

# **Official Transcript of Proceedings**

## **NUCLEAR REGULATORY COMMISSION**

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

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1 UNITED STATES OF AMERICA

2 NUCLEAR REGULATORY COMMISSION

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4 ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

5 (ACRS)

6 + + + + +

7 SUBCOMMITTEE ON MATERIALS, METALLURGY AND

8 REACTOR FUELS

9 + + + + +

10 TUESDAY

11 JANUARY 14, 2014

12 + + + + +

13 ROCKVILLE, MARYLAND

14 + + + + +

15 The Subcommittee met at the Nuclear  
16 Regulatory Commission, Two White Flint North, Room T2B1,  
17 11545 Rockville Pike, at 8:30 a.m., Ronald G. Ballinger,  
18 Chairman, presiding.

19 COMMITTEE MEMBERS:

20 RONALD G. BALLINGER, Chairman

21 J. SAM ARMIJO

22 JOY REMPE

23 PETER C. RICCARDELLA

24 STEPHEN P. SCHULTZ

25 GORDON R. SKILLMAN

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1

2 NRC STAFF PRESENT:

3 CHRISTOPHER L. BROWN, Designated Federal

4 Official

5 JOHN BURKE

6 MICHAEL CASE

7 GANESH CHERUVENKI

8 AL CSONTOS

9 DARRELL DUNN

10 BOB EINZIGER

11 ISTVAN FRANKL

12 MIRELA GAVRILAS

13 MAKUTESWARA SRINIVASAN

14 APPAJOSULA RAO

15 DAVID RUDLAND

16 GARY STEVENS

17 BRIAN THOMAS

18 ROB TREGONING

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1	A G E N D A	
2	ACRS Subcommittee Chairman Remarks.....	4
3	Staff Opening Remarks.....	6
4	Overview of RES Projects - Component	
5	Integrity Branch.....	20
6	Overview of RES Projects - Corrosion	
7	and Metallurgy Branches.....	80
8	Stress Corrosion Cracking, Susceptibility	
9	of Austenitic Stainless Steel for Spent	
10	Fuel Dry Storage Canisters.....	121
11	Q and A.....	141
12		
13		
14		
15		
16		
17		
18		
19		
20		
21		
22		
23		
24		
25		

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## 1 P R O C E E D I N G S

2 8:30 a.m.

3 Opening Remarks and Objectives

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

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

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

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

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

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

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

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

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

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

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

12 Staff Opening Remarks

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

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

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

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

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

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

25                  So that's one of the advantages of the

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

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

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

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

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

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

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

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

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

25 Then the big one that a lot of people miss

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

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

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

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

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

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

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

12                  MEMBER SKILLMAN: Thank you.

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

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

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

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

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

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

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

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

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

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

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

25                  MR. CASE: NRR prioritizes -- all the

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

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

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

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

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

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

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

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

19                  CHAIR BALLINGER: Thank you.

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

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1 we might have been able to predict.

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

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

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

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

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

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

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

6                   MEMBER ARMIJO: EPRI.

7                   MR. CASE: And EPRI.

8                   MEMBER ARMIJO: Yeah, they did --

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

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

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

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

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

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

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

17                  MR. CASE: That's right.

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

25                  We did our own, industry did their own. As

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

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

10 MEMBER ARMIJO: Okay.

11 CHAIR BALLINGER: Okay. Next up.

12 Overview of RES Projects

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

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

25 Again, the purpose of this beginning part

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

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

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

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

25 This is an overview of everything that we

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

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

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

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

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

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

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

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

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

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

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1 the other areas.

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

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

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

18                  MR. RUDLAND: That's correct.

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

23                  MR. RUDLAND: I can definitely highlight  
24 that.

25                  MEMBER SCHULTZ: Okay.

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

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

10                  MEMBER SCHULTZ: And then came, as Mike  
11 indicated, 2011, Fukushima as well as the budget-related  
12 impacts that could explain the reasons why we don't have  
13 2011-2012 as much as 2010 and now 2013.

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

19                  MEMBER SCHULTZ: Thank you.

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

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

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

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

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

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

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

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

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

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

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

25 As the regulatory guides are being reviewed

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

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

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

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

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

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

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

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

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

10 MEMBER SKILLMAN: Thank you.

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

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

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

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

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

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

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

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

25 So this work is ongoing, and right now most

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

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

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

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

24 5061(a), which is the alternate PTS rule,  
25 we're just in the process of publishing the regulatory

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

7 One of the other things that Oak Ridge is  
8 working on is developing this reactor embrittlement  
9 archive project, and basically is keeping a database of  
10 all of the embrittlement data, and it's been online since  
11 2012, hosted through Oak Ridge. And again, we're  
12 funding those things as the budgets permit.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

17 MEMBER ARMIJO: That's a lot of reports.

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

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

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

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

7 So we talked about the EPRI agreement.  
8 Like I mentioned, the ongoing EPRI agreement expires in  
9 '14, and we're in the process of trying to figure out how  
10 we want to extend that, because there's new topics and  
11 some topics are finished, and there's some topics that  
12 we're trying to decide whether, what's the best way to  
13 work cooperatively with EPRI.

