case.

I don't -- I had mentioned here in the outline that we did some work with specimens with chloride and non-chloride salts mixed together. I'll just summarize that. When we have chlorides present, you get cracking, and even if we add, you know, things that are nitrates, that you might think would be an inhibitor to localized corrosion processes, we still get cracking of the specimens in those cases. Okay.

So conclusions. For simulated sea salt, we get stress corrosion cracking of stainless steels, but in a temperature range from about 35 to 80 degrees C, when we have a relative humidity that's high enough to get deliquescence of the sea salt, or at least some of the components of sea salt to occur, and at lower

temperature, that relative humidity can be reached when we have an absolute humidity value that's below 30 grams per meter cubed.

So this is a realistic condition for getting, having material be exposed to these conditions, and getting cracking to occur. We observed cracking at very low salt concentrations, about ten times less than what the Japanese observed, and at very low strain values that, you know.

So we haven't done testing under conditions that are unrealistic. We would fully expect to have residual strains about 0.4 for some of these dry cask storage systems.

CHAIR BALLINGER: 0.4 percent.

MR. DUNN: 0.4 percent, yes. Oh yes, yes. Good catch. The sensitized material is more susceptible to stress corrosion cracking than material in the as-received condition. I don't think that's a surprise, and no stress corrosion cracking was observed for specimens exposed to the non-chloride bearing species.

So regulatory use will be for safety evaluations for initial, and license renewal of site-specific storage facilities. In cask systems, with certificates of compliance that can be used in a variety of locations. I had mentioned the information

notice that we put out in 2012. I don't think we necessarily have plans to update that, but that's a possibility.

We do have a public meeting on January 24th. It's part of this risk-informed resolution protocol for chloride stress corrosion cracking. This was originally a meeting that was supposed to happen on December 10th, and had to be cancelled because of the inclement weather.

But that meeting will take place and it will be a public meeting, and we will be discussing the results of this work with industry. We're still participating in the EPRI-extended storage collaboration program, where you know, they've -- there is ongoing work by industry here, including looking at some of the dry cask storage systems as they go through the license renewal process. I think I'm mostly on time.

Q and A

CHAIR BALLINGER: Well, pretty much. Are there any questions from the group?

MEMBER RICCARDELLA: Can I ask something? What's the typical operating temperature of the welds on these canisters?

MR. DUNN: Yeah. The temperature is dictated by the maximum cladding temperature. So it

depends on how the cask is loaded. But initially, with a large cask with a fairly high heat load, we can be at temperatures on the surface of the canisters that might be high enough, where deliquescence could not occur.

But if we go out, of course, longer in time, they'll be decay and the temperature of the cask will decrease. One of the things that was done at Calvert Cliffs during that inspection was to attempt to measure the temperature of the actual canister there.

That was a fairly old, I think it was about 17 or 18 years old, and it was a fairly low load. So its temperature was below 80 C. I don't remember the exact number. There was an issue with how they were trying to measure that. But its temperature was within the range where we could potentially have deliquescence of deposited sea salts.

MEMBER RICCARDELLA: And I'm assuming the only place we're really concerned is at the closure welds, or the other welds of concern also?

MR. DUNN: None of the welds in the canister are mitigated. So there's no solution heat treatment, no other residual stress mitigation that takes place. So you'll have a longitudinal weld down that xis of the cask, and most of them there also will be a circumferential weld, where the two plates are welded

together, and then of course you have the closure, the plate at the bottom and plate at the top for a closure weld.

So there's all of those welds we would at this point say would be equally likely to be susceptible.

MEMBER RICCARDELLA: And there's no temperature monitor? I assume temperature monitoring wouldn't be that difficult a thing.

MR. DUNN: There is currently no temperature monitoring of the welded stainless steel dry cask storage systems.

MEMBER RICCARDELLA: They're inside concrete casks, so you can't --

MR. DUNN: Yes.

MEMBER RICCARDELLA: --just go shoot them with a infrared.

MR. DUNN: Right. Well, there's other problems of doing infrared, and doing infrared of shiny metallic surfaces doesn't work very well to begin with, and there are potentially ways to measure temperature.

You know, obviously temperatures are monitored inside reactor systems. So the technology exists. Retrofitting those into the existing dry cask storage systems would be the challenge.

MEMBER ARMIJO: Has industry done anything

to propose some sort of mitigating, literally washing them down periodically or covering?

MR. DUNN: At this point, there has not been a proposed mitigation.

MEMBER ARMIJO: Are they waiting for them to crack? Because then the next step is how deep is the crack, and will it peak, and all of that sort of stuff. Do we think somebody would take some initiative and look into the potential for --

MR. DUNN: Well, industry is active in the area. So they know that this is an issue. Obviously, this is part of this risk-informed resolution protocol that we're talking with industry. They had developed a plan to do assess whether or not material would be susceptible, and we're continuing to discuss that with them. I think when they get the results of this, they will probably have to think a little more.

MEMBER ARMIJO: A lot depends also on the orientation of these casks. Some are horizontal, some are vertical. I would think if they were longitudinal welds, in effect it was probably whatever condenses on it just runs right off.

MR. DUNN: And actually what little data we do have would suggest that the deposition of chloride, as you might expect on horizontal surfaces, you can get

more chloride deposited there versus a --

MEMBER ARMIJO: Yeah, a rounded, horizontal surface.

MR. CSONTOS: So a couple of comments here.

MR. DUNN: Yes.

MR. CSONTOS: This is a success story for us. I'm from NMSS, and we've been dealing with this issue for a while, doing experiments and what-not. Industry, at the last estate meeting which was in December, December 8th I believe, they had the failure modes and effects analysis report that came out.

They're going to be publishing that. That has a lot of your questions that you asked, Sam. With the horizontal surfaces, they have some evidence or some swipes from Hope Creek and Calvert Cliffs. Hope Creek actually had some pollen in it and some seeds in it.

So there are, you know, they have some of the data. But the good thing here is that at that estate meeting, the failure modes and effects contractors all indicated that this is now they consider it an issue for some plants in the years, in single year time frames, not into the decades.

You know in the past, you know, when this started what seven years ago for this project, six, seven years ago, we were in this state of we believe it could

happen, and industry said that it couldn't happen.

And we went through this IRP program. We're going to close that program at the July 24th meeting, public meeting, because of this work and the industry's own work. So it's a success story that this research has supported us in the regulatory frame, you know, where we are, to address this issue.

MEMBER ARMIJO: Well you know, if the containers had been kept hot, you know, you can't get stress corrosion cracking without a liquid phase. You have to have an electrolyte, and if they were stayed above your 80 degrees or 100 degrees C, nothing's going to happen.

But these things eventually cool down, okay. When you put them in a marine environment, there's just no question you're going to have enough eventually do to some cracking. Whether it will actually cause a leak in the container, that's a lot more work.

But why take the risk and why all the, you know, the cost? Eventually, you'll have to pay a cost for inspection or repair or replacement or analysis. And the other thing, for marine environments, why in the world didn't they just use carbon steels?

They won't stress corrosion crack. They'll look ugly, they'll pit, but that's not very deep.

So you know, and I believe there are some carbon steel casks.

MR. DUNN: There are carbon steel, bolted carbon steel, and they're protected with a paint coating that has to be maintained.

MEMBER ARMIJO: Yeah. But they don't crack. The chlorides won't crack them.

MR. DUNN: Different degradation modes, but not stress corrosion cracking.

MR. EINZIGER: A couple of things. You know, they do use carbon steel and usually they paint over them, and when they examine them, the paint is sort of cracking off and there's all sorts of pits under them of unknown depth. So you know --

MEMBER ARMIJO: You know pitting, Bob. It's self-limiting. It's not going to pit all the way through those --

MR. EINZIGER: Well, I think that there's some discussion about that. But getting back to your mitigation, there have been people that are looking at mitigation. They're looking at peaning, they're looking at stress-relieving them in various ways.

They haven't -- they've even looked at washing them down. But you have to make sure that when you do mitigation, that you're not making things worse

in other arenas. Remember, these just aren't -- we show cartoons of these canisters sitting in concrete barrier.

But there's lots of blockages in that way. There's things holding these things centered that can trap salt, and the ones that have been the horizontal configuration are sitting on rails, and you wouldn't want to wash the salt right down into the crevice where it's meeting the rails. You might make another issue.

MEMBER ARMIJO: You just wash the hell out of it, Bob.

MR. EINZIGER: Well --

MEMBER ARMIJO: No. I'm not saying it casually, but you know, if you can take the salt off, the best way to take it off is washing it off, instead of waiting for it to crack and then coming back --

MR. EINZIGER: I agree, and that would be great if we had a handle on does the salt take 20 years to deposit a critical amount. Then we'd have to wash it once every 20 years, or does it take 25 minutes, in which case we just keep a constant stream of water on the thing.

MEMBER ARMIJO: No, it doesn't take 25 years, Bob.

MR. EINZIGER: You know, it depends on the level of salt that you have to have down there, to have a problem. But I'm going to second what Al said, because

when we started this thing, we knew that there was going to be a problem, and it was going to occur somewhere between probably about ten years and 400 years.

I think that industry's work now is showing that if we're going to have a problem, it's going to be happening in tens of years.

MR. CSONTOS: Can I say something? Ten second.

CHAIR BALLINGER: We're insisting on becoming the same as an MIT faculty meeting. We automatically go to the end of time.

MR. CSONTOS: This work is feeding into a license renewal strategy. We have created a license renewal strategy task force in NMSS and it's NMSS staff and our staff, Research staff, and we're looking into all the questions that Sam just asked, mitigation, inspections, monitoring, your monitoring that you were talking about earlier.

We're trying to incorporate all this into a reasonable strategy for license renewal for these canisters, knowing now what we know versus what we didn't know back in the day.

MALE PARTICIPANT: Thank you.

CHAIR BALLINGER: Well thank you very, very much for that presentation, and as usual, it's too brief

and there's a lot more information that we could use. But if there aren't any other questions, then I can use the gavel one more time.

MEMBER ARMIJO: Yes, you can.

CHAIR BALLINGER: We will adjourn until one o'clock.

(Whereupon, at 11:59 a.m., the meeting was concluded.)

ACRS Meeting of the Subcommittee on Materials, Metallurgy, & Reactor Fuels

Subcommittee Briefing on Metallurgy and Materials Projects

Tuesday, January 14, 2014

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

Item	Topic	Presenter(s)	Time
1	Opening Remarks and Objectives	**Dr. Ron Ballinger, ACRS**	8:30 - 8:35 a.m.
2	Staff Opening Remarks	Mr. Michael Case, RES	8:35 - 8:40 a.m.
3	Overview of RES Projects - Component Integrity Branch	Dr. David Rudland, RES	8:40 - 9:10 a.m.
4	Extremely Low Probability of Rupture (xLPR)	Dr. David Rudland, RES	9:10 – 9:40 a.m.
5	Q&A	**ACRS Subcommittee**	9:40 – 10:00 a.m.
	Break		**10:00. – 10:15 a.m.**
6	Overview of RES projects - Corrosion and Metallurgy Branch	Mr. John Burke, RES	10:15 – 10:45 a.m.
7	Stress Corrosion Cracking Susceptibility of Austenitic Stainless Steels for Spent Fuel Dry Storage Canisters	Mr. Darell Dunn, RES	10:45 – 11:15 a.m.
8	Q&A	**ACRS Subcommittee**	11:15 - 11:45 a.m.
9	Adjourn	**Dr. Ron Ballinger, ACRS**	11:45 a.m.

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9	Adjourn	**Dr. Ron Ballinger, ACRS**	11:45 a.m.

Component Integrity Branch Research Activities

David Rudland
Branch Chief
RES/DE/CIB

ACRS Meeting of the Subcommittee on Materials, Metallurgy, & Reactor Fuels
January 14, 2014
Rockville, MD

U.S.NRC
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Introduction
Purpose, Outcomes, Process

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- **Purpose**
  - Provide an overview of research topic areas and capabilities in Office of Nuclear Regulatory Research, Division of Engineering, Component integrity Branch as they support program offices needs
- **Outcomes**
  - Achieve a common understanding of RES/DE/CIB project areas and capabilities
  - Demonstrate projects are meeting, or have met, their goals
  - Demonstrate the project value added to the NRC
- **Process**
  - Overview of the major ongoing RES/DE/CIB projects
  - Detailed description of xLPR Version 2.0

CIB Materials Research

General Technical Areas

United States Nuclear Regulatory Commission
Protecting People and the Environment

Work Request/Product

CIB Capabilities

CIB Capabilities	UNR#	UNR work title	MOU	Updates	Current Contracts
xLPR/Piping/CRDM/BMI	NRR-2010-018	Development of A Probabilistic Method For Evaluating The Probability Of Leak-Before-Break Of Nickel Based Alloys Exposed To Primary Water Environments	xLPR (2012) WRS (2012)	• xLPR pilot study NUREG - 2012 • ACRS xLPR presentations 2012/2013 • ACRS WRS Presentation 2013 • WRS NUREG 2013 • WRS validation • Emergent Support for LBB & Flaw Evaluations • CRDM/BMI work • ASME Code Support	• V6444- Emc2 - LBB Reg guide • V6411 - PNNL - xLPR inspection • V6375 - Battelle - Piping integrity • V6260 - SNL - xLPR V2 • Internal efforts on xLPR, WRS Validation, LBB support, flaw evaluation support
	NRR-2013-xxx	Implementation Of Probabilistic Methods For Evaluating Leak-Before-Break Of Nickel Based Alloys Exposed To Primary Water Environments			
	NRR-2013-yyy	Flaw Evaluation, Repair And Mitigation Techniques For Primary Water Stress Corrosion Cracking			
	NRO-2013-zzz	Technical LBB Support for New Reactors			
RPV	NRR-2007-001	RPV Integrity issues	none	• Appendix H to NRR/NRO • RG199R3/TBD NUREG • Appendix G revision TBD • 50.61a Reg guide/NUREG under review • ASME Code Support	• N6438 - ORNL - RPV
NDE	NRR-2013-009	Evaluating The Reliabilty Of Nondestructive Examinations Of Vessels And Piping	NDE VP (2013) NDE (2011)	• 50.61a RPV Inspection review; • VT of RPV Internals; • UT in lieu of RT for fabrication, • Assess Industry Actions re: DMW, HPDE, CASS, • Inspector training/qualifications (PDI) • Effectiveness and reliability of field NDE • NDE modeling	• V6323 - PNNL - Capabilities and Reliability of NDE • V6411 - PNNL - xLPR inspection • V6097 - PNNL - Effect/Reliab of UT in lieu of RT • N6593 - PNNL - Assess Emerging NDE Methods • G6022 - ASME Grant - Convergence of International Codes
	NRR-2010-014	Volumetric Examination of Vessels and Piping (NDE VP)			
	NRR-2010-120 NRO-2010-008	Request for NDE of Polyethylene Piping and Fittings			
HDPE	NRR-2006-007	Development of a Technical Database on the Use of HDPE in Safety Related Piping Systems	HDPE (2011)	• HDPE piping in buried class 3 safety systems • Assess industry efforts • ASME Code Support	• V6245 - Emc2 - HDPE testing
EAF	NRR-2010-019 NRO-2010-006	Support for Environmental Fatigue Consultation and High Energy Line Break Criteria	EAF (50% co-funding by EPRI; expired 12/31/2012)	• Draft revision to NUREG/CR-6909 - June 2013. • Finalize NUREG/CR-6909 Rev. 1 for public review -- December 2013. • Revise Reg. Guide 1.207 for public review -- January 2014. • Issue NUREG and Reg. Guide - December 2014 • ASME Code Support	• V6069/V8269 - ANL - completed 9/30/2013

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Overview of RES/DE/CIB Project Areas

Integrity of Reactor Pressure Vessels

Purpose and Overview

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- **Purpose**
  - Assess and document in technical reports the currency and adequacy of RPV rules and Reg guides. Update as required
- **Core Capabilities**
  - Embrittlement, Fracture Mechanics, Probabilistic Coding
- **Project Staff**
  - Mark Kirk, Gary Stevens, Michael Benson, Eric Focht
  - Contractor: ORNL (N6438)
- **Industry Cooperation**
  - EPRI MOU under development
- **Basis/Prioritization**
  - Requesting Office: NRR (UNR-2007-001). Updated being developed

RPV Integrity Work

UNR 2007-001 Investigations

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NRC Document	Last Rev	Regulatory Questions	Current Activities	Staff	ORNL*	ASME
Reg. Guide 1.99 (Embrittlement Prediction)	1988	Is current guidance adequate in view new data and understandings of embrittlement?	• Evaluation deferred in 2010 • Renewed effort to complete technical review and forge staff consensus	X		
10 CFR 50 App. H (Surveillance)	1984	• Is it still adequate to reference a 1982 ASTM standard? • Augmented guidance on integrated surveillance • Changes to reporting requirements	• Reviewed adequacy in 2008. Deferred. • Support NRR in renewed rulemaking push (SECY paper)	X		
10 CFR 50 App. G (Normal Operations)	1984	Is current guidance adequate in view of results from probabilistic studies and current understanding of flaws present RPVs?	Comprehensive evaluation of tech basis being concluded. TLRs being issued.	X	X	X
Reg. Guide 1.161 (Low Upper Shelf)	1995	Is current guidance adequate in view of new data?	Update ASME SC-XI App K, then retire RG	X		X
10 CFR 50.61 (PTS)	2010	Improve quality & uniformity of submittals by providing Inspection & surveillance guidance	DG-1299 developed, in NRR review	X	X	

* - All ORNL support is provided by project N6438

RPV Integrity Work

Status and Schedule

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- **Ongoing support of emergent needs**
  - Doel (10/12 to 1/13)
  - Palisades (2/13 to date)
  - Reg. Issue Summary (RIS) on Extended Beltline (4/13 to date – out for public comment 3/14; issued 6/14)