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

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

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

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

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

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

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

10 MEMBER SCHULTZ: With PDI involved in that.

11 MR. RUDLAND: PDI, yeah, yeah.

12 MALE PARTICIPANT: PDI is --

13 MEMBER SCHULTZ: Performance  
14 Demonstration Initiative.

15 MR. RUDLAND: Performance Demonstration  
16 Initiative.

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

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

21 MEMBER SCHULTZ: Good, thank you.

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

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1 typical to inspect with --

2 MEMBER SCHULTZ: Cask pipe?

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

9 MEMBER SCHULTZ: Where's IRSN? Huh?

10 MR. RUDLAND: France.

11 MEMBER SCHULTZ: Huh?

12 MR. RUDLAND: France.

13 MEMBER SCHULTZ: Okay.

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

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

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

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

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

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

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

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

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

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

3 MR. RUDLAND: It's UT.

4 MEMBER ARMIJO: It is UT? Will it work?

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

7 MEMBER ARMIJO: It sort of works.

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

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

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

19 MEMBER ARMIJO: Not your classic flaw?

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

22 MEMBER ARMIJO: Sure.

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

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1 we can free up some funds for that particular effort.

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

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

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

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

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

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

24 CHAIR BALLINGER: Because they have a big  
25 program.

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

6                   CHAIR BALLINGER: Thanks.

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

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

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

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

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

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

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

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

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

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

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

3 MR. RUDLAND: Right.

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

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

11 CHAIR BALLINGER: Okay.

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

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

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

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

3 MR. RUDLAND: Yep.

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

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

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

15 CHAIR BALLINGER: Do they fill it out?

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

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

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1 CHAIR BALLINGER: Okay, good.

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

4 CHAIR BALLINGER: I would hope not.

5 (Simultaneous speaking.)

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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1 programs were sufficient.

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

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

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

25                  Then in 2010, NRR submitted a User Need

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

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

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

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

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

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

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

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

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

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

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

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

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

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

25 If we do have a through-wall leaking

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

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

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

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

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

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

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

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

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

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

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

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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

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1           in the mean values.

2           MEMBER RICCARDELLA:     These are mean  
3        values?

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

9           MEMBER RICCARDELLA:   What was the form of  
10      mitigation?

11          MR. RUDLAND:   This one was MSIP.

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

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

21          MEMBER SKILLMAN:   Gotcha.

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

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

7                   MEMBER SKILLMAN: So experiments have been  
8 performed?

9                   MR. RUDLAND: Experiments have been  
10 performed.

11                  MEMBER SKILLMAN: Many, many experiments.

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

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

25                  So you have to be able to qualitatively

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

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

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

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

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

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

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

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

13                  MEMBER ARMIJO: What is that?

14                  MR. RUDLAND: It's called GoldSim.

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

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

22                  So we needed to expand what we did in Version  
23 1 for materials loads, mechanisms, mitigations,  
24 everything associated with those lines of proof of LBB,  
25 and we expanded our quality assurance program that was

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

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

6 MR. RUDLAND: Trained.

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

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

11 MEMBER SCHULTZ: Right.

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

15 MEMBER SCHULTZ: Sure.

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

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

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

25 MEMBER SCHULTZ: Right.

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

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

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

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

15                  MR. RUDLAND: Right.

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

22                  MR. RUDLAND: Right.

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

25                  MR. RUDLAND: Yeah.

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

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

11 MEMBER SCHULTZ: Thank you.

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

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

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

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1 Version 2 developmental process.

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

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

8 MEMBER RICCARDELLA: At a cost?

9 MR. RUDLAND: I'm not charging anything.

10 MEMBER ARMIJO: Done when?

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

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

16 MR. RUDLAND: Will be.

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

20 MR. RUDLAND: Right, right.

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

23 MR. RUDLAND: Yeah.

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

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1 important also?

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

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

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

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

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

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1 independent.

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

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

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

11 MR. RUDLAND: To develop the inputs.

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

15 MR. RUDLAND: That's correct.

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

19 MR. RUDLAND: Yes, that's correct.

20 MEMBER SKILLMAN: Thank you.

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

25 MEMBER SKILLMAN: I think some licensees

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

4 MR. RUDLAND: Yes, that's right.

5 MEMBER SKILLMAN: Okay, thank you.

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

11 MR. RUDLAND: Yeah.

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

15 (Simultaneous speaking.)

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

18 MR. RUDLAND: Right.

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

25 MR. RUDLAND: Right, you know, and the

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

4 MEMBER SKILLMAN: I understand, yeah.

5 MR. RUDLAND: So it's --

6 MEMBER SKILLMAN: Sep lines or something.

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

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

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

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

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

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

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

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

14 MEMBER SCHULTZ: Sure. I understand that  
15 bullet.

16 MEMBER RICCARDELLA: If you're lucky.

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

20 MR. RUDLAND: That's right.

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

25 MR. RUDLAND: Exactly, that's right.

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

8 MEMBER RICCARDELLA: Even what is in it.

9 MR. RUDLAND: That's right.

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

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

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

22 MEMBER RICCARDELLA: Okay, thank you.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

6 (Simultaneous speaking.)

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

9 MEMBER RICCARDELLA: Yeah.

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

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

17 MR. RUDLAND: Right.

18 MEMBER RICCARDELLA: Or is that the Program  
19 Integration Group?

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

24 MEMBER RICCARDELLA: And are there  
25 involvement in that group?

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

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

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

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

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1 March.

2 We'll then spend between March and  
3 September going through the full V&V effort for the code,  
4 in hopes to publish and release the code in September of  
5 2014 or thereabouts.

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

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

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

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

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

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

9 (No response.)

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

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

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

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

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

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1 MEMBER ARMIJO: 10:17?

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

3 MALE PARTICIPANT: That's what you said.

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

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

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

11 CHAIR BALLINGER: Think we can go without  
12 him?

13 MR. BROWN: Just hit the gavel.

14 MALE PARTICIPANT: You've got a quorum.

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

17 MEMBER REMPE: Use the gavel.

18 CHAIR BALLINGER: Oh, oh, oh.

19 (Laughter.)