- **Ongoing revision of current regulations and standards related to RPV integrity**
  - 10 CFR 50 App. H – 2014
  - 10 CFR 50.61a - completed in 2010. DG-1299 to be released for public comment Summer 2014
  - 10 CFR 50 App. G, RG1.161, & RG1.99
    - In all cases documentation of technical work being completed (2014)
    - Discussions will follow with NRR and NRO regarding need to and schedule for changes to the regulatory documents

- **Reactor embrittlement archive project (REAP)**
  - Available on-line since 2012
  - Enhanced search and capabilities will be added budget permitting

Nondestructive Evaluation

Purpose and Overview

- **Purpose**
  - Confirm industry's new and revised NDE methods and qualification processes to the examination of new construction and operating plants
- **Core Capability**
  - NDE methods, qualification, and modelling
- **Project Staff**
  - Wally Norris, Carol Nove, Iouri Prokofiev, Josh Kusnick
  - Contractor: PNNL (V6323, V6411, V6097, V6286)
- **Industry Cooperation**: EPRI, IRSN/CEA
- **Basis/Prioritization**
  - Requesting Office: NRR UNRs: 2013-009, 2010-014, 2010-020, 2010-018); NRO UNR: 2010-008

Nondestructive Evaluation

Status and Schedule

- **Schedule/Status**
  - V6323: Effectiveness and Reliability of NDE for Vessels and Piping
    - Period of Performance: 05/01/12 – 05/31/17
    - 21 reports
  - V6097: UT in Lieu of RT for Repairs and Modifications
    - Project ends 8/31/14
    - 1 NUREG
  - V6286: Program to Assess Reliability of Emerging Nondestructive Techniques
    - Project ends 06/15
    - 1 NUREG

Nondestructive Evaluation

Status and Schedule

- **Schedule/Status**:
  - EPRI Agreement: MOU on Nondestructive Examination
    - Current MOU ends 03/31/14; extension in development
    - 10 reports
  - IRSN Agreement: Cooperation on the Inspection of Coarse-grained Materials and Dissimilar Metal Welds of Reactor System Components
    - Period of Performance:01/01/14 – 12/31/17
    - 7 reports

High Density Polyethylene

Purpose and Overview

- **Purposes**
  - Confirm proposed requirements for use in ASME Class 3 safety-related applications
  - Support NRR and NRO in ASME code actions and roadmap, and relief requests
- **Core Capability**
  - HDPE testing and analysis
- **Project Staff**
  - Eric Focht
  - Contractor: Emc^2 (V6245)
- **Industry Cooperation**
  - MOU with EPRI on HDPE piping integrity
  - Industry collaboration through the Nuclear Energy Standards Coordination Collaborative (NESCC)
- **Basis/Prioritization**
  - Requesting Office: NRR (UNR-2006-007, UNR-2011-001)

High Density Polyethylene

Status and Schedule

- **Status**
  - Confirmatory research on parent and fusion joint integrity
    - Specimen and pipe section testing underway
  - NDE
    - Limited evaluations of fusion joints to confirm detection capabilities
- **Schedule**
  - Impacted significantly by sequestration/budget issues
  - Piping integrity evaluation ends in FY14
  - NDE on hold starting mid-FY14

Environmental Assisted Fatigue

Purpose and Overview

- **Purpose**
  - To update the existing EAF evaluation methodology and develop techniques for applying this method for structural and component evaluations
- **Core Capability**
  - Environmental fatigue testing, data analysis
- **Project Staff**
  - RES: Gary Stevens
  - Contractor: ANL (Dr. Omesh Chopra)
- **Industry Cooperation**
  - EPRI MOU Addenda on EAF (expired 12/31/2012)
    - Research was 48% co-funded by EPRI
- **Basis/Prioritization**
  - Requesting Offices: NRR and NRO (Dual User Need)
    - UNR NRR-2010-019/NRO-2010-006

Environmental Assisted Fatigue

Status and Schedule

- **Deliverables**
  - Knowledge management turnover from Contractor
  - Revision to NUREG/CR-6909
  - Revision to Reg. Guide 1.207
- **Status**
  - Research complete; finalizing documents for public comment process
- **Schedule**
  - Final drafts of documents anticipated by 01/31/2014
  - Public comment period Summer 2014
  - Issued in 2015

Extremely Low Probability of Rupture (xLPR)

Purpose

- 10CFR50 Appendix A GDC-4 allows local dynamic effects of pipe ruptures to be excluded from design basis if pipe ruptures have Extremely Low Probability of occurrence

- Effect is to eliminate need for whip restraints and jet impingement shields

- Conservative deterministic flaw tolerance analyses developed and incorporated in SRP3.6.3 to demonstrate leak-before-break (LBB) and satisfy GDC-4. No active degradation!

- No quantitative procedure available for assessing probability of occurrence with active degradation

NRR User Need Requests

Past

- **NRR-2005-011 – PWSCC in LBB systems**
  - LBB short term solution confirmation.
    - Mitigation
    - Inspection
  - Develop LBB long term solution strategy
  - Closed out July 2011

- **NRR-2006-006 – PWSCC in Nickel-based Alloy Components**
  - RPV head integrity issues
  - CRDM/Butt weld probabilistic rupture assessment
  - Crack growth rate confirmation
  - PWSCC NDE
  - Closed out July 2011

NRR User Need Request

Current

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- **NRR-2010-018 – Probabilistic Method for LBB**
  - Develop long term LBB solution including impact of short term solution.
  - Deliver a flexible, modular probabilistic fracture mechanics code for evaluation of PWSCC in dissimilar metal butt welds - eXtremely Low Probability of Rupture (xLPR) code
    - Include active degradation modes
    - Include inspection/mitigation/repair strategies
    - Correctly quantify, characterize, and propagate uncertainties
  - Deliver technical basis and Regulatory Guide for LBB
  - UNR currently being updated

Core Capabilities
xLPR

- **Capabilities**
  - Fracture Mechanics
  - Stress Corrosion Cracking
  - Weld Residual Stress Analyses and Measurements
  - Probabilistic/Stochastic Modeling
  - NDE/Probability of Detection and Sizing
- **Staff**
  - David Rudland, Eric Focht, Gary Stevens, Michael Benson, Shah Malik, Josh Kusnick
- **Contractors**
  - SNL(V6260), Emc^2(V6444), Battelle(V6375), PNNL(V6411), ORNL(N6438)

Code Development
Team Members

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Code Development Leads
David Rudland – U.S. NRC
Craig Harrington – EPRI

Computational Group
Remi Dingreville– Sandia National Laboratories
Mike McDevitt– EPRI
Cedric Sallaberry – Sandia National Laboratories
Aubrey Eckert– Sandia National Laboratories
Mariner, Paul– Sandia National Laboratories
Patrick Mattie - Sandia National Laboratories
Robert Kurth – Emc2
Dilip Dedhia – Structural Integrity Associates
David Harris– Structural Integrity Associates
Paul Williams – Oak Ridge National Laboratory
Scott Sanborn – PNNL
Ian Miller – GoldSim
Ryan Roper - GoldSim

Inputs Group
Guy DeBoo – Exelon
Gary Stevens – U.S. NRC
Ashok Nana – AREVA NP Inc.
Nathan Palm – Westinghouse

Program Integration Board
Denny Weakland - Ironwood Consulting
Bruce Bishop – PEAI
Rob Tregoning – U.S. NRC
Jay Collins– U.S. NRC
Ted Sullivan – PNNL

Program Manager
Nate Leech - Demark

Models Group
Marjorie Erickson – PEAI
Eric Focht– U.S. NRC
Mike Benson– U.S. NRC
Mark Kirk – U.S. NRC
Kyle Schmitt – Dominion Engineering
John Broussard– Dominion Engineering
Glenn White– Dominion Engineering
Chris Casarez – Dominion Engineering
Do-Jun Shim – Emc2
Elizabeth Kurth – Emc2
Bud Brust – Emc2
Suresh Kalyanam– Emc2
Sean Yin – Oak Ridge National Laboratory
Richard Bass – Oak Ridge National Laboratory
Cliff Lange – Structural Integrity Associates
Steven Xu – Kinectrics
Doug Scarth – Kinectrics
Russ Cipolla – Aptech
Mike Hill – UC Davis
Steve Fyfitch – AREVA NP Inc.
Rick Olson – Battelle
Andrew Cox – Battelle
Lee Fredette – Battelle
Bruce Young – Battelle
Patrick Heasler – PNNL
Mark Dennis - EPRI
Carl Latiolais- EPRI
Thiago Seuaciuc-Osorio- EPRI

QA Group
Nancy Kyle – Theseus
xLPR Team

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EPRI ELECTRIC POWER RESEARCH INSTITUTE

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE U.S. DEPARTMENT OF ENERGY

Sandia National Laboratories

PEAI

Structural Integrity Associates, Inc.

Exelon.

Pacific Northwest NATIONAL LABORATORY

KINECTRICS

Emc²

AREVA

Dominion Engineering, Inc.

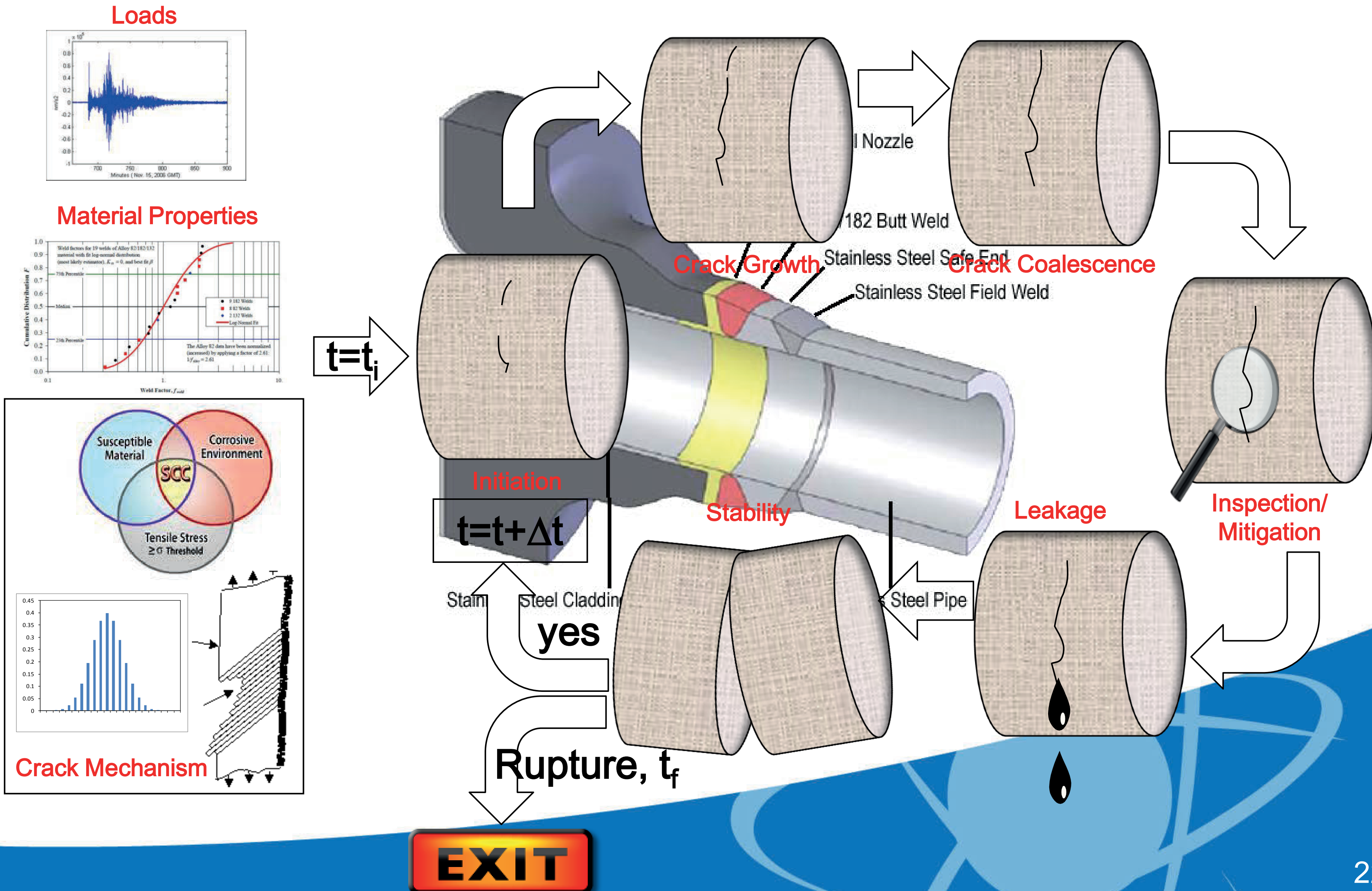
GoldSim

Westinghouse

Battelle *The Business of Innovation*

Cooperative effort between NRC and EPRI through Memorandum of Understanding

PFM Technical Flow

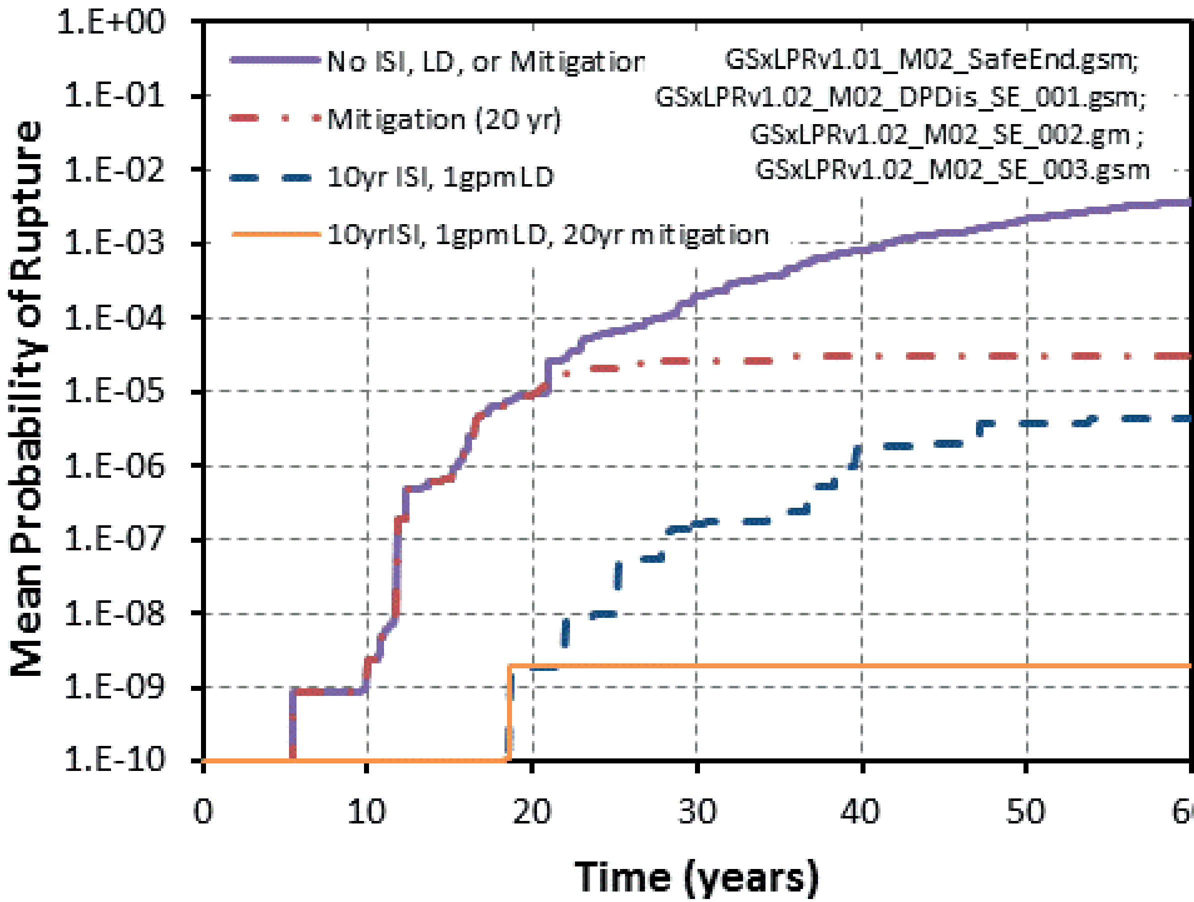


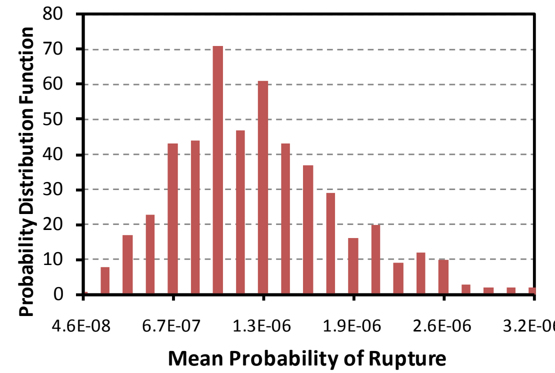
xLPR Pilot Study

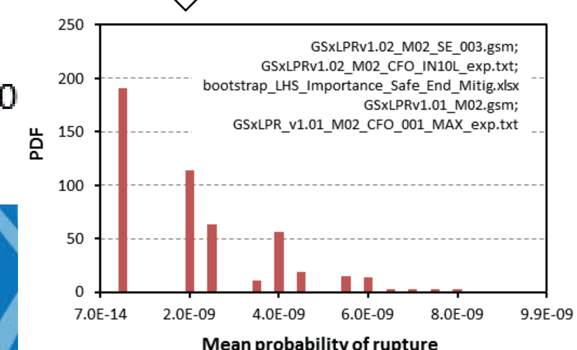
- Conducted from 2009-2011
- Pilot study objectives
  - Develop and assess xLPR management structure
  - Determine the appropriate probabilistic framework
  - Assess the feasibility of developing a modular-based probabilistic fracture mechanics computer code
- Focused on pressurizer surge nozzle DM weld with PWSCC
- Development of Version 1.0 code using comprehensive configuration management
- Developed detailed program plan (objective, schedule, deliverables, budget, communications) for Version 1.0 and Version 2.0 code

xLPR Code Feasibility

Westinghouse-type pressurizer surge nozzle dissimilar metal weld







Pilot Study Results

- The project team demonstrated that **<u>it is feasible</u>** to develop a modular-based probabilistic fracture mechanics code within a cooperative agreement while properly accounting for the problem uncertainties