20 MR. BROWN: Power and authority.

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

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

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1 CHAIR BALLINGER: You're controlling the  
2 computer?

3 MALE PARTICIPANT: Resistance is futile.

4 (Simultaneous speaking.)

5 Overview of RES Projects-CM Branch

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

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

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

21 CHAIR BALLINGER: I thought you had control  
22 of that?

23 MR. BURKS: No, I do.

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

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

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

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

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

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

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1       2012 and 2013, and the focus here was on measurement  
2       uncertainty, as well as the monitoring degradation of  
3       neutron absorbers. Next page please.

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

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

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

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

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

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

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

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

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

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

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

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

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

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1 a comment.

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

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

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

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

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

17 MEMBER SCHULTZ: There was a rationale.

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

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

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1 have cracking issues at least.

2 MR. EINZIGER: It's possible.

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

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

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

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

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

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

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

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

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

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

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

3 MR. DUNN: I do not remember --

4 CHAIR BALLINGER: The IRP Texas A&M?

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

8 MR. EINZIGER: Bob Einziger from the NRC.  
9 No one's doing the work on this one. There's currently  
10 a DOE call out for proposals to do this work. It's a  
11 \$3 million project over three years, and I think the call  
12 closes in a couple of months, to see whether somebody is  
13 going to do it.

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

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

25 MR. EINZIGER: Well obviously if no one

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

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

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

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

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

23 MR. EINZIGER: Can we what?

24 CHAIR BALLINGER: The end reactor fuel  
25 program.

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1 MR. EINZIGER: Yes, what about it?

2 CHAIR BALLINGER: You know well about that.

3 There's a lot of data out there on drying. Is that being  
4 mined?

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

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

17 CHAIR BALLINGER: Do you know if they still  
18 have the canisters monitoring out there in Richland? I  
19 know they had several storage canister systems that were  
20 buttoned up and then instrumented, and they recorded  
21 basically -- recorded pressure versus time, maybe  
22 hydrogen as well. Is that still ongoing or did they just  
23 --

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

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

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

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

13 MEMBER ARMIJO: Now if people are loading  
14 and drying casks all the time in the industry, now don't  
15 they have to meet some sort of drying criterion that says  
16 after you've done this process, show that you've removed  
17 99.9 percent of the water or something? Don't they have  
18 some sort of a regulatory requirement that they have to  
19 meet?

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

22 MEMBER REMPE: I think this --

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

25 MR. FRANKL: Yeah. We will --

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

17 MEMBER REMPE: The high burnup  
18 demonstration.

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

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

3 CHAIR BALLINGER: We'd better get going  
4 here.

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

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

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

25 The work is -- the research is continuing,

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

4 The next topic is containment liner  
5 corrosion. There were multiple objectives here. First  
6 --

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

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

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

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1 systems right now.

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

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

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

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

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1 not enough --

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

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

5 (Simultaneous speaking.)

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

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

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

17 MEMBER REMPE: Okay.

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

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

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

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

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

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

25 MEMBER SKILLMAN: Before you change topics

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1 please.

2 MR. FRANKL: Okay.

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

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

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

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

20 MEMBER ARMIJO: Beaver Valley was bigger  
21 than that.

22 MR. DUNN: Beaver Valley was much --

23 CHAIR BALLINGER: Much more. More like  
24 three inches.

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

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1 three quarters an inch by an inch.

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

4 MALE PARTICIPANT: Upper side of a 2 by 4.

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

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

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

13 MEMBER SKILLMAN: Thank you.

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

16 MR. DUNN: Of the paint.

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

19 MR. DUNN: Not by the ILRT.

20 MEMBER ARMIJO: Yeah.

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

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1 vessel head.

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

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

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

17                   MR. FRANKL: This was the original head.

18                   MEMBER RICCARDELLA: The head that was  
19 replaced?

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

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1 thermal and neutron embrittlement in cask austenitic  
2 stainless steels.

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

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

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

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

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

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

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

23                   (Off mic comments.)

24                   MR. RAO: I want to hear his question.

25                   CHAIR BALLINGER: Okay. This is an effect

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

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

11 MALE PARTICIPANT: Microphone.

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

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

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

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

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

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

12 MR. RAO: Yes. We are -- actually, we have  
13 done that testing in both PWR conditions and also deoxy  
14 water, D water. It's control. That's how we're testing  
15 --.

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

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

19 CHAIR BALLINGER: Okay.

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

23 MR. DUNN: Cast?

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

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1 are the particular components of concern?

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

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

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

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

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

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

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

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

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

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

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

17 MEMBER ARMIJO: Okay, thank you.

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

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

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1 MR. BURKS: I think those are backwards.

2 MR. FRANKL: Oh, those are backwards.

3 Sorry, yes, sorry. The objective was to -- the  
4 regulatory use will be to develop safety evaluation  
5 criteria on nickel-based primary system pressure  
6 boundary component, subject to PWSQC degradation.

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

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

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

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

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

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1 steels in castings --

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

4 MEMBER ARMIJO: Yeah, okay.

5 MR. DUNN: Okay.

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

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

14 MEMBER ARMIJO: Yeah, okay.

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

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

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

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

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

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

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

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1 Light Water Reactor Sustainability program.

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

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

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

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

23 MR. FRANKL: Yeah.

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

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

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

6 MR. FRANKL: I believe Srsini, would you  
7 please come to the microphone.

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

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

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

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

25 MEMBER ARMIJO: You know, my problem is

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

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

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

18                   CHAIR BALLINGER: At least to define a gap.

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

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

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1 us to follow up on.

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

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

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

16 CHAIR BALLINGER: Right.

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

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

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

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

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

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

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

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

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

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1 testing.