- Identified potential efficiency gains in the program management structure

- Selected commercial software as the computational framework
  - Based on the framework code comparison, a cost analysis, and long term prospects

xLPR Version 2.0

- Version 2.0 is expanded to handle welds within piping systems approved for LBB
  - Appropriate materials, loads, degradation mechanisms, mitigation, inspection, leak detection

- Rigorous quality assurance including verification and validation (V&V) process

- Capabilities of Version 2.0 will meet requirements for LBB lines, but must stay within available cost and schedule limitations

- Model inclusion in xLPR Version 2.0 does not guarantee regulatory approval.

xLPR Benefits to NRC

- Quantified solution to LBB issue
  - Regulatory Guide
  - Update to SRP3.6.3

- Fully QA'ed modular probabilistic fracture mechanics code for reactor pressure boundary integrity
  - LBB including evaluation of mitigation for DM welds
  - Research tool for prioritization
  - TBS – 50.46a
  - Risk informed ISI
  - GSI191
  - Effects of seismic loading on integrity
  - Easily adaptable to other applications

xLPR Acceptance

- Office of Nuclear Reactor Regulation (NRR) leading effort to develop xLPR Acceptance criteria

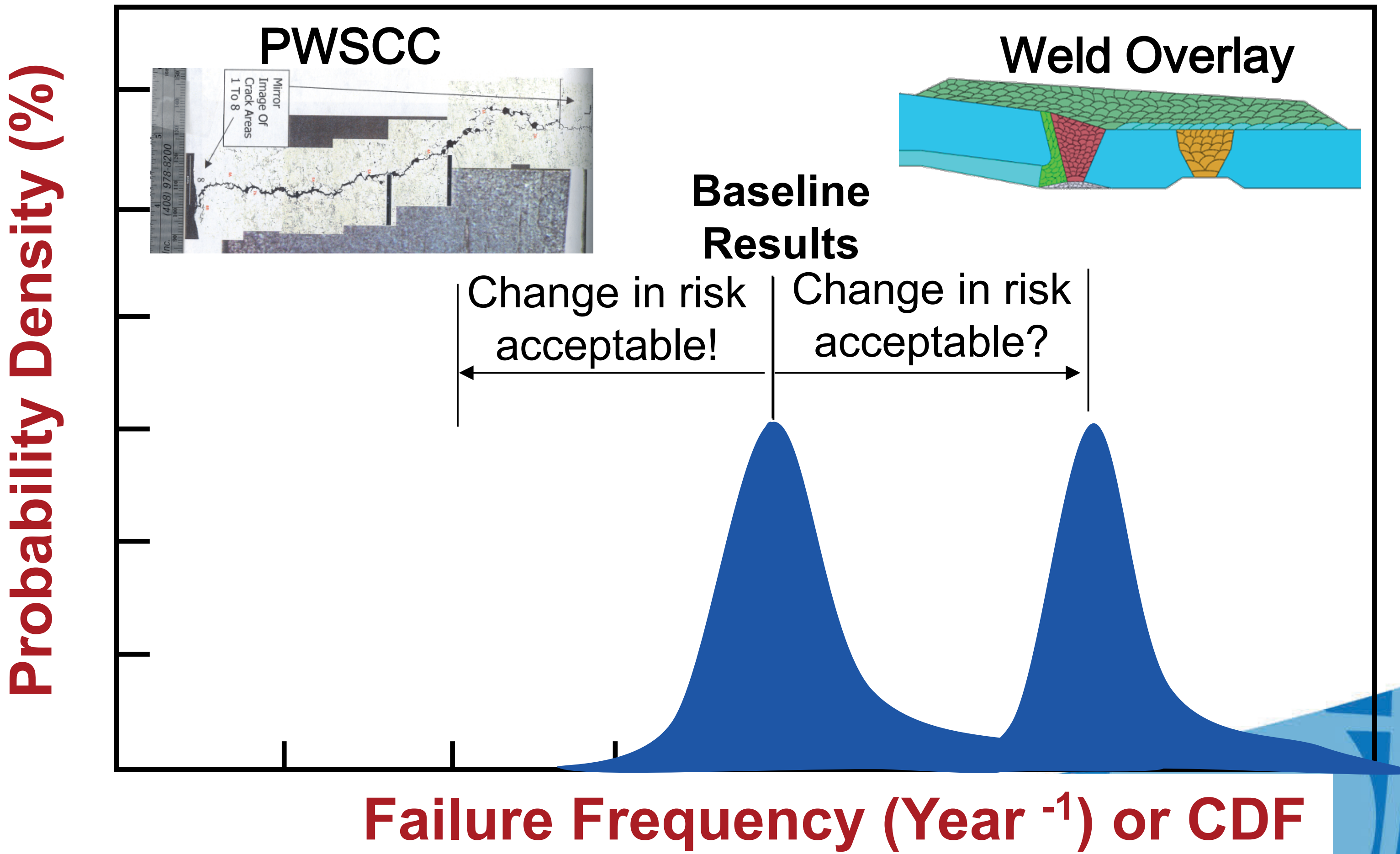
- Acceptance questions considered
  - What constitutes acceptable inputs?
  - What constitutes acceptable results?
    - Guidance on risk limits as an NRC regulatory position for LBB
  - What constitutes an acceptable delivery vehicle for this information?
    - NUREG? Regulatory Guide? Other?
  - Who conducts evaluations?
    - Industry? NRC? Plant specific analysis? Generic analysis?

- Acceptance criteria under development

- The xLPR Acceptance group will evaluate changes in risk (Δ-Risk)
  - Intent is to use existing acceptable risk values

Using xLPR for LBB

Conduct analyses with baseline conditions (as used in SRP3.6.3)
Conduct analyses with modified condition



Possible Acceptance Criteria

Under Development

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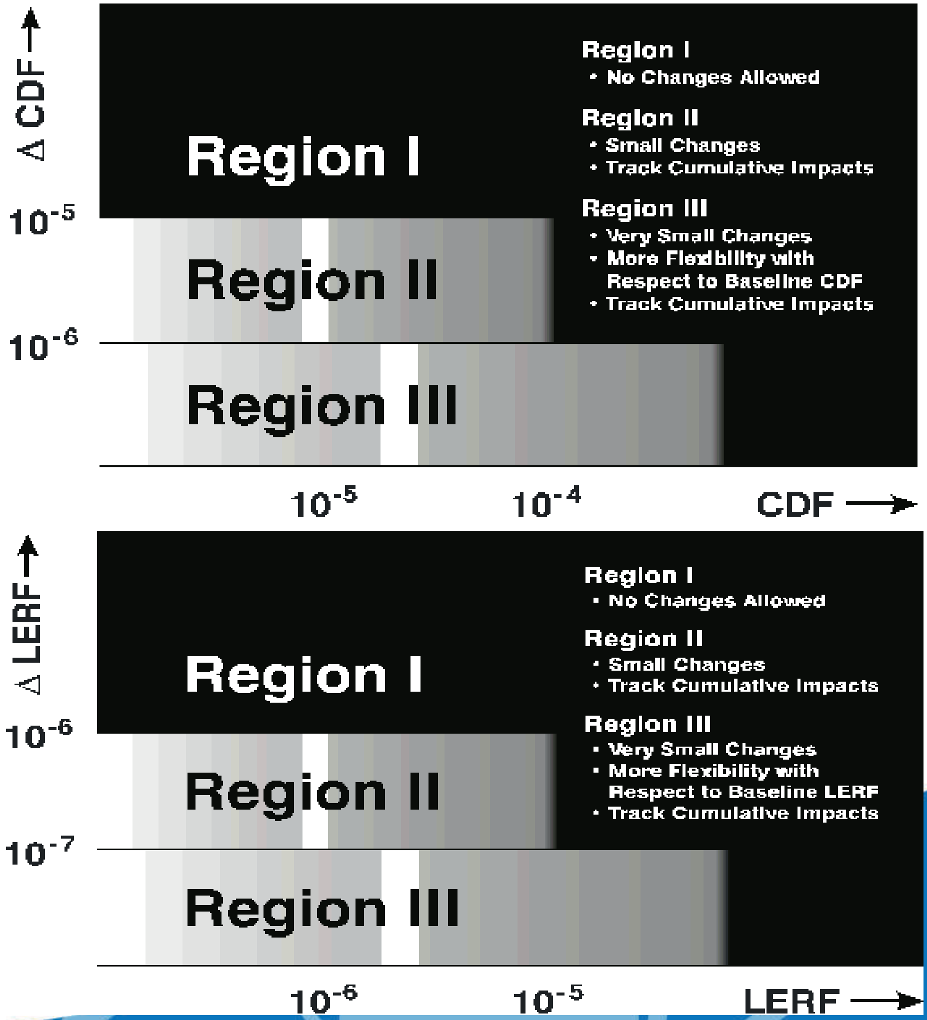
- Regulatory Guide 1.174 provides guidance on
  - Core Damage Frequency (CDF) and ΔCDF
  - Large Early Release Frequency (LERF) and ΔLERF
- Advantage
  - Criteria developed
  - NRC has experience with RG1.174 approach
- Work is continuing



Extremely Low Probability of Rupture (xLPR)

Status and Schedule

- xLPR Version 2 (LBB) underway
- Project Deliverables:
  - Version 1.0 (pilot study) - March 2012
  - Version 2.0 (LBB)
    - Beta March 2014
    - V&V code - Sept 2014
    - Delayed due to sequestration/budget issues
  - LBB Regulatory Guide – 2015/2016
- RES/DE/CIB have briefed ACRS on xLPR, WRS, and PWSCC crack initiation

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Corrosion & Metallurgy Branch
Division of Engineering
Office of Nuclear Regulatory Research

Meeting of

the ACRS Subcommittee on Materials, Metallurgy, & Reactor Fuels

January 14, 2014

Introduction

- **Purpose**
  - Provide an overview of research topic areas in the Corrosion and Metallurgy Branch (CMB) as they support program offices needs
- **Outcomes**
  - Achieve a common understanding of RES/DE/CMB project areas and capabilities
  - Demonstrate the project value added to the NRC
- **Process**
  - Overview of the major ongoing RES/DE/CMB projects
  - Detailed review of the Stress Corrosion Cracking of Dry Casks Project

Aging of Neutron Absorbers in Spent Fuel Pools

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- **Purpose**: Develop technical bases for the aging management of neutron absorber materials
- **Basis**: User Need Request (UNR) NRR-2010-015 and NRR-2013-005: Develop the Technical Bases for the Evaluation of Neutron Absorbing Materials in Spent Fuel Pools
- **Regulatory Use:** Review license amendment requests and determine what future regulatory actions may be warranted
- **Contract Support**: Consultants Tom Haley and Mohamad Al-Shiekhly, and ORNL
  - Technical Letter Report (TLR), “Boraflex, RACKLIFE, and BADGER: Description and Uncertainties,” September, 2012
  - TLR, “Initial Assessment of Uncertainties Associated with the BADGER Methodology,” September, 2012
  - TLR, “Monitoring Degradation of Phenolic Resin-Based Neutron Absorbers in Spent Nuclear Fuel Pools,” June, 2013

Aging of Neutron Absorbers in Spent Fuel Pools (cont.)

- **Key Results**:
  - BADGER methodology uncertainties, e.g., excessive gamma field, head misalignment and setpoint drift for electronics, can significantly impact measurement results
  - Predicted degradation for Boraflex and phenolic resin neutron absorbers and, thus, the postulated mechanisms are consistent with operating experience
    - for Boraflex the degradation can be related to gamma dose
    - for phenolic resin neutron absorbers, there is no straight correlation between gamma dose and degradation

Stress Corrosion Cracking of Dry Storage Canisters

- **Purpose:** Evaluate the SCC susceptibility of austenitic stainless steel for spent fuel dry storage canisters exposed to atmospheric chloride salts
- **Basis**: UNR NMSS-2011-002: Extended Storage and Transportation Regulatory Program Review, which continued work from UNR NMSS-2005-001: Determine Susceptibility of Austenitic Stainless Steel Spent Fuel Storage Casks to Chloride-Induced Stress Corrosion Cracking Under Coastal Atmosphere Exposure
- **Regulatory Use:** Inform safety evaluations and licensing actions for storage facilities
- **Contract support**: Center for Nuclear Waste Regulatory Analyses (CNWRA)
  - Draft NUREG/CR-7170, "Assessment of Stress Corrosion Cracking Susceptibility for Austenitic Stainless Steels Exposed to Atmospheric Chloride and Non-Chloride Salts," March 2014
  - NUREG/CR-7030, "Atmospheric Stress Corrosion Cracking Susceptibility of Welded and Unwelded 304, 304L, and 316L Austenitic Stainless Steels Commonly Used for Dry Cask Storage Containers Exposed to Marine Environments," October 2010

Stress Corrosion Cracking of Dry Storage Canisters (cont.)

- **Key Results:**
  - Austenitic stainless steels are susceptible to chloride stress corrosion cracking (SCC) under environmental conditions where accumulated salts can absorb moisture from the environment
  - SCC initiation is observed at the lowest salt surface concentration tested, 0.1 g/m^2, which is much lower than reported in some previous studies
  - SCC initiation is observed at low strains (0.4%), where the stress is close to the yield strength of the austenitic stainless steels
  - No SCC was observed with non chloride salts that are expected from atmospheric deposits from non-coastal environments

Vacuum Drying of Spent Fuel Canisters

- **Purpose:** Develop a test plan for measuring the quantity of residual water that remains in spent fuel canisters after vacuum drying
- **Basis**: UNR NMSS-2011-002: Extended Storage and Transportation Regulatory Program Review
- **Regulatory Use:** Determine if experimental testing could be used to confirm the adequacy of current regulatory guidance for vacuum drying during canister loading
- **Contract Support**: CNWRA
  - TLR, "Vacuum Drying Test Plan," July 2013
  - TLR, "Overview of Vacuum Drying and Factors Affecting the Quantity of Residual Water," July 2013

Vacuum Drying of Spent Fuel Canisters (cont.)

- **Key Results:**
  - Testing can be conducted using specially instrumented fuel assembly and canister mockups to determine the amount of residual water remaining after drying of a loaded spent fuel storage canister/cask
  - A test plan to measure the residual water was developed and equipment necessary to conduct the measurements is commercially available
  - No testing is planned by NRC at this time because a similar project is being sponsored by DOE

Functional Monitoring of Dry Cask Storage Systems

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- **Purpose(s):** Review available monitoring technologies (e.g. temperature, humidity, corrosion, etc.) for spent fuel dry storage casks, and identify where improved technology may enhance future monitoring capabilities

- **Basis**: UNR NMSS-2011-002: Extended Storage and Transportation Regulatory Program Review

- **Regulatory Use:** Develop regulatory guidance for monitoring and evaluation of proposed industry actions to mitigate degradation in dry cask storage systems

- **Contract support**: CNWRA
  - Draft TLR, “Available Methods For Functional Monitoring of Dry Cask Storage Systems (DCSS),” February 2014

Functional Monitoring of Dry Cask Storage Systems (cont.)

- **Key Results:**
  - Monitoring temperature and relative humidity on external surfaces of storage canisters/casks is feasible by adapting existing probes and instrumentation
  - Monitoring corrosion and cracking on canisters casks requires advances in the state of the art and would be difficult to implement safely
  - Monitoring internal structures systems and components does not appear to be possible with existing dry cask storage system designs

Containment Liner Corrosion

- **Purpose(s):** Develop a model to calculate the corrosion rates for a liner plate abutted by debris embedded in the concrete, and develop a model to estimate the leakage from containment during a design-basis loss-of-coolant accident
- **Basis**: UNR NRR-2010-002: Containment Liner Corrosion
- **Regulatory Use:** Determine if additional inspections of the containment liner are needed beyond that currently implemented in accordance with the ASME Code Section XI Subsection IWE
- **Contract Support**: CNWRA
  - TLR, "Containment Building Liner Corrosion – Corrosion and Leak Rate Models," July 2013
  - TLR, "Containment Liner Corrosion Operating Experience Report Revision 1," August 2011
  - Nuclear Containment Steel Liner Corrosion Workshop, July 2011

Containment Liner Corrosion (cont.)

- **Key Results:**
  - Corrosion cell at liner is not likely to support both a high corrosion rate and large corroded area
  - Through wall corrosion of the containment liner is initiated from foreign objects left in concrete during initial construction
  - Leak rate is controlled by the size of the hole in the containment liner when the hole is small (~10 mm^2)
  - Radioisotope releases would be largely restricted by a narrow gap between liner and containment wall and the concrete permeability

Leak Path Assessment of North Anna CRDM Nozzle 63

- **Purpose:** Evaluate phased-array ultrasonic testing (UT) to detect a primary water leakage path between reactor upper head penetration and the reactor pressure vessel head
- **Basis**: UNR NRR-2006-006: Information on PWSCC of Nickel-Base Alloy Primary Pressure Boundary Components
- **Regulatory Use:** The results are expected to help the staff interpret and evaluate licensee' ultrasonic leak path assessments for upper head penetrations
- **Contract Support**: PNNL
  - NUREG/CR-7142, "Ultrasonic Phased Array Assessment of the Interference Fit and Leak Path of the North Anna Unit 2 Control Rod Drive Mechanism Nozzle 63 with Destructive Validation," August 2012

Leak Path Assessment of North Anna CRDM Nozzle 63 (cont.)