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

6 MEMBER ARMIJO: Yes.

7 CHAIR BALLINGER: Yeah.

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

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

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

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

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

3 CHAIR BALLINGER: Okay, thank you.

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

10 The work was initiated with a User Need. In  
11 2012, on steam generator inspection and integrity  
12 issues, which builds upon research conducted with  
13 previous User Need, including the ones on consequential  
14 steam generator tube rupture. This research will  
15 support the technical evaluations of the licensee  
16 submissions and inspections of steam generator tubes.

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

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

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1 examples, one on leakage models.

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

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

16                  Stress Corrosion Cracking

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

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

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

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

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

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

25 MR. DUNN: Yes, they do.

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1 MEMBER ARMIJO: But they also put them in  
2 buildings.

3 MR. DUNN: That's correct.

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

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

8 MEMBER ARMIJO: Yeah.

9 MR. DUNN: Okay. So previous to NRC  
10 research, there was a NUREG CR published in 2010 that had  
11 some of the initial work that was done in this effort,  
12 and in that work, testing was performed using 304, 304-L,  
13 316-L, U-bend specimens. There was a technique  
14 developed to deposit simulated sea salt on the surface  
15 of these specimens, without inducing cracking.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

17                 MEMBER SKILLMAN: Thank you.

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

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

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1 deposited on the surface.

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

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

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

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

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

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

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

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

16 That's what CRIEPI had indicated was sort  
17 of a threshold concentration, where they, you know, above  
18 which they would take backing and below which they  
19 weren't. At 0.1, it's very difficult to put less than  
20 0.1 grams per meter squared of salt on a specimen  
21 repeatedly, and in fact the specimens in those cases  
22 don't really look like they have too much on them.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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1 conditions.

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

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

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

14                  MR. DUNN: Yes.

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

17                  MR. DUNN: Yes.

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

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

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1 stress corrosion cracking at 43 C.

2 MR. DUNN: Right.

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

5 MR. DUNN: To 62?

6 MEMBER SKILLMAN: Yes please. One more.

7 In that particular case, in the top column, in the top  
8 matrix you show the cooler temperatures with no stress  
9 corrosion cracking, and at the higher temperatures,  
10 stress corrosion cracking.

11 MR. DUNN: Right.

12 MEMBER SKILLMAN: I'm confused.

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

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

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

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

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

18           MR. DUNN: That appears to be the case.

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

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

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

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

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

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

18 MEMBER RICCARDELLA: Thank you.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

14 CHAIR BALLINGER: 0.4 percent.

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

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

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

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

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

18 Q and A

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

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

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

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

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

10                  That was a fairly old, I think it was about  
11 17 or 18 years old, and it was a fairly low load. So its  
12 temperature was below 80 C. I don't remember the exact  
13 number. There was an issue with how they were trying to  
14 measure that. But its temperature was within the range  
15 where we could potentially have deliquescence of  
16 deposited sea salts.

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

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

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

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

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

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

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

14 MR. DUNN: Yes.

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

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

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

25 MEMBER ARMIJO: Has industry done anything

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

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

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

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

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

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

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1 more chloride deposited there versus a --

2 MEMBER ARMIJO: Yeah, a rounded,  
3 horizontal surface.

4 MR. CSONTOS: So a couple of comments here.

5 MR. DUNN: Yes.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

11                 MR. EINZIGER: Well --

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

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

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

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

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

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

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

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

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

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

23 MALE PARTICIPANT: Thank you.

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

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

4 MEMBER ARMIJO: Yes, you can.

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

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

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

## Subcommittee Briefing on Metallurgy and Materials Projects

Tuesday, January 14, 2014



Item	Topic	Presenter(s)	Time
1	Opening Remarks and Objectives	<b>Dr. Ron Ballinger, ACRS</b>	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	<b>ACRS Subcommittee</b>	9:40 – 10:00 a.m.
	<b>Break</b>		<b>10:00. – 10:15 a.m.</b>
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	<b>ACRS Subcommittee</b>	11:15 - 11:45 a.m.
9	Adjourn	<b>Dr. Ron Ballinger, ACRS</b>	11:45 a.m.

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8	Q&A	<b>ACRS Subcommittee</b>	11:15 - 11:45 a.m.
9	Adjourn	<b>Dr. Ron Ballinger, ACRS</b>	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**