- **Key Results:**
  - Leakage path detected by UT was confirmed by destructive examination of the nozzle
  - Pattern of boric acid deposits observed with phased-array ultrasonic testing UT was in agreement with observations from destructive examination
  - Minimal corrosion of the low alloy steel reactor pressure vessel head was observed

Irradiation-Assisted Degradation

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- **Purpose:** Develop the technical bases for assessing irradiation-assisted degradation of reactor core internals and potential synergetic effects between thermal and neutron embrittlement in cast austenitic stainless steels (CASS)

- **Basis**: UNR NRR-2012-008: Environmentally Assisted Degradation of Light Water Reactor Internal Components

- **Regulatory Use:** Evaluate effectiveness of aging management programs as required by MRP-227A

- **Contract Support**: EPRI, PNL, ANL, and INL
  - TLR, "Slow Strain Rate Tensile Tests on Irradiated Stainless Steels in PWR Environment," June 2012
  - TLR, "Cracking of Irradiated Stainless Steels in Low Corrosion Potential Environments," May 2013
  - NUREG/CR-7128, "Void Swelling and Microstructure of Austenitic Stainless Steels Irradiated in the BOR- 60 Reactor," November 2012
  - TLR, "Crack Growth Rate and Fracture Toughness Tests on Irradiated Cast Stainless Steels," November 2012

Irradiation-Assisted Degradation (cont.)

- **Key Results:**
  - In low corrosion potential environments representative of PWR conditions, testing of both cold worked and non-cold worked stainless steels exhibited increasing SCC crack growth rates with increasing fluence levels from 5 up to 25 dpa
  - Consistent with previous test results at lower fluence levels, the fracture toughness of these same stainless steels decreases with increasing fluence up to 8 dpa; between ~5 and 8 dpa, the J values at crack initiation were below 100 kJ/m2
  - In a limited set of thermally aged cast austenitic stainless steel samples, low dose (0.08 dpa) neutron irradiation decreased fracture toughness in addition to the decrease from thermal ageing alone

Primary Water Stress Corrosion Cracking

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- **Purpose**: Evaluate the use of high chromium alloys and weld metals used in replacement components and repairs for PWSCC mitigation
- **Basis**: UNR NRR-2006-006: PWSCC of Nickel-Based Alloy Primary Pressure Boundary Components, which was an extension of UNR NRR-2010-018: Development of a Probabilistic Method for Evaluating the Probability of Leak-Before-Break of Nickel-Based Alloys
- **Regulatory Use**: Develop safety evaluation criteria of Ni-base primary system pressure boundary components subject to PWSCC degradation
- **Contract Support:** PNL and ANL
  - NUREG/CR-7103, “Stress Corrosion Cracking in Nickel-Base Alloys,” Vol. 1, September 2011, & Vol. 2, April 2012
  - TLR, “Primary Water Stress Corrosion Cracking Tests and Metallurgical Analyses of Davis-Besse Control Rod Drive Mechanism Nozzle #4,” August 2013
  - NUREG/CR-7137, “Stress Corrosion Cracking in Nickel-Base Alloys 690 and 152 Weld in Simulated PWR Environment,” June 2012

Primary Water Stress Corrosion Cracking (cont.)

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- **Key Results:**
  - Alloy 690 is strongly resistant to PWSCC unless subjected to cold work
  - In initial testing, alloy 690 weld heat affected zones (HAZ) also appears to be resistant to PWSCC
  - Alloy 52 and 152 weld metals are more resistant to PWSCC compared to alloys 82 and 182
  - Preliminary testing has shown that disimilar metal weld dilution zones may be susceptible to PWSCC

Subsequent License Renewal

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- **Purpose**: Provide technical information to support the development of a regulatory framework for licensing a second period of extended operation, i.e., from 60 to 80 years
- **Basis**: UNR 2010-006: Research Support in Developing Technical Information to Support License Renewal Beyond 60 Years
- **Regulatory Use**: Develop subsequent license renewal guidance bases documents
- **Contract Support:** ORNL & ANL and MOUs with EPRI and DOE
  - TLR, "Aging Management Program Effectiveness Audits," May 2013
  - TLR, "Evaluation of International Periodic Safety Assessments," December 2013
- **Key Results:**
  - LR guidance documents will be revised in a few places because of audit results at Ginna, Nine Mile-1, & Robinson-2
  - No generic conclusions can be drawn from only 3 audits
  - The review of PSR lessons learned showed no deficiencies or shortcomings in the reactor oversight program or license renewal process

Expanded Materials Degradation Assessment

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- **Purpose: I**dentify knowledge gaps and research needs related to materials degradation for plant operation up to 80 years
- **Basis:** UNR NRR-2010-006: Research Support in Developing Technical Information to Support Evaluating the Feasibility of License Renewal Beyond 60 Years, which expands on UNR NRR-2004-003: NUREG/CR-6923, "Expert Panel Report on Proactive Materials Degradation Assessment"
- **Regulatory Use:** Develop technical input for regulatory reviews of potential subsequent license renewal applications and prioritize NRC research needs
- **Contract support**: ORNL co-funded by DOE Light Water Reactor Sustainability Program

  5 draft NUREG/CR reports, June 2014:

  Volume 1: Executive Summary of EMDA Process and Results

  Volume 2: Aging of Core Internals and Piping Systems

  Volume 3: Aging of Reactor Pressure Vessels

  Volume 4: Aging of Concrete and Civil Structures

  Volume 5: Aging of Cables and Cable Systems

Expanded Materials Degradation Assessment (cont.)

- **Key Results:**
  - No surprises or new mechanisms were identified by the expert panels
  - Additional information is needed to address knowledge gaps for subsequent license renewal, for example in the area of irradiation assisted degradation
  - Experts are in good agreement about what issues should be addressed further
  - General consensus exists regarding long term degradation mechanisms

Steam Generator Research

- **Purpose:** Bolster the technical bases for SG non-destructive evaluations, tube integrity and consequential SG tube rupture (CSGTR)
- **Basis**: UNR NRR-2012-010: SG Inspection and Integrity Issues , which builds upon research conducted under all previous ones including the ones for CSGTR
- **Regulatory Use**: Support technical evaluations of licensee submissions and inspections of SG tubes
- **Contract Support**: ANL; 7 draft NUREG/CR reports and one draft TLR are under staff review:
  - Draft NUREG/CR, "Consequential SGTR Analysis For Westinghouse and Combustion Engineering Plants With Thermally-Treated Alloy 600 and 690 Steam Generator Tubes," April 2014
  - Draft NUREG/CR, "Algorithms to Automatically Analyze Eddy Current Data," May 2014
  - Draft NUREG/CR, "Creep and Leak Rate Models for Alloy 690 Steam Generator Tubes," June 2014

Steam Generator Research (cont.)

- Draft NUREG/CR, "Stability of Circumferential Flaws in Once-through Steam Generator Tubes Under Thermal Loading During LOCA, MSLB, and FWLB," July 2014
- Draft NUREG/CR, "Leak Rates and Burst Pressures for Flaws in the U-bend Region of Steam Generator Tubes," August 2014
- Draft NUREG/CR, "Assessment of Eddy Current Methods to Detect and Size Flaws in the U-bend Region of Steam Generator Tubes," September 2014
- Draft NUREG/CR, "Development and Validation of Models for Predicting Leakage from Degraded Tube-to-Tubesheet Joints During Severe Accidents," July 2014
- Draft TLR, "Evaluation of Examination Guidelines for Pulled Steam Generator Tubes," April 2014

Steam Generator Research (cont.)

- **Key Results (preliminary):**
  - Industry inspection and integrity models are often confirmed by NRC-sponsored research
  - Research periodically results in changes to industry guidelines or practices:
    - Leakage model – research found possible issues and industry changed guidelines
    - Pressurization rate – it was observed that rate can affect burst pressure; led to industry imposing limits on rates for in-situ and laboratory tube pressure testing.
    - Non-destructive examination – analyses under this program led industry to new work on inservice inspection data acquisition

Stress Corrosion Cracking Susceptibility of Austenitic Stainless Steels for Spent Fuel Dry Storage Canisters

Darrell Dunn
Corrosion & Metallurgy Branch
Division of Engineering
Office of Nuclear Regulatory Research

Meeting with the ACRS Subcommittee on Materials, Metallurgy, & Reactor Fuels

January 14, 2014

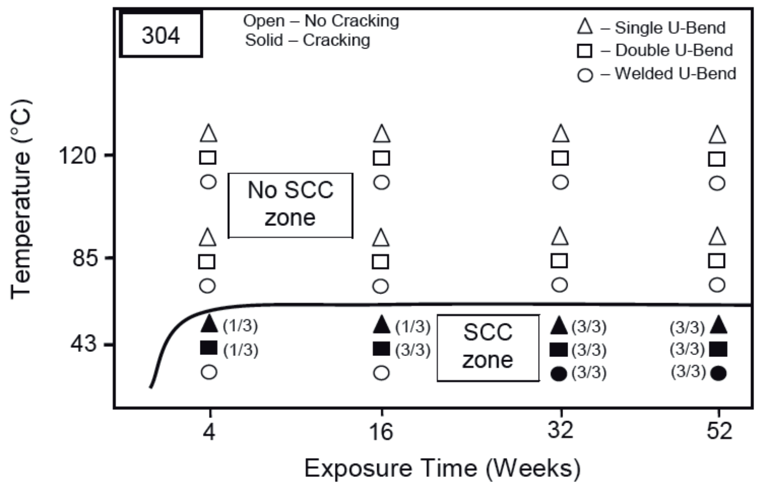
U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

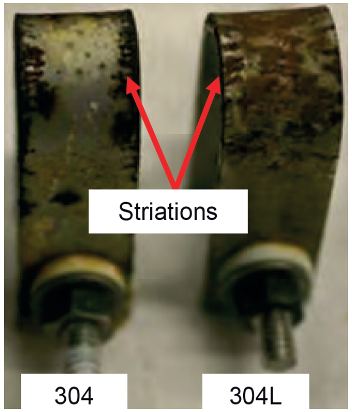
Background

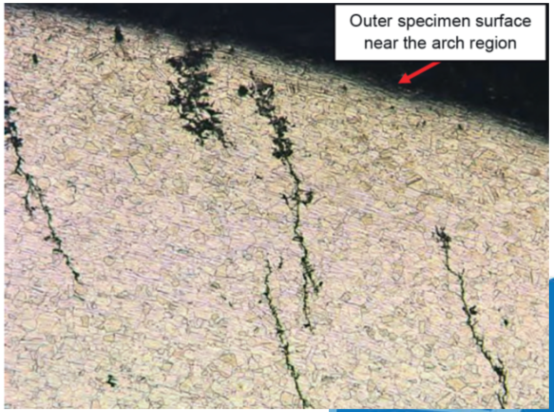
- Austenitic stainless steel is susceptible to stress corrosion cracking (SCC) in chloride-rich (i.e., marine) atmospheres
- Japanese studies at Central Research Institute for the Electric Power Industry (CRIEPI) since early 2000s
- Electric Power Research Institute (EPRI) topical reports in the mid-2000s
- Plant operational experience of SCC for outdoor stainless steel tanks and piping systems at near-coastal plants in the 1990s through 2000s

Previous NRC Research

- Office of Nuclear Regulatory Research (RES) sponsored at Southwest Research Institute, published as NUREG/CR-7030 in 2010
- Type 304 and 316 stainless steel U-bends deposited with simulated sea salt and exposed for up to 1 year at 43, 85, and 120 ^{o}C
- Only cracking at lowest temperature because relative humidity (RH) high enough for deliquescence







Specimens exposed at 43 ^{o}C

Motivation for Current Research

- Differences between CRIEPI studies and NUREG/CR-7030, including CRIEPI reports of SCC initiation at less aggressive conditions

- Important degradation scenario in the NRC report "Identification and Prioritization of the Technical Information Needs Affecting Potential Regulation of Extended Storage and Transportation of Spent Nuclear Fuel" (TIN Report) and other gap analyses

- Office of Nuclear Materials Safety and Safeguards (NMSS) User Need Request NMSS-2011-002, "Extended Storage and Transportation Regulatory Program Review"

Scope of Research Program

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- RES sponsored program at Center for Nuclear Waste Regulatory Analyses between October 2011 and October 2013

- Chloride salt tests, primarily with simulated sea salt:
  - Deliquescence measurements
  - Cyclic humidity
  - Elevated temperature
  - High humidity
  - Various strain levels

- Non-chloride species tests with nitrate, sulfate, and ammonium-rich salts:
  - Deliquescence measurements
  - Exposure only to non-chloride species
  - Exposure to chloride and non-chloride species mixtures

- Results of the research program will be published as NUREG/CR-7170 in early 2014

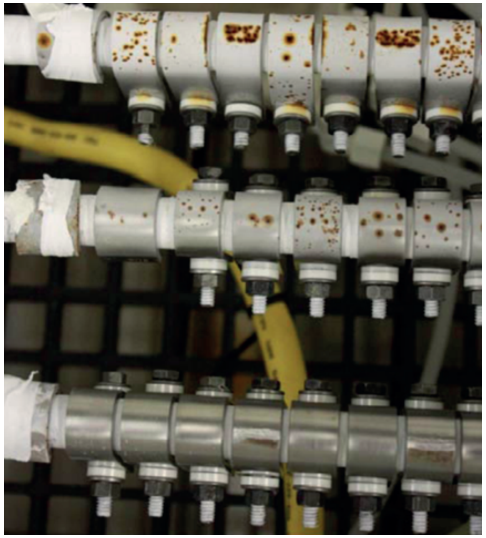
Cyclic Humidity SCC Testing

- Test objectives:
  - Limit absolute humidity (AH) to about 30 g/m^3
  - Vary test temperature
  - Vary surface salt concentration and material condition

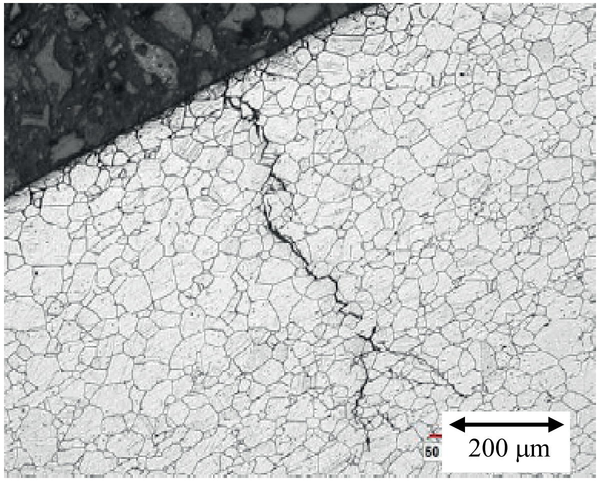
- Test methodology:
  - Deposited 0.1, 1, or 10 g/m^2 of sea salt on ASTM G30 U-bend specimens
    - Expose to salt fog for various times
    - Quantity determined by control specimen weight gain
  - Type 304 in as-received or furnace sensitized (2 hours at 650 ^{o}C) conditions
  - Exposed in test chamber to cyclic AH between about 15 and 30 g/m^3

Test Results

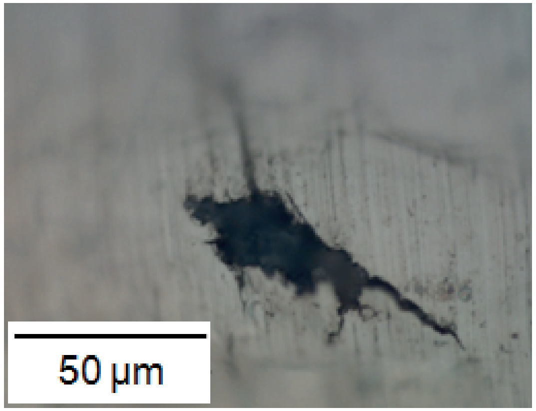
Specimen Temp. (°C)	RH Range (%)	Exposure Time	SCC Observed?	Lowest salt concentration at which SCC was observed
27	56-100	8 months	No	N/A – salt deliquesced and drained off
35	38-76	4 – 12 months	Yes	0.1
45	23-46	4 – 12 months	Yes	0.1
52	16-33	2.5 – 8 months	Yes	1
60	12-23	6.5 months	Yes	10



Pitting on specimens at 10 g/m² (top), 1 g/m² (middle), and 0.1 g/m² (bottom)



Cross section of sensitized, 0.1 g/m² specimen at 45°C after 4 months



Top view of sensitized, 10 g/m² specimen at 60°C for 6.5 months

Elevated Temperature SCC Testing

- Test objective: Evaluate SCC susceptibility at temperature up to 80 °C
- Test methodology:
  - Deposited 10 g/m^2 of sea salt on ASTM G30 U-bend specimens
  - Exposed specimens in test chamber at different humidity levels at 60 and 80 °C

Test Conditions			
Specimen Temp. (° C)	**Relative Humidity (%)**	**Absolute Humidity (g/m^3)**	**Maximum Test Duration (Months)**
60	22	29	1
	25	33	2.75
	30	39	5.75
	35	46	1
	40	52	1.5
80	28	82	2.5
	35	102	2.25
	40	117	1

Test Results

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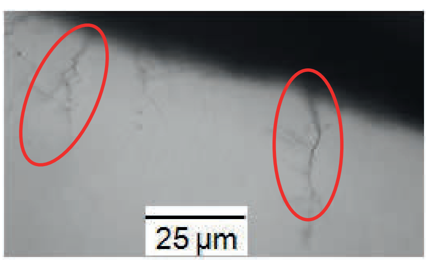
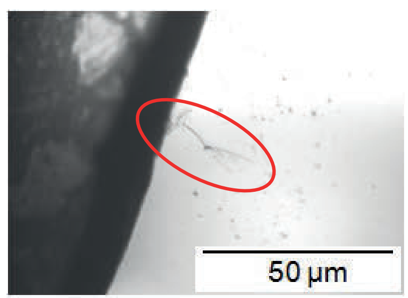
- SCC initiation observed at RH as low as 25% at 60 °C and 28% at 80 °C, though at AH above 30 g/m^3
- Sensitized specimens showed greater extent of cracking