# 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

	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)	<ul style="list-style-type: none"> <li>• xLPR pilot study NUREG - 2012</li> <li>• ACRS xLPR presentations 2012/2013</li> <li>• ACRS WRS Presentation 2013</li> <li>• WRS NUREG 2013</li> <li>• WRS validation</li> <li>• Emergent Support for LBB &amp; Flaw Evaluations</li> <li><input type="checkbox"/> CRDM/BMI work</li> <li>• ASME Code Support</li> </ul>	<ul style="list-style-type: none"> <li>• V6444- Emc2 - LBB Reg guide</li> <li>• V6411 - PNNL - xLPR inspection</li> <li>• V6375 - Battelle - Piping integrity</li> <li>• V6260 - SNL - xLPR V2</li> <li>• Internal efforts on xLPR, WRS Validation, LBB support, flaw evaluation support</li> </ul>
	NRR-2013-xxx	Implementation Of Probabilistic Methods For Evaluating Leak-Before-Break Of Nickel Based Alloys Exposed To Primary Water Environments			
	NRR-2013-yyyy	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	<ul style="list-style-type: none"> <li><input checked="" type="checkbox"/> Appendix H to NRR/NRO</li> <li>• RG199R3/TBD NUREG</li> <li>• Appendix G revision TBD</li> <li><input type="checkbox"/> 50.61a Reg guide/NUREG under review</li> <li>• ASME Code Support</li> </ul>	<ul style="list-style-type: none"> <li>• N6438 - ORNL - RPV</li> </ul>
NDE	NRR-2013-009	Evaluating The Reliability Of Nondestructive Examinations Of Vessels And Piping	NDE VP (2013) NDE (2011)	<ul style="list-style-type: none"> <li>• 50.61a RPV Inspection review;</li> <li>• VT of RPV Internals;</li> <li>• UT in lieu of RT for fabrication,</li> <li>• Assess Industry Actions re: DMW, HPDE, CASS,</li> <li>• Inspector training/qualifications (PDI)</li> <li>• Effectiveness and reliability of field NDE</li> <li>• NDE modeling</li> </ul>	<ul style="list-style-type: none"> <li>• V6323 - PNNL - Capabilities and Reliability of NDE</li> <li>• V6411 - PNNL - xLPR inspection</li> <li>• V6097 - PNNL - Effect/Reliab of UT in lieu of RT</li> <li>• N6593 - PNNL - Assess Emerging NDE Methods</li> <li>• G6022 - ASME Grant - Convergence of International Codes</li> </ul>
HDPE	NRR-2010-014	Volumetric Examination of Vessels and Piping (NDE VP)			
EAF	NRR-2010-120 NRO-2010-008	Request for NDE of Polyethylene Piping and Fittings			
	NRR-2006-007	Development of a Technical Database on the Use of HDPE in Safety Related Piping Systems	HDPE (2011)	<ul style="list-style-type: none"> <li>• HDPE piping in buried class 3 safety systems</li> <li>• Assess industry efforts</li> <li>• ASME Code Support</li> </ul>	<ul style="list-style-type: none"> <li>• V6245 - Emc2 - HDPE testing</li> </ul>
	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)	<ul style="list-style-type: none"> <li>• Draft revision to NUREG/CR-6909 - June 2013.</li> <li>• Finalize NUREG/CR-6909 Rev. 1 for public review -- December 2013.</li> <li><input type="checkbox"/> Revise Reg. Guide 1.207 for public review -- January 2014.</li> <li>• Issue NUREG and Reg. Guide - December 2014</li> <li>• ASME Code Support</li> </ul>	<ul style="list-style-type: none"> <li><input type="checkbox"/> V6069/V8269 - ANL - completed 9/30/2013</li> </ul>

# 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

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?	<ul style="list-style-type: none"> <li>Evaluation deferred in 2010</li> <li>Renewed effort to complete technical review and forge staff consensus</li> </ul>	X		
10 CFR 50 App. H (Surveillance)	1984	<ul style="list-style-type: none"> <li>Is it still adequate to reference a 1982 ASTM standard?</li> <li>Augmented guidance on integrated surveillance</li> <li>Changes to reporting requirements</li> </ul>	<ul style="list-style-type: none"> <li>Reviewed adequacy in 2008. Deferred.</li> <li>Support NRR in renewed rulemaking push (SECY paper)</li> </ul>	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	

# 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

- **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<sup>2</sup> (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 PWS SCC 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<sup>2</sup>(V6444), Battelle(V6375), PNNL(V6411), ORNL(N6438)

# Code Development

## Team Members

### 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

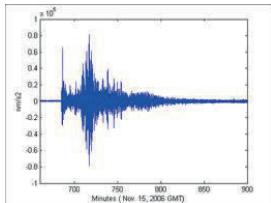
xLPR Team



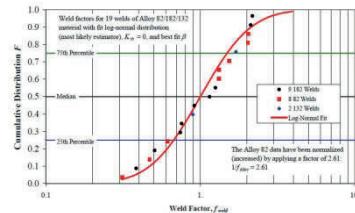
**Cooperative effort between NRC and EPRI through Memorandum of Understanding**