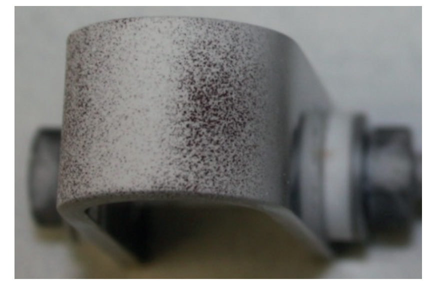
Sensitized, 60 °C, 30% RH

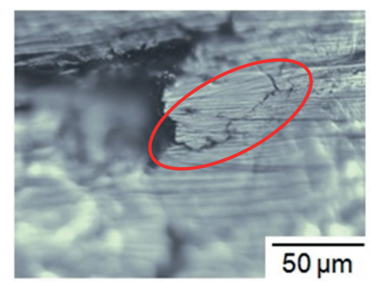


As-received, 80 °C, 35% RH



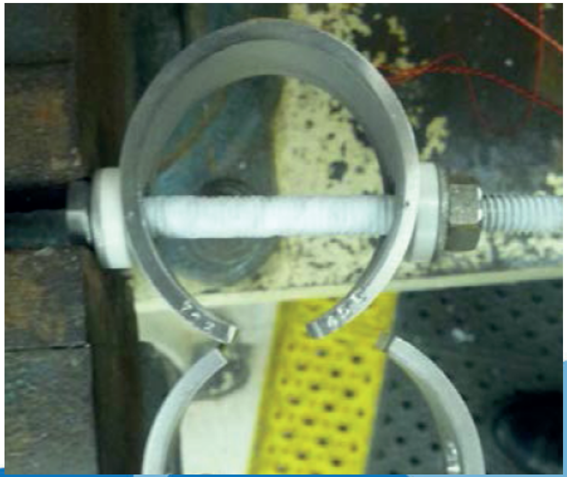
Sensitized, 80 °C, 28% RH





C-Ring SCC Testing

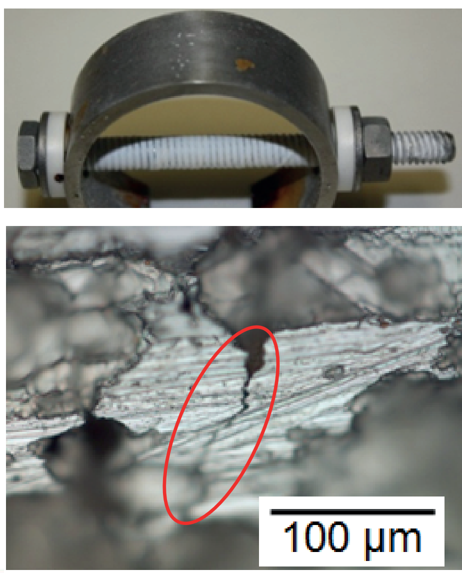
- Test objective: Evaluate lower strain condition relative to U-bend specimens
- Test methodologies:
  - Specimens fabricated following ASTM G38-01 and deposited with 1 or 10 g/m^2 of salt
  - Specimens strained to slightly above yield stress (~0.4% strain) or 1.5% strain, as measured by strain gage
  - Specimens exposed at conditions of 35^{o}C and 72% RH, 45^{o}C and 44% RH, and 52^{o}C and 32% RH (AH ~ 30 g/m^3 at each temperature)



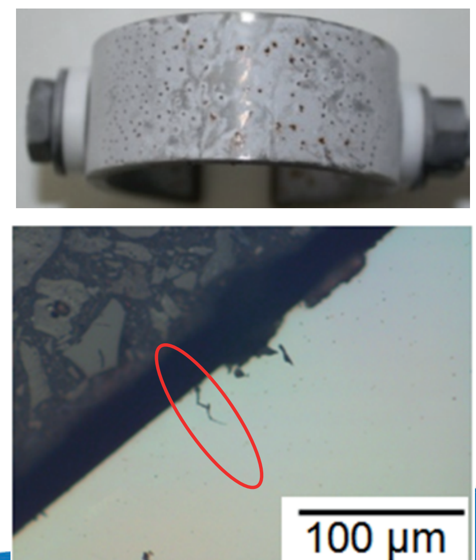
Test Results

Specimen Temp. (° C)	RH (%)	AH (g/m³)	Salt Concentration (g/m²)	Strain (%)	Exposure Time (months)	Crack Initiation
35	72	29	1	0.4	2	No
			10	0.4	3	Sensitized only
45	44	29	1	0.4	3	No
			10	0.4	3	No
				1.5	2	Sensitized and as-received
52	32	29	1	0.4	2	Sensitized and as-received
			10	0.4	3	Sensitized only
				1.5	2	Sensitized and as-received

Sensitized, 35°C, 0.4% strain, 10 g/m² salt



As-received, 45°C, 1.5% strain, 10 g/m² salt



Sensitized, 52°C, 0.4% strain, 1 g/m² salt

Non-Chloride-Bearing Species

- Other atmospheric species could arise from industrial, agricultural, and commercial activities

- Survey of atmospheric monitoring data in U.S. identified common species containing ammonium, sulfate, and nitrate ions

- Representative set of species were selected for testing:
  - Ammonium sulfate – $(NH_4)_2SO_4$
  - Ammonium bisulfate – NH_4HSO_4
  - Ammonium nitrate – NH_4NO_3
  - Fly ash – class F, mostly alumina, silica, and iron, less than 20% lime

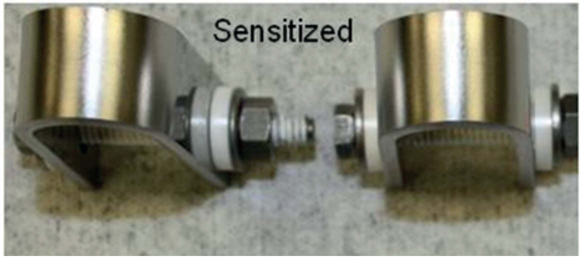
- Type 304 stainless steel U-bend specimens were exposed to the non-chloride-bearing species

Test Results

- No cracking observed on specimens exposed to any species, even at high RH
- Most specimens near pristine after removing salt, except for extensive general corrosion on specimens exposed to NH_4HSO_4
  - Deliquescent solution pH for most species is in range of about 4 to 5.
  - Deliquescent solution pH for NH_4HSO_4 is about -1 to -2.

Specimens exposed to NH_4NO_3

Specimens exposed to $NH_4NO_3 + (NH_4)_2SO_4$ mixture



Specimens exposed to NH_4HSO_4

Conclusions

- For simulated sea salt, SCC on Type 304 stainless steel is observed between 35 and 80 ^{o}C when RH is higher than about 20 to 30%. At lower temperatures, this RH may be reached at AH well below 30 g/m^3.

- SCC initiation is observed at salt quantity as low as 0.1 g/m^2 or strain as low as 0.4. The extent of cracking increases with increasing salt quantity or strain.

- Sensitized material seems more susceptible to SCC than material in as-received condition.

- No SCC was observed for specimens exposed to non-chloride-bearing species.

Regulatory Use

- Safety evaluations for initial and license renewal of site-specific storage facilities and cask system certificates of compliance

- Information Notice 2012-20, “Chloride-Induced Stress Corrosion Cracking of Austenitic Stainless Steel and Maintenance of Dry Cask Storage System Canisters”

- NRC–Nuclear Energy Institute Risk Informed Resolution Protocol on chloride-induced SCC

- EPRI Extended Storage Collaboration Program

Component Integrity Branch Research Activities

David Rudland
Branch Chief
RES/DE/CIB

ACRS Meeting of the Subcommittee on Materials, Metallurgy, & Reactor Fuels
January 14, 2014
Rockville, MD

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Introduction

Purpose, Outcomes, Process

- **Purpose**
  - Provide an overview of research topic areas and capabilities in Office of Nuclear Regulatory Research, Division of Engineering, Component integrity Branch as they support program offices needs
- **Outcomes**
  - Achieve a common understanding of RES/DE/CIB project areas and capabilities
  - Demonstrate projects are meeting, or have met, their goals
  - Demonstrate the project value added to the NRC
- **Process**
  - Overview of the major ongoing RES/DE/CIB projects
  - Detailed description of xLPR Version 2.0

CIB Materials Research
General Technical Areas

Work Request/Product

CIB Capabilities

	UNR#	UNR work title	MOU	Updates	Current Contracts
xLPR/Piping/CRDM/BMI	NRR-2010-018	Development of A Probabilistic Method For Evaluating The Probability Of Leak-Before-Break Of Nickel Based Alloys Exposed To Primary Water Environments	xLPR (2012) WRS (2012)	• xLPR pilot study NUREG - 2012 • ACRS xLPR presentations 2012/2013 • ACRS WRS Presentation 2013 • WRS NUREG 2013 • WRS validation • Emergent Support for LBB & Flaw Evaluations • CRDM/BMI work • ASME Code Support	• V6444- Emc2 - LBB Reg guide • V6411 - PNNL - xLPR inspection • V6375 - Battelle - Piping integrity • V6260 - SNL - xLPR V2 • Internal efforts on xLPR, WRS Validation, LBB support, flaw evaluation support
	NRR-2013-xxx	Implementation Of Probabilistic Methods For Evaluating Leak-Before-Break Of Nickel Based Alloys Exposed To Primary Water Environments			
	NRR-2013-yyy	Flaw Evaluation, Repair And Mitigation Techniques For Primary Water Stress Corrosion Cracking			
	NRO-2013-zzz	Technical LBB Support for New Reactors			
RPV	NRR-2007-001	RPV Integrity issues	none	• Appendix H to NRR/NRO • RG199R3/TBD NUREG • Appendix G revision TBD • 50.61a Reg guide/NUREG under review • ASME Code Support	• N6438 - ORNL - RPV
NDE	NRR-2013-009	Evaluating The Reliabilty Of Nondestructive Examinations Of Vessels And Piping	NDE VP (2013) NDE (2011)	• 50.61a RPV Inspection review; • VT of RPV Internals; • UT in lieu of RT for fabrication, • Assess Industry Actions re: DMW, HPDE, CASS, • Inspector training/qualifications (PDI) • Effectiveness and reliability of field NDE • NDE modeling	• V6323 - PNNL - Capabilities and Reliability of NDE • V6411 - PNNL - xLPR inspection • V6097 - PNNL - Effect/Reliab of UT in lieu of RT • N6593 - PNNL - Assess Emerging NDE Methods • G6022 - ASME Grant - Convergence of International Codes
	NRR-2010-014	Volumetric Examination of Vessels and Piping (NDE VP)			
	NRR-2010-120 NRO-2010-008	Request for NDE of Polyethylene Piping and Fittings			
HDPE	NRR-2006-007	Development of a Technical Database on the Use of HDPE in Safety Related Piping Systems	HDPE (2011)	• HDPE piping in buried class 3 safety systems • Assess industry efforts • ASME Code Support	• V6245 - Emc2 - HDPE testing
EAF	NRR-2010-019 NRO-2010-006	Support for Environmental Fatigue Consultation and High Energy Line Break Criteria	EAF (50% co-funding by EPRI; expired 12/31/2012)	• Draft revision to NUREG/CR-6909 - June 2013. • Finalize NUREG/CR-6909 Rev. 1 for public review -- December 2013. • Revise Reg. Guide 1.207 for public review -- January 2014. • Issue NUREG and Reg. Guide - December 2014 • ASME Code Support	• V6069/V8269 - ANL - completed 9/30/2013

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Overview of RES/DE/CIB Project Areas

Integrity of Reactor Pressure Vessels

Purpose and Overview

- **Purpose**
  - Assess and document in technical reports the currency and adequacy of RPV rules and Reg guides. Update as required
- **Core Capabilities**
  - Embrittlement, Fracture Mechanics, Probabilistic Coding
- **Project Staff**
  - Mark Kirk, Gary Stevens, Michael Benson, Eric Focht
  - Contractor: ORNL (N6438)
- **Industry Cooperation**
  - EPRI MOU under development
- **Basis/Prioritization**
  - Requesting Office: NRR (UNR-2007-001). Updated being developed

RPV Integrity Work

UNR 2007-001 Investigations

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NRC Document	Last Rev	Regulatory Questions	Current Activities	Staff	ORNL*	ASME
Reg. Guide 1.99 (Embrittlement Prediction)	1988	Is current guidance adequate in view new data and understandings of embrittlement?	• Evaluation deferred in 2010 • Renewed effort to complete technical review and forge staff consensus	X		
10 CFR 50 App. H (Surveillance)	1984	• Is it still adequate to reference a 1982 ASTM standard? • Augmented guidance on integrated surveillance • Changes to reporting requirements	• Reviewed adequacy in 2008. Deferred. • Support NRR in renewed rulemaking push (SECY paper)	X		
10 CFR 50 App. G (Normal Operations)	1984	Is current guidance adequate in view of results from probabilistic studies and current understanding of flaws present RPVs?	Comprehensive evaluation of tech basis being concluded. TLRs being issued.	X	X	X
Reg. Guide 1.161 (Low Upper Shelf)	1995	Is current guidance adequate in view of new data?	Update ASME SC-XI App K, then retire RG	X		X
10 CFR 50.61 (PTS)	2010	Improve quality & uniformity of submittals by providing Inspection & surveillance guidance	DG-1299 developed, in NRR review	X	X	

* - All ORNL support is provided by project N6438

RPV Integrity Work

Status and Schedule

- **Ongoing support of emergent needs**
  - Doel (10/12 to 1/13)
  - Palisades (2/13 to date)
  - Reg. Issue Summary (RIS) on Extended Beltline (4/13 to date – out for public comment 3/14; issued 6/14)

- **Ongoing revision of current regulations and standards related to RPV integrity**
  - 10 CFR 50 App. H – 2014
  - 10 CFR 50.61a - completed in 2010. DG-1299 to be released for public comment Summer 2014
  - 10 CFR 50 App. G, RG1.161, & RG1.99
    - In all cases documentation of technical work being completed (2014)
    - Discussions will follow with NRR and NRO regarding need to and schedule for changes to the regulatory documents

- **Reactor embrittlement archive project (REAP)**
  - Available on-line since 2012
  - Enhanced search and capabilities will be added budget permitting

Nondestructive Evaluation

Purpose and Overview

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- **Purpose**
  - Confirm industry's new and revised NDE methods and qualification processes to the examination of new construction and operating plants
- **Core Capability**
  - NDE methods, qualification, and modelling
- **Project Staff**
  - Wally Norris, Carol Nove, Iouri Prokofiev, Josh Kusnick
  - Contractor: PNNL (V6323, V6411, V6097, V6286)
- **Industry Cooperation**: EPRI, IRSN/CEA
- **Basis/Prioritization**
  - Requesting Office: NRR UNRs: 2013-009, 2010-014, 2010-020, 2010-018); NRO UNR: 2010-008

Nondestructive Evaluation

Status and Schedule

- **Schedule/Status**
  - V6323: Effectiveness and Reliability of NDE for Vessels and Piping
    - Period of Performance: 05/01/12 – 05/31/17
    - 21 reports
  - V6097: UT in Lieu of RT for Repairs and Modifications
    - Project ends 8/31/14
    - 1 NUREG
  - V6286: Program to Assess Reliability of Emerging Nondestructive Techniques
    - Project ends 06/15
    - 1 NUREG

Nondestructive Evaluation

Status and Schedule

- **Schedule/Status**:
  - EPRI Agreement: MOU on Nondestructive Examination
    - Current MOU ends 03/31/14; extension in development
    - 10 reports
  - IRSN Agreement: Cooperation on the Inspection of Coarse-grained Materials and Dissimilar Metal Welds of Reactor System Components
    - Period of Performance:01/01/14 – 12/31/17
    - 7 reports

High Density Polyethylene

Purpose and Overview

- **Purposes**
  - Confirm proposed requirements for use in ASME Class 3 safety-related applications
  - Support NRR and NRO in ASME code actions and roadmap, and relief requests

- **Core Capability**
  - HDPE testing and analysis

- **Project Staff**
  - Eric Focht
  - Contractor: Emc^2 (V6245)

- **Industry Cooperation**
  - MOU with EPRI on HDPE piping integrity
  - Industry collaboration through the Nuclear Energy Standards Coordination Collaborative (NESCC)

- **Basis/Prioritization**
  - Requesting Office: NRR (UNR-2006-007, UNR-2011-001)

High Density Polyethylene

Status and Schedule

- **Status**
  - Confirmatory research on parent and fusion joint integrity
    - Specimen and pipe section testing underway
  - NDE
    - Limited evaluations of fusion joints to confirm detection capabilities

- **Schedule**
  - Impacted significantly by sequestration/budget issues
  - Piping integrity evaluation ends in FY14
  - NDE on hold starting mid-FY14

Environmental Assisted Fatigue

Purpose and Overview

- **Purpose**
  - To update the existing EAF evaluation methodology and develop techniques for applying this method for structural and component evaluations
- **Core Capability**
  - Environmental fatigue testing, data analysis
- **Project Staff**
  - RES: Gary Stevens
  - Contractor: ANL (Dr. Omesh Chopra)
- **Industry Cooperation**
  - EPRI MOU Addenda on EAF (expired 12/31/2012)
    - Research was 48% co-funded by EPRI
- **Basis/Prioritization**
  - Requesting Offices: NRR and NRO (Dual User Need)
    - UNR NRR-2010-019/NRO-2010-006

Environmental Assisted Fatigue

Status and Schedule

- **Deliverables**
  - Knowledge management turnover from Contractor
  - Revision to NUREG/CR-6909
  - Revision to Reg. Guide 1.207
- **Status**
  - Research complete; finalizing documents for public comment process
- **Schedule**
  - Final drafts of documents anticipated by 01/31/2014
  - Public comment period Summer 2014
  - Issued in 2015

Extremely Low Probability of Rupture (xLPR)

Purpose

- 10CFR50 Appendix A GDC-4 allows local dynamic effects of pipe ruptures to be excluded from design basis if pipe ruptures have Extremely Low Probability of occurrence

- Effect is to eliminate need for whip restraints and jet impingement shields

- Conservative deterministic flaw tolerance analyses developed and incorporated in SRP3.6.3 to demonstrate leak-before-break (LBB) and satisfy GDC-4. No active degradation!