# PFM Technical Flow

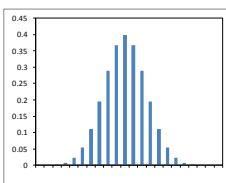
## Loads



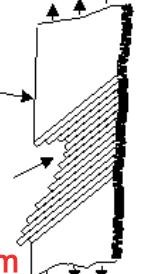
## Material Properties



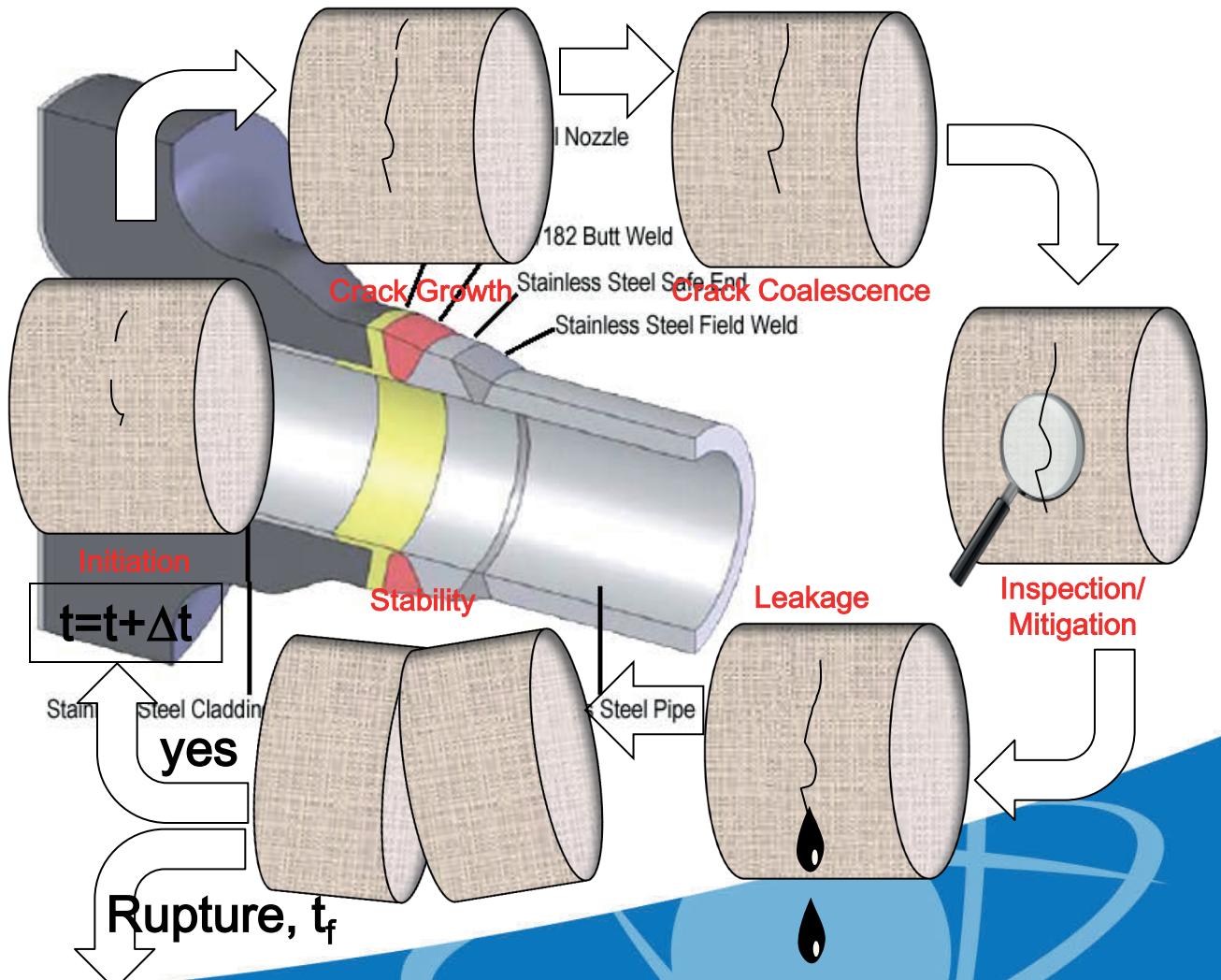
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## Crack Mechanism



**EXIT**

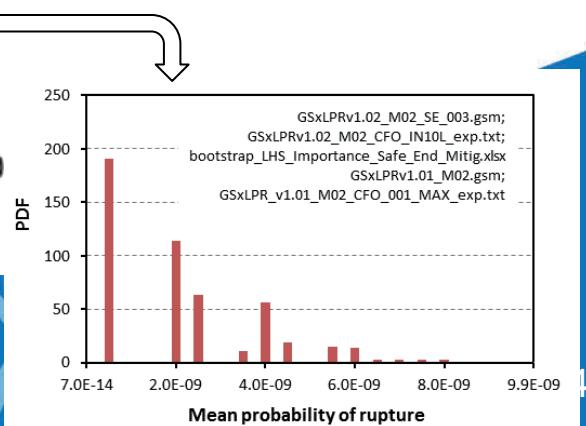
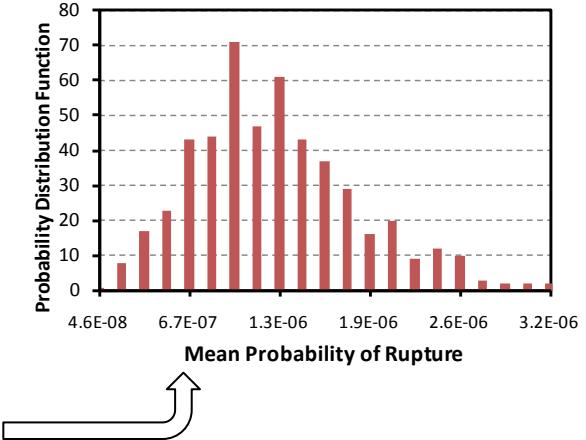
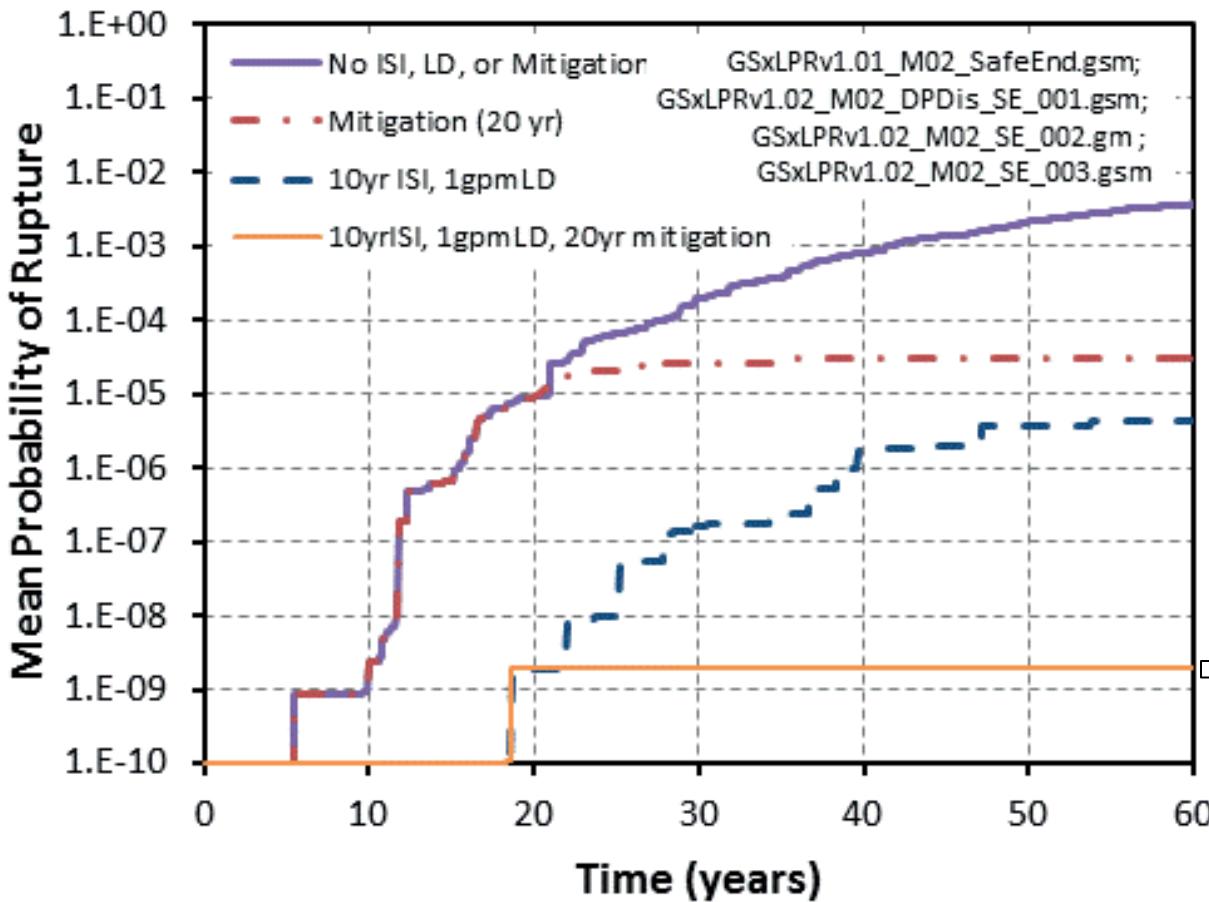


# xLPR Pilot Study

- 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 **it is feasible** 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



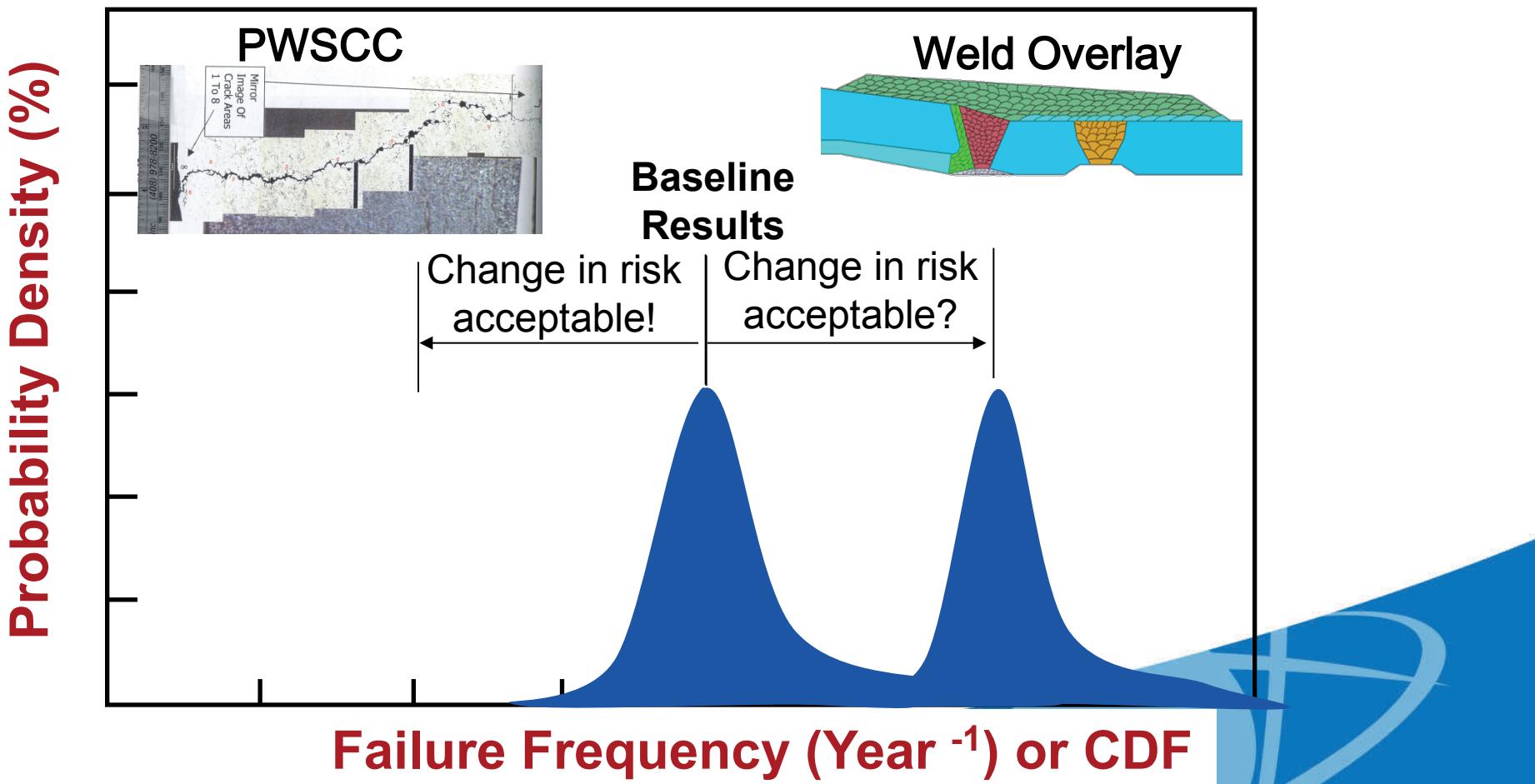
- Quantified solution to LBB issue
  - Regulatory Guide
  - Update to SRP3.6.3
- Fully QA'ed modular probabilistic fracture mechanics code for reactor pressure boundary integrity
  - LBB including evaluation of mitigation for DM welds
  - Research tool for prioritization
  - TBS – 50.46a
  - Risk informed 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 ( $\Delta$ -Risk)
  - Intent is to use existing acceptable risk values