- No quantitative procedure available for assessing probability of occurrence with active degradation

NRR User Need Requests

Past

- **NRR-2005-011 – PWSCC in LBB systems**
  - LBB short term solution confirmation.
    - Mitigation
    - Inspection
  - Develop LBB long term solution strategy
  - Closed out July 2011
- **NRR-2006-006 – PWSCC in Nickel-based Alloy Components**
  - RPV head integrity issues
  - CRDM/Butt weld probabilistic rupture assessment
  - Crack growth rate confirmation
  - PWSCC NDE
  - Closed out July 2011

NRR User Need Request

Current

- **NRR-2010-018 – Probabilistic Method for LBB**
  - Develop long term LBB solution including impact of short term solution.
  - Deliver a flexible, modular probabilistic fracture mechanics code for evaluation of PWSCC in dissimilar metal butt welds - eXtremely Low Probability of Rupture (xLPR) code
    - Include active degradation modes
    - Include inspection/mitigation/repair strategies
    - Correctly quantify, characterize, and propagate uncertainties
  - Deliver technical basis and Regulatory Guide for LBB
  - UNR currently being updated

Core Capabilities

xLPR

- **Capabilities**
  - Fracture Mechanics
  - Stress Corrosion Cracking
  - Weld Residual Stress Analyses and Measurements
  - Probabilistic/Stochastic Modeling
  - NDE/Probability of Detection and Sizing
- **Staff**
  - David Rudland, Eric Focht, Gary Stevens, Michael Benson, Shah Malik, Josh Kusnick
- **Contractors**
  - SNL(V6260), Emc^2(V6444), Battelle(V6375), PNNL(V6411), ORNL(N6438)

Code Development

Team Members

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<u>Code Development Leads</u>
David Rudland – U.S. NRC
Craig Harrington – EPRI

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Aubrey Eckert– Sandia National Laboratories
Mariner, Paul– Sandia National Laboratories
Patrick Mattie - Sandia National Laboratories
Robert Kurth – Emc2
Dilip Dedhia – Structural Integrity Associates
David Harris– Structural Integrity Associates
Paul Williams – Oak Ridge National Laboratory
Scott Sanborn – PNNL
Ian Miller – GoldSim
Ryan Roper - GoldSim

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Nathan Palm – Westinghouse

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Bruce Bishop – PEAI
Rob Tregoning – U.S. NRC
Jay Collins– U.S. NRC
Ted Sullivan – PNNL

<u>Program Manager</u>
Nate Leech - Demark

<u>Models Group</u>
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Eric Focht– U.S. NRC
Mike Benson– U.S. NRC
Mark Kirk – U.S. NRC
Kyle Schmitt – Dominion Engineering
John Broussard– Dominion Engineering
Glenn White– Dominion Engineering
Chris Casarez – Dominion Engineering
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Elizabeth Kurth – Emc2
Bud Brust – Emc2
Suresh Kalyanam– Emc2
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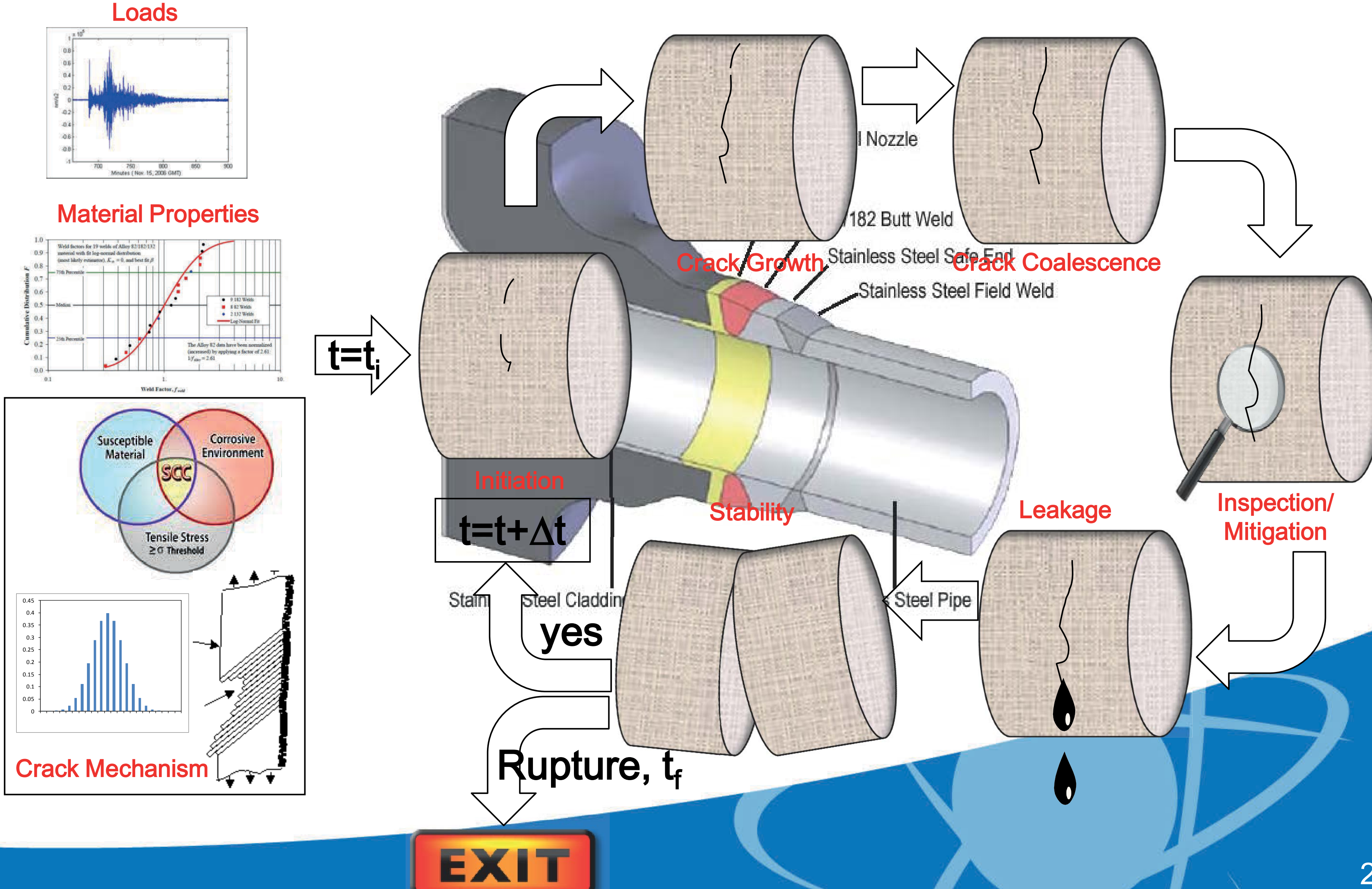
Cliff Lange – Structural Integrity Associates
Steven Xu – Kinectrics
Doug Scarth – Kinectrics
Russ Cipolla – Aptech
Mike Hill – UC Davis
Steve Fyfitch – AREVA NP Inc.
Rick Olson – Battelle
Andrew Cox – Battelle
Lee Fredette – Battelle
Bruce Young – Battelle
Patrick Heasler – PNNL
Mark Dennis - EPRI
Carl Latiolais- EPRI
Thiago Seuaciuc-Osorio- EPRI

<u>QA Group</u>
Nancy Kyle – Theseus
xLPR Team

U.S.NRC United States Nuclear Regulatory Commission *Protecting People and the Environment*
EPRI ELECTRIC POWER RESEARCH INSTITUTE
OAK RIDGE NATIONAL LABORATORY MANAGED BY UT-BATTELLE FOR THE U.S. DEPARTMENT OF ENERGY
Sandia National Laboratories
PEAI
Structural Integrity Associates, Inc.
Exelon
Pacific Northwest NATIONAL LABORATORY
KINECTRICS
Emc2
GoldSim
AREVA
Dominion Engineering, Inc.
Westinghouse
Battelle *The Business of Innovation*

Cooperative effort between NRC and EPRI through Memorandum of Understanding

PFM Technical Flow



xLPR Pilot Study

- Conducted from 2009-2011
- Pilot study objectives
  - Develop and assess xLPR management structure
  - Determine the appropriate probabilistic framework
  - Assess the feasibility of developing a modular-based probabilistic fracture mechanics computer code
- Focused on pressurizer surge nozzle DM weld with PWSCC
- Development of Version 1.0 code using comprehensive configuration management
- Developed detailed program plan (objective, schedule, deliverables, budget, communications) for Version 1.0 and Version 2.0 code

xLPR Code Feasibility

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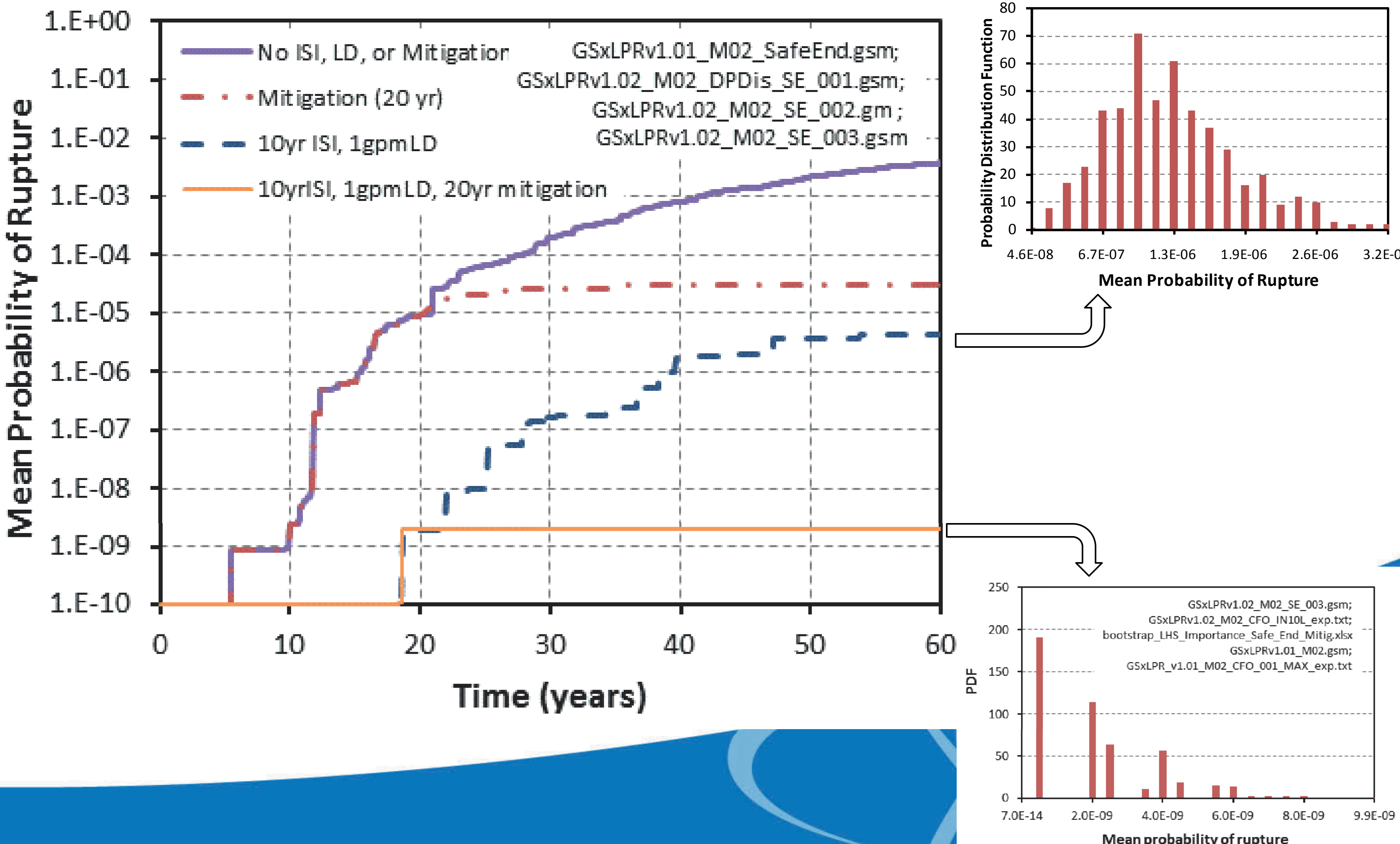
Westinghouse-type pressurizer surge nozzle dissimilar metal weld



Pilot Study Results

- The project team demonstrated that **<u>it is feasible</u>** to develop a modular-based probabilistic fracture mechanics code within a cooperative agreement while properly accounting for the problem uncertainties

- Identified potential efficiency gains in the program management structure

- Selected commercial software as the computational framework
  – Based on the framework code comparison, a cost analysis, and long term prospects

xLPR Version 2.0

- Version 2.0 is expanded to handle welds within piping systems approved for LBB
  - Appropriate materials, loads, degradation mechanisms, mitigation, inspection, leak detection

- Rigorous quality assurance including verification and validation (V&V) process

- Capabilities of Version 2.0 will meet requirements for LBB lines, but <u>must stay</u> within available cost and schedule limitations

- Model inclusion in xLPR Version 2.0 does not guarantee regulatory approval.

xLPR Benefits to NRC

- Quantified solution to LBB issue
  - Regulatory Guide
  - Update to SRP3.6.3

- Fully QA'ed modular probabilistic fracture mechanics code for reactor pressure boundary integrity
  - LBB including evaluation of mitigation for DM welds
  - Research tool for prioritization
  - TBS – 50.46a
  - Risk informed ISI
  - GSI191
  - Effects of seismic loading on integrity
  - Easily adaptable to other applications

xLPR Acceptance

- Office of Nuclear Reactor Regulation (NRR) leading effort to develop xLPR Acceptance criteria

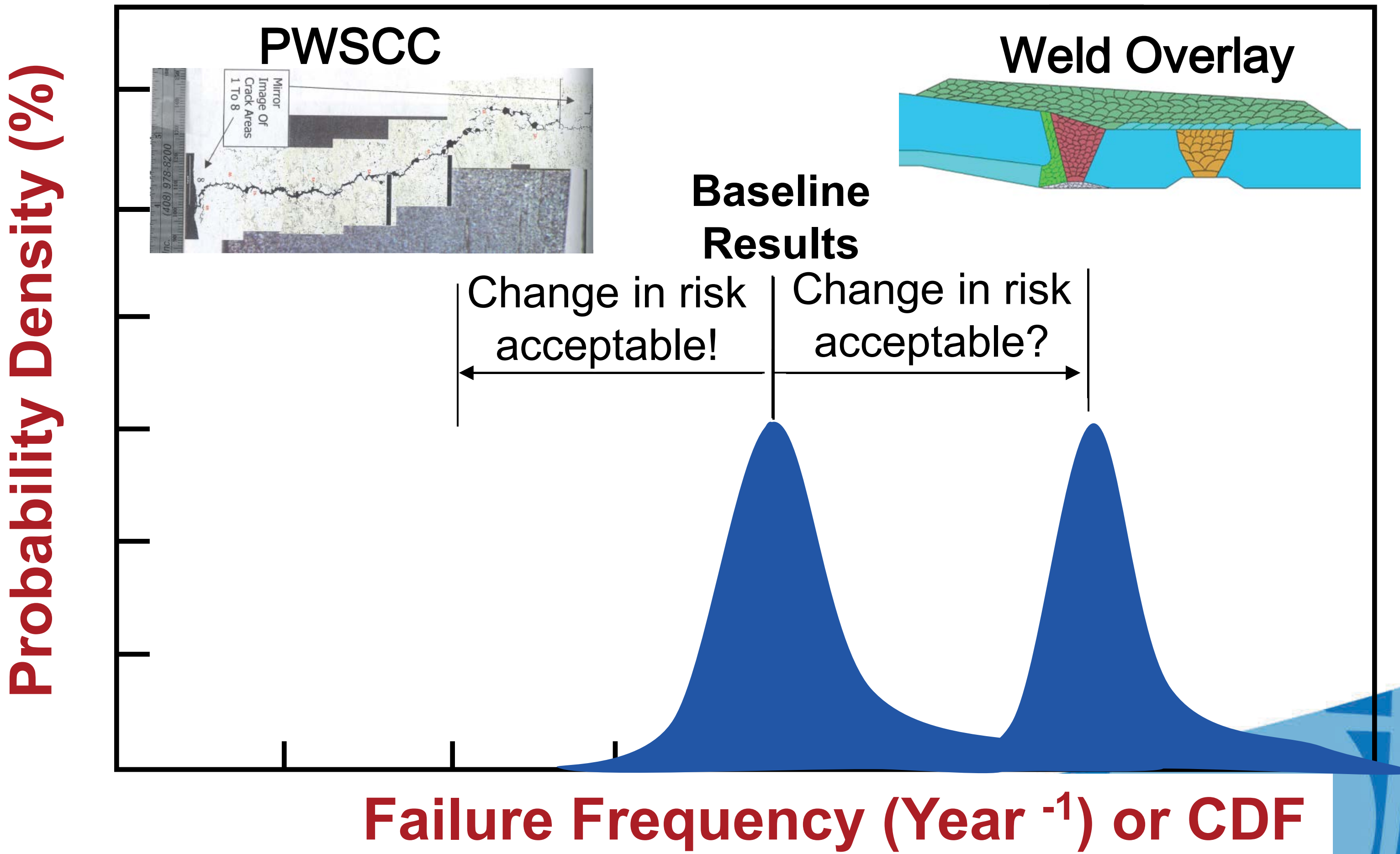
- Acceptance questions considered
  - What constitutes acceptable inputs?
  - What constitutes acceptable results?
    - Guidance on risk limits as an NRC regulatory position for LBB
  - What constitutes an acceptable delivery vehicle for this information?
    - NUREG? Regulatory Guide? Other?
  - Who conducts evaluations?
    - Industry? NRC? Plant specific analysis? Generic analysis?

- Acceptance criteria under development

- The xLPR Acceptance group will evaluate changes in risk (Δ-Risk)
  - Intent is to use existing acceptable risk values

Using xLPR for LBB

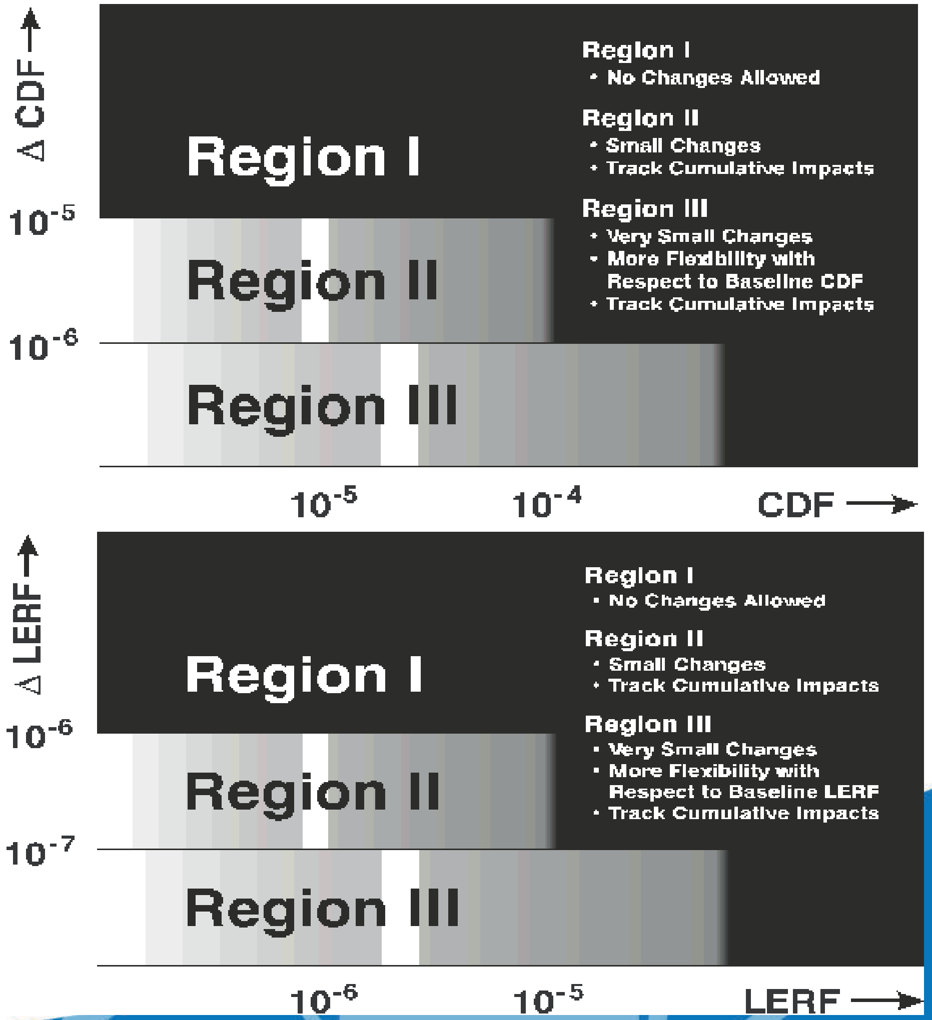
Conduct analyses with baseline conditions (as used in SRP3.6.3)
Conduct analyses with modified condition



Possible Acceptance Criteria

Under Development

- Regulatory Guide 1.174 provides guidance on
  - Core Damage Frequency (CDF) and ΔCDF
  - Large Early Release Frequency (LERF) and ΔLERF
- Advantage
  - Criteria developed
  - NRC has experience with RG1.174 approach
- Work is continuing



Extremely Low Probability of Rupture (xLPR)

Status and Schedule

- xLPR Version 2 (LBB) underway
- Project Deliverables:
  - Version 1.0 (pilot study) - March 2012
  - Version 2.0 (LBB)
    - Beta March 2014
    - V&V code - Sept 2014
    - Delayed due to sequestration/budget issues
  - LBB Regulatory Guide – 2015/2016
- RES/DE/CIB have briefed ACRS on xLPR, WRS, and PWSCC crack initiation

Corrosion & Metallurgy Branch
Division of Engineering
Office of Nuclear Regulatory Research

Meeting of

the ACRS Subcommittee on Materials, Metallurgy, & Reactor Fuels

January 14, 2014

Introduction

- **Purpose**
  - Provide an overview of research topic areas in the Corrosion and Metallurgy Branch (CMB) as they support program offices needs
- **Outcomes**
  - Achieve a common understanding of RES/DE/CMB project areas and capabilities
  - Demonstrate the project value added to the NRC
- **Process**
  - Overview of the major ongoing RES/DE/CMB projects
  - Detailed review of the Stress Corrosion Cracking of Dry Casks Project

Aging of Neutron Absorbers in Spent Fuel Pools

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- **Purpose**: Develop technical bases for the aging management of neutron absorber materials
- **Basis**: User Need Request (UNR) NRR-2010-015 and NRR-2013-005: Develop the Technical Bases for the Evaluation of Neutron Absorbing Materials in Spent Fuel Pools
- **Regulatory Use:** Review license amendment requests and determine what future regulatory actions may be warranted
- **Contract Support**: Consultants Tom Haley and Mohamad Al-Shiekhly, and ORNL
  - Technical Letter Report (TLR), “Boraflex, RACKLIFE, and BADGER: Description and Uncertainties,” September, 2012
  - TLR, “Initial Assessment of Uncertainties Associated with the BADGER Methodology,” September, 2012
  - TLR, “Monitoring Degradation of Phenolic Resin-Based Neutron Absorbers in Spent Nuclear Fuel Pools,” June, 2013

Aging of Neutron Absorbers in Spent Fuel Pools (cont.)

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- **Key Results**:
  - BADGER methodology uncertainties, e.g., excessive gamma field, head misalignment and setpoint drift for electronics, can significantly impact measurement results
  - Predicted degradation for Boraflex and phenolic resin neutron absorbers and, thus, the postulated mechanisms are consistent with operating experience
    - for Boraflex the degradation can be related to gamma dose
    - for phenolic resin neutron absorbers, there is no straight correlation between gamma dose and degradation

Stress Corrosion Cracking of Dry Storage Canisters

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- **Purpose:** Evaluate the SCC susceptibility of austenitic stainless steel for spent fuel dry storage canisters exposed to atmospheric chloride salts
- **Basis**: UNR NMSS-2011-002: Extended Storage and Transportation Regulatory Program Review, which continued work from UNR NMSS-2005-001: Determine Susceptibility of Austenitic Stainless Steel Spent Fuel Storage Casks to Chloride-Induced Stress Corrosion Cracking Under Coastal Atmosphere Exposure
- **Regulatory Use:** Inform safety evaluations and licensing actions for storage facilities
- **Contract support**: Center for Nuclear Waste Regulatory Analyses (CNWRA)
  - Draft NUREG/CR-7170, “Assessment of Stress Corrosion Cracking Susceptibility for Austenitic Stainless Steels Exposed to Atmospheric Chloride and Non-Chloride Salts,” March 2014
  - NUREG/CR-7030, “Atmospheric Stress Corrosion Cracking Susceptibility of Welded and Unwelded 304, 304L, and 316L Austenitic Stainless Steels Commonly Used for Dry Cask Storage Containers Exposed to Marine Environments," October 2010

Stress Corrosion Cracking of Dry Storage Canisters (cont.)

- **Key Results:**
  - Austenitic stainless steels are susceptible to chloride stress corrosion cracking (SCC) under environmental conditions where accumulated salts can absorb moisture from the environment
  - SCC initiation is observed at the lowest salt surface concentration tested, 0.1 g/m^2, which is much lower than reported in some previous studies
  - SCC initiation is observed at low strains (0.4%), where the stress is close to the yield strength of the austenitic stainless steels
  - No SCC was observed with non chloride salts that are expected from atmospheric deposits from non-coastal environments

Vacuum Drying of Spent Fuel Canisters

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- **Purpose:** Develop a test plan for measuring the quantity of residual water that remains in spent fuel canisters after vacuum drying
- **Basis**: UNR NMSS-2011-002: Extended Storage and Transportation Regulatory Program Review
- **Regulatory Use:** Determine if experimental testing could be used to confirm the adequacy of current regulatory guidance for vacuum drying during canister loading
- **Contract Support**: CNWRA
    - TLR, "Vacuum Drying Test Plan," July 2013
    - TLR, "Overview of Vacuum Drying and Factors Affecting the Quantity of Residual Water," July 2013

Vacuum Drying of Spent Fuel Canisters (cont.)

- **Key Results:**
  - Testing can be conducted using specially instrumented fuel assembly and canister mockups to determine the amount of residual water remaining after drying of a loaded spent fuel storage canister/cask
  - A test plan to measure the residual water was developed and equipment necessary to conduct the measurements is commercially available
  - No testing is planned by NRC at this time because a similar project is being sponsored by DOE

Functional Monitoring of Dry Cask Storage Systems

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- **Purpose(s):** Review available monitoring technologies (e.g. temperature, humidity, corrosion, etc.) for spent fuel dry storage casks, and identify where improved technology may enhance future monitoring capabilities

- **Basis**: UNR NMSS-2011-002: Extended Storage and Transportation Regulatory Program Review

- **Regulatory Use:** Develop regulatory guidance for monitoring and evaluation of proposed industry actions to mitigate degradation in dry cask storage systems

- **Contract support**: CNWRA
  - Draft TLR, "Available Methods For Functional Monitoring of Dry Cask Storage Systems (DCSS)," February 2014

Functional Monitoring of Dry Cask Storage Systems (cont.)

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- **Key Results:**
  - Monitoring temperature and relative humidity on external surfaces of storage canisters/casks is feasible by adapting existing probes and instrumentation
  - Monitoring corrosion and cracking on canisters casks requires advances in the state of the art and would be difficult to implement safely
  - Monitoring internal structures systems and components does not appear to be possible with existing dry cask storage system designs

Containment Liner Corrosion

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- **Purpose(s):** Develop a model to calculate the corrosion rates for a liner plate abutted by debris embedded in the concrete, and develop a model to estimate the leakage from containment during a design-basis loss-of-coolant accident
- **Basis**: UNR NRR-2010-002: Containment Liner Corrosion
- **Regulatory Use:** Determine if additional inspections of the containment liner are needed beyond that currently implemented in accordance with the ASME Code Section XI Subsection IWE
- **Contract Support**: CNWRA
  - TLR, "Containment Building Liner Corrosion – Corrosion and Leak Rate Models," July 2013
  - TLR, "Containment Liner Corrosion Operating Experience Report Revision 1," August 2011
  - Nuclear Containment Steel Liner Corrosion Workshop, July 2011

Containment Liner Corrosion (cont.)

- **Key Results:**
  - Corrosion cell at liner is not likely to support both a high corrosion rate and large corroded area
  - Through wall corrosion of the containment liner is initiated from foreign objects left in concrete during initial construction
  - Leak rate is controlled by the size of the hole in the containment liner when the hole is small (~10 mm^2)
  - Radioisotope releases would be largely restricted by a narrow gap between liner and containment wall and the concrete permeability

Leak Path Assessment of North Anna CRDM Nozzle 63

- **Purpose:** Evaluate phased-array ultrasonic testing (UT) to detect a primary water leakage path between reactor upper head penetration and the reactor pressure vessel head
- **Basis**: UNR NRR-2006-006: Information on PWSCC of Nickel-Base Alloy Primary Pressure Boundary Components
- **Regulatory Use:** The results are expected to help the staff interpret and evaluate licensee' ultrasonic leak path assessments for upper head penetrations
- **Contract Support**: PNNL
  - NUREG/CR-7142, "Ultrasonic Phased Array Assessment of the Interference Fit and Leak Path of the North Anna Unit 2 Control Rod Drive Mechanism Nozzle 63 with Destructive Validation," August 2012

Leak Path Assessment of North Anna CRDM Nozzle 63 (cont.)

- **Key Results:**
  - Leakage path detected by UT was confirmed by destructive examination of the nozzle
  - Pattern of boric acid deposits observed with phased-array ultrasonic testing UT was in agreement with observations from destructive examination
  - Minimal corrosion of the low alloy steel reactor pressure vessel head was observed

Irradiation-Assisted Degradation

- **Purpose:** Develop the technical bases for assessing irradiation-assisted degradation of reactor core internals and potential synergetic effects between thermal and neutron embrittlement in cast austenitic stainless steels (CASS)

- **Basis**: UNR NRR-2012-008: Environmentally Assisted Degradation of Light Water Reactor Internal Components

- **Regulatory Use:** Evaluate effectiveness of aging management programs as required by MRP-227A

- **Contract Support**: EPRI, PNL, ANL, and INL
  - TLR, "Slow Strain Rate Tensile Tests on Irradiated Stainless Steels in PWR Environment," June 2012
  - TLR, "Cracking of Irradiated Stainless Steels in Low Corrosion Potential Environments," May 2013
  - NUREG/CR-7128, "Void Swelling and Microstructure of Austenitic Stainless Steels Irradiated in the BOR- 60 Reactor," November 2012
  - TLR, "Crack Growth Rate and Fracture Toughness Tests on Irradiated Cast Stainless Steels," November 2012

Irradiation-Assisted Degradation (cont.)

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- **Key Results:**
  - In low corrosion potential environments representative of PWR conditions, testing of both cold worked and non-cold worked stainless steels exhibited increasing SCC crack growth rates with increasing fluence levels from 5 up to 25 dpa
  - Consistent with previous test results at lower fluence levels, the fracture toughness of these same stainless steels decreases with increasing fluence up to 8 dpa; between ~5 and 8 dpa, the J values at crack initiation were below 100 kJ/m2
  - In a limited set of thermally aged cast austenitic stainless steel samples, low dose (0.08 dpa) neutron irradiation decreased fracture toughness in addition to the decrease from thermal ageing alone

Primary Water Stress Corrosion Cracking

- **Purpose**: Evaluate the use of high chromium alloys and weld metals used in replacement components and repairs for PWSCC mitigation
- **Basis**: UNR NRR-2006-006: PWSCC of Nickel-Based Alloy Primary Pressure Boundary Components, which was an extension of UNR NRR-2010-018: Development of a Probabilistic Method for Evaluating the Probability of Leak-Before-Break of Nickel-Based Alloys
- **Regulatory Use**: Develop safety evaluation criteria of Ni-base primary system pressure boundary components subject to PWSCC degradation
- **Contract Support:** PNL and ANL
    - NUREG/CR-7103, "Stress Corrosion Cracking in Nickel-Base Alloys," Vol. 1, September 2011, & Vol. 2, April 2012
    - TLR, "Primary Water Stress Corrosion Cracking Tests and Metallurgical Analyses of Davis-Besse Control Rod Drive Mechanism Nozzle #4," August 2013
    - NUREG/CR-7137, "Stress Corrosion Cracking in Nickel-Base Alloys 690 and 152 Weld in Simulated PWR Environment," June 2012

Primary Water Stress Corrosion Cracking (cont.)

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- **Key Results:**
  - Alloy 690 is strongly resistant to PWSCC unless subjected to cold work
  - In initial testing, alloy 690 weld heat affected zones (HAZ) also appears to be resistant to PWSCC
  - Alloy 52 and 152 weld metals are more resistant to PWSCC compared to alloys 82 and 182
  - Preliminary testing has shown that disimilar metal weld dilution zones may be susceptible to PWSCC

Subsequent License Renewal

- **Purpose**: Provide technical information to support the development of a regulatory framework for licensing a second period of extended operation, i.e., from 60 to 80 years
- **Basis**: UNR 2010-006: Research Support in Developing Technical Information to Support License Renewal Beyond 60 Years
- **Regulatory Use**: Develop subsequent license renewal guidance bases documents
- **Contract Support:** ORNL & ANL and MOUs with EPRI and DOE
  - TLR, “Aging Management Program Effectiveness Audits,” May 2013
  - TLR, “Evaluation of International Periodic Safety Assessments,” December 2013
- **Key Results:**
  - LR guidance documents will be revised in a few places because of audit results at Ginna, Nine Mile-1, & Robinson-2
  - No generic conclusions can be drawn from only 3 audits
  - The review of PSR lessons learned showed no deficiencies or shortcomings in the reactor oversight program or license renewal process

Expanded Materials Degradation Assessment

United States Nuclear Regulatory Commission
Protecting People and the Environment

- **Purpose: I**dentify knowledge gaps and research needs related to materials degradation for plant operation up to 80 years
- **Basis:** UNR NRR-2010-006: Research Support in Developing Technical Information to Support Evaluating the Feasibility of License Renewal Beyond 60 Years, which expands on UNR NRR-2004-003: NUREG/CR-6923, “Expert Panel Report on Proactive Materials Degradation Assessment”
- **Regulatory Use:** Develop technical input for regulatory reviews of potential subsequent license renewal applications and prioritize NRC research needs
- **Contract support**: ORNL co-funded by DOE Light Water Reactor Sustainability Program

  5 draft NUREG/CR reports, June 2014:

  Volume 1: Executive Summary of EMDA Process and Results

  Volume 2: Aging of Core Internals and Piping Systems

  Volume 3: Aging of Reactor Pressure Vessels

  Volume 4: Aging of Concrete and Civil Structures

  Volume 5: Aging of Cables and Cable Systems

Expanded Materials Degradation Assessment (cont.)

- **Key Results:**
  - No surprises or new mechanisms were identified by the expert panels
  - Additional information is needed to address knowledge gaps for subsequent license renewal, for example in the area of irradiation assisted degradation
  - Experts are in good agreement about what issues should be addressed further
  - General consensus exists regarding long term degradation mechanisms

Steam Generator Research

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- **Purpose:** Bolster the technical bases for SG non-destructive evaluations, tube integrity and consequential SG tube rupture (CSGTR)
- **Basis**: UNR NRR-2012-010: SG Inspection and Integrity Issues , which builds upon research conducted under all previous ones including the ones for CSGTR
- **Regulatory Use**: Support technical evaluations of licensee submissions and inspections of SG tubes
- **Contract Support**: ANL; 7 draft NUREG/CR reports and one draft TLR are under staff review:
  - Draft NUREG/CR, "Consequential SGTR Analysis For Westinghouse and Combustion Engineering Plants With Thermally-Treated Alloy 600 and 690 Steam Generator Tubes," April 2014
  - Draft NUREG/CR, "Algorithms to Automatically Analyze Eddy Current Data," May 2014
  - Draft NUREG/CR, "Creep and Leak Rate Models for Alloy 690 Steam Generator Tubes," June 2014

Steam Generator Research (cont.)