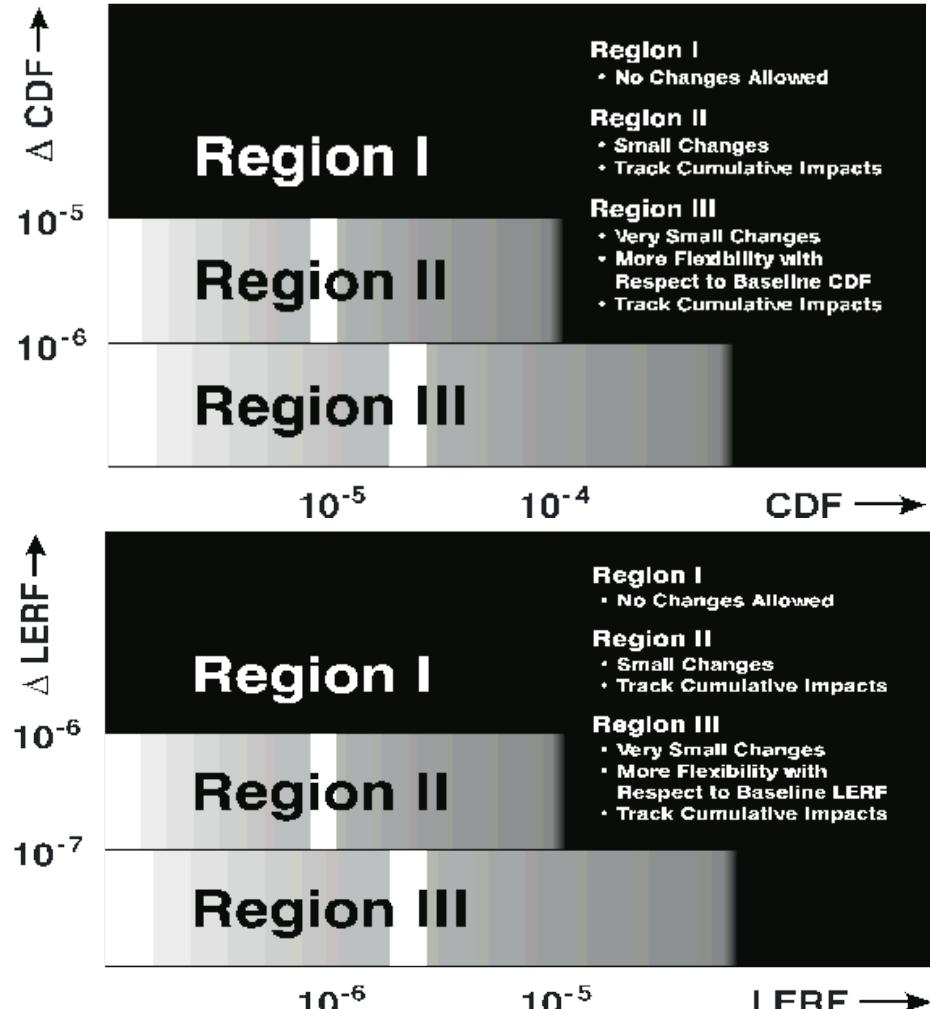
# Using xLPR for LBB

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  $\Delta$ CDF
  - Large Early Release Frequency (LERF) and  $\Delta$ LERF
- 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



- **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<sup>2</sup>, 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

- **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 ( $\sim 10 \text{ mm}^2$ )
  - 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 PWSCL 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.)

- **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/m<sup>2</sup>
- 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.)

- **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 dissimilar 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

- **Purpose:** Identify 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**

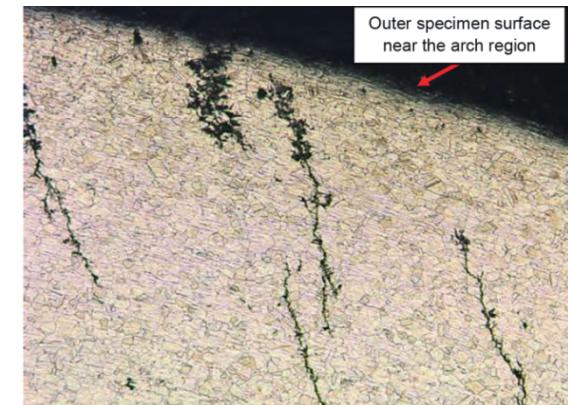
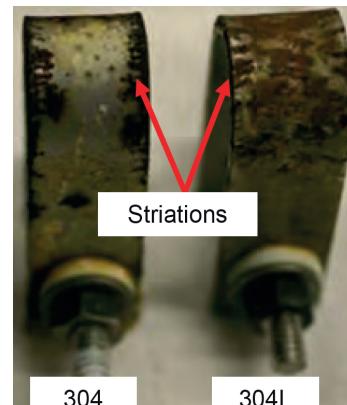