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- Draft NUREG/CR, "Stability of Circumferential Flaws in Once-through Steam Generator Tubes Under Thermal Loading During LOCA, MSLB, and FWLB," July 2014
- Draft NUREG/CR, "Leak Rates and Burst Pressures for Flaws in the U-bend Region of Steam Generator Tubes," August 2014
- Draft NUREG/CR, "Assessment of Eddy Current Methods to Detect and Size Flaws in the U-bend Region of Steam Generator Tubes," September 2014
- Draft NUREG/CR, "Development and Validation of Models for Predicting Leakage from Degraded Tube-to-Tubesheet Joints During Severe Accidents," July 2014
- Draft TLR, "Evaluation of Examination Guidelines for Pulled Steam Generator Tubes," April 2014

Steam Generator Research (cont.)

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- **Key Results (preliminary):**
  - Industry inspection and integrity models are often confirmed by NRC-sponsored research
  - Research periodically results in changes to industry guidelines or practices:
    - Leakage model – research found possible issues and industry changed guidelines
    - Pressurization rate – it was observed that rate can affect burst pressure; led to industry imposing limits on rates for in-situ and laboratory tube pressure testing.
    - Non-destructive examination – analyses under this program led industry to new work on inservice inspection data acquisition

Stress Corrosion Cracking Susceptibility of Austenitic Stainless Steels for Spent Fuel Dry Storage Canisters

Darrell Dunn
Corrosion & Metallurgy Branch
Division of Engineering
Office of Nuclear Regulatory Research

Meeting with the ACRS Subcommittee on Materials, Metallurgy, & Reactor Fuels

January 14, 2014

U.S.NRC
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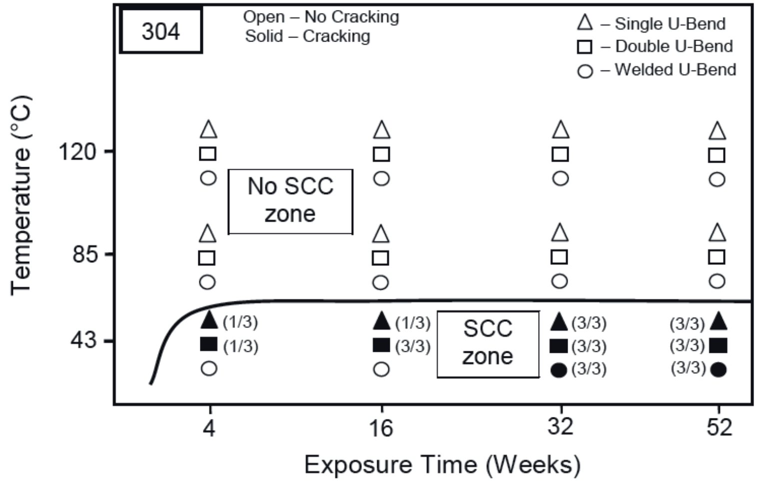
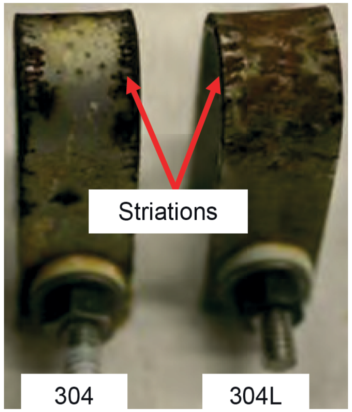
Background

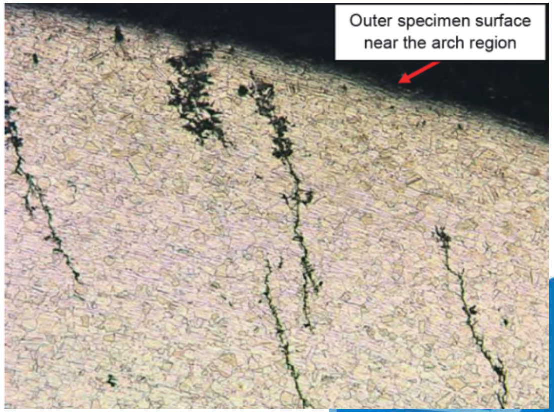
- Austenitic stainless steel is susceptible to stress corrosion cracking (SCC) in chloride-rich (i.e., marine) atmospheres
- Japanese studies at Central Research Institute for the Electric Power Industry (CRIEPI) since early 2000s
- Electric Power Research Institute (EPRI) topical reports in the mid-2000s
- Plant operational experience of SCC for outdoor stainless steel tanks and piping systems at near-coastal plants in the 1990s through 2000s

Previous NRC Research

- Office of Nuclear Regulatory Research (RES) sponsored at Southwest Research Institute, published as NUREG/CR-7030 in 2010
- Type 304 and 316 stainless steel U-bends deposited with simulated sea salt and exposed for up to 1 year at 43, 85, and 120 °C
- Only cracking at lowest temperature because relative humidity (RH) high enough for deliquescence







Specimens exposed at 43 °C

Motivation for Current Research

- Differences between CRIEPI studies and NUREG/CR-7030, including CRIEPI reports of SCC initiation at less aggressive conditions

- Important degradation scenario in the NRC report "Identification and Prioritization of the Technical Information Needs Affecting Potential Regulation of Extended Storage and Transportation of Spent Nuclear Fuel" (TIN Report) and other gap analyses

- Office of Nuclear Materials Safety and Safeguards (NMSS) User Need Request NMSS-2011-002, "Extended Storage and Transportation Regulatory Program Review"

Scope of Research Program

United States Nuclear Regulatory Commission
Protecting People and the Environment

- RES sponsored program at Center for Nuclear Waste Regulatory Analyses between October 2011 and October 2013

- Chloride salt tests, primarily with simulated sea salt:
  - Deliquescence measurements
  - Cyclic humidity
  - Elevated temperature
  - High humidity
  - Various strain levels

- Non-chloride species tests with nitrate, sulfate, and ammonium-rich salts:
  - Deliquescence measurements
  - Exposure only to non-chloride species
  - Exposure to chloride and non-chloride species mixtures

- Results of the research program will be published as NUREG/CR-7170 in early 2014

Cyclic Humidity SCC Testing

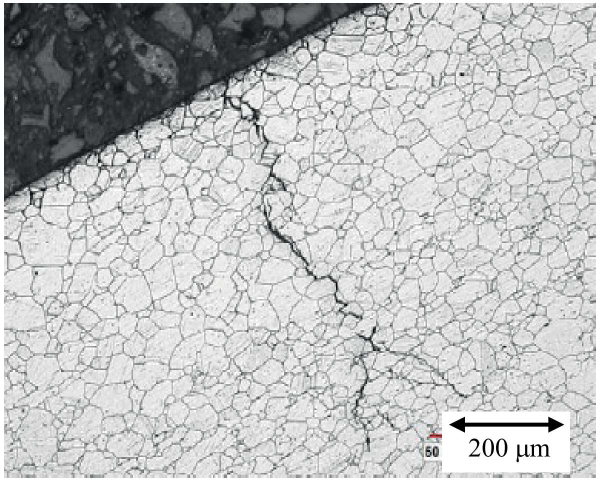
- Test objectives:
  - Limit absolute humidity (AH) to about 30 g/m^3
  - Vary test temperature
  - Vary surface salt concentration and material condition

- Test methodology:
  - Deposited 0.1, 1, or 10 g/m^2 of sea salt on ASTM G30 U-bend specimens
    - Expose to salt fog for various times
    - Quantity determined by control specimen weight gain
  - Type 304 in as-received or furnace sensitized (2 hours at 650 ^{o}C) conditions
  - Exposed in test chamber to cyclic AH between about 15 and 30 g/m^3

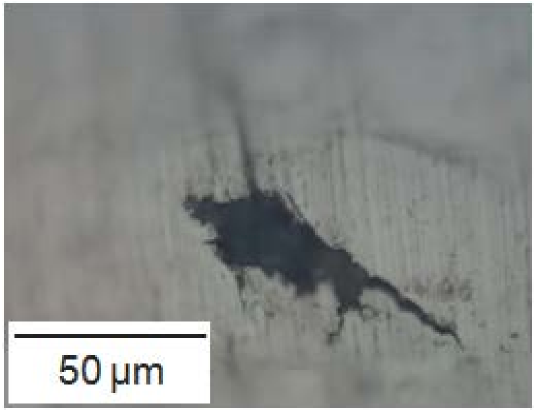
Test Results

Specimen Temp. (°C)	RH Range (%)	Exposure Time	SCC Observed?	Lowest salt concentration at which SCC was observed
27	56-100	8 months	No	N/A – salt deliquesced and drained off
35	38-76	4 – 12 months	Yes	0.1
45	23-46	4 – 12 months	Yes	0.1
52	16-33	2.5 – 8 months	Yes	1
60	12-23	6.5 months	Yes	10

Pitting on specimens at 10 g/m^2 (top), 1 g/m^2 (middle), and 0.1 g/m^2 (bottom)



Cross section of sensitized, 0.1 g/m^2 specimen at 45°C after 4 months



Top view of sensitized, 10 g/m^2 specimen at 60°C for 6.5 months

Elevated Temperature SCC Testing

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Protecting People and the Environment

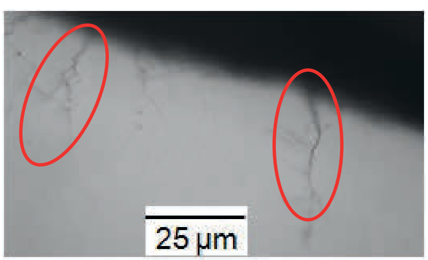
- Test objective: Evaluate SCC susceptibility at temperature up to 80 °C
- Test methodology:
  - Deposited 10 g/m^2 of sea salt on ASTM G30 U-bend specimens
  - Exposed specimens in test chamber at different humidity levels at 60 and 80 °C

Test Conditions			
Specimen Temp. (° C)	**Relative Humidity (%)**	**Absolute Humidity (g/m^3)**	**Maximum Test Duration (Months)**
60	22	29	1
	25	33	2.75
	30	39	5.75
	35	46	1
	40	52	1.5
80	28	82	2.5
	35	102	2.25
	40	117	1

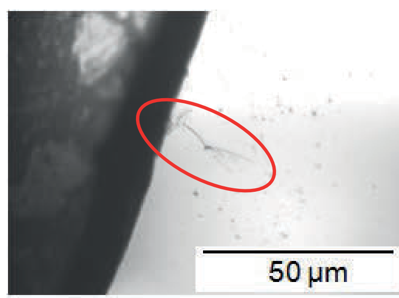
Test Results

- SCC initiation observed at RH as low as 25% at 60 ^{o}C and 28% at 80 ^{o}C, though at AH above 30 g/m^3
- Sensitized specimens showed greater extent of cracking

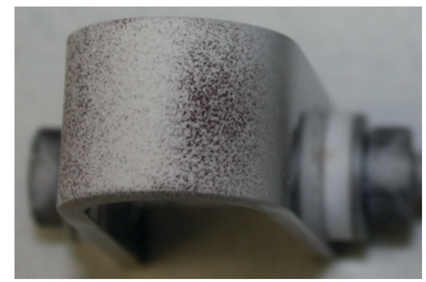
Sensitized, 60 ^{o}C, 30% RH

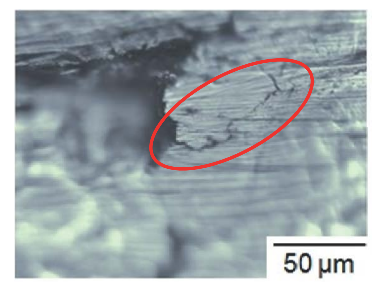


As-received, 80 ^{o}C, 35% RH



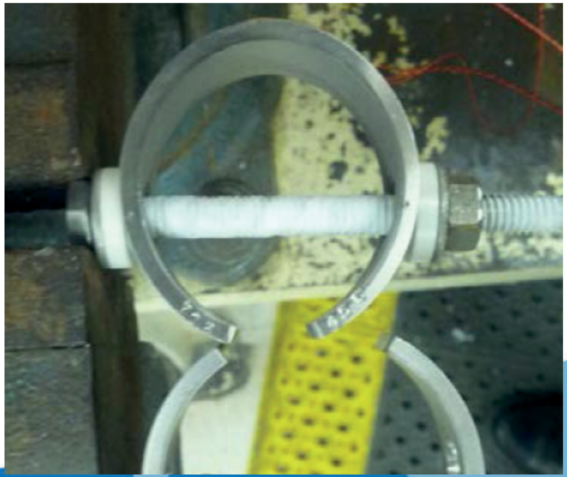
Sensitized, 80 ^{o}C, 28% RH





C-Ring SCC Testing

- Test objective: Evaluate lower strain condition relative to U-bend specimens
- Test methodologies:
  - Specimens fabricated following ASTM G38-01 and deposited with 1 or 10 g/m^2 of salt
  - Specimens strained to slightly above yield stress (~0.4% strain) or 1.5% strain, as measured by strain gage
  - Specimens exposed at conditions of 35°C and 72% RH, 45°C and 44% RH, and 52°C and 32% RH (AH ~ 30 g/m^3 at each temperature)



Test Results

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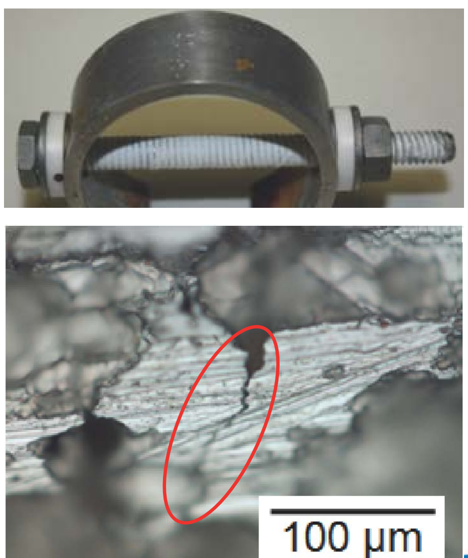
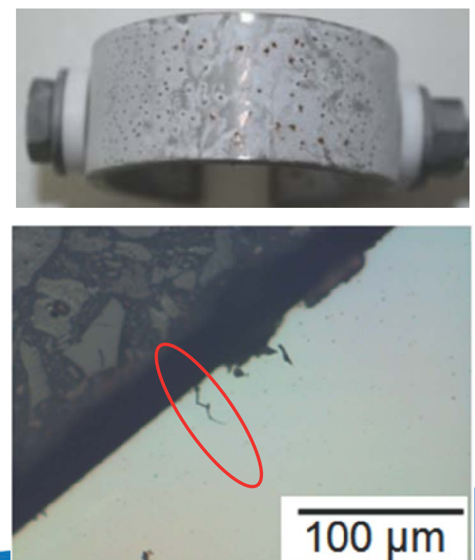
Specimen Temp. (° C)	RH (%)	AH (g/m³)	Salt Concentration (g/m²)	Strain (%)	Exposure Time (months)	Crack Initiation
35	72	29	1	0.4	2	No
			10	0.4	3	Sensitized only
45	44	29	1	0.4	3	No
			10	0.4	3	No
				1.5	2	Sensitized and as-received
52	32	29	1	0.4	2	Sensitized and as-received
			10	0.4	3	Sensitized only
				1.5	2	Sensitized and as-received

Sensitized, 35°C, 0.4% strain, 10 g/m² salt



As-received, 45°C, 1.5% strain, 10 g/m² salt



Sensitized, 52°C, 0.4% strain, 1 g/m² salt

Non-Chloride-Bearing Species

- Other atmospheric species could arise from industrial, agricultural, and commercial activities

- Survey of atmospheric monitoring data in U.S. identified common species containing ammonium, sulfate, and nitrate ions

- Representative set of species were selected for testing:
  - Ammonium sulfate – $(NH_4)_2SO_4$
  - Ammonium bisulfate – NH_4HSO_4
  - Ammonium nitrate – NH_4NO_3
  - Fly ash – class F, mostly alumina, silica, and iron, less than 20% lime

- Type 304 stainless steel U-bend specimens were exposed to the non-chloride-bearing species

Test Results

- No cracking observed on specimens exposed to any species, even at high RH
- Most specimens near pristine after removing salt, except for extensive general corrosion on specimens exposed to NH_4HSO_4
  - Deliquescent solution pH for most species is in range of about 4 to 5.
  - Deliquescent solution pH for NH_4HSO_4 is about -1 to -2.

Specimens exposed to NH_4NO_3

Specimens exposed to $NH_4NO_3 + (NH_4)_2SO_4$ mixture

Specimens exposed to NH_4HSO_4

Conclusions

- For simulated sea salt, SCC on Type 304 stainless steel is observed between 35 and 80 °C when RH is higher than about 20 to 30%. At lower temperatures, this RH may be reached at AH well below 30 g/m^3.
- SCC initiation is observed at salt quantity as low as 0.1 g/m^2 or strain as low as 0.4. The extent of cracking increases with increasing salt quantity or strain.
- Sensitized material seems more susceptible to SCC than material in as-received condition.
- No SCC was observed for specimens exposed to non-chloride-bearing species.

Regulatory Use

- Safety evaluations for initial and license renewal of site-specific storage facilities and cask system certificates of compliance
- Information Notice 2012-20, "Chloride-Induced Stress Corrosion Cracking of Austenitic Stainless Steel and Maintenance of Dry Cask Storage System Canisters"
- NRC–Nuclear Energy Institute Risk Informed Resolution Protocol on chloride-induced SCC
- EPRI Extended Storage Collaboration Program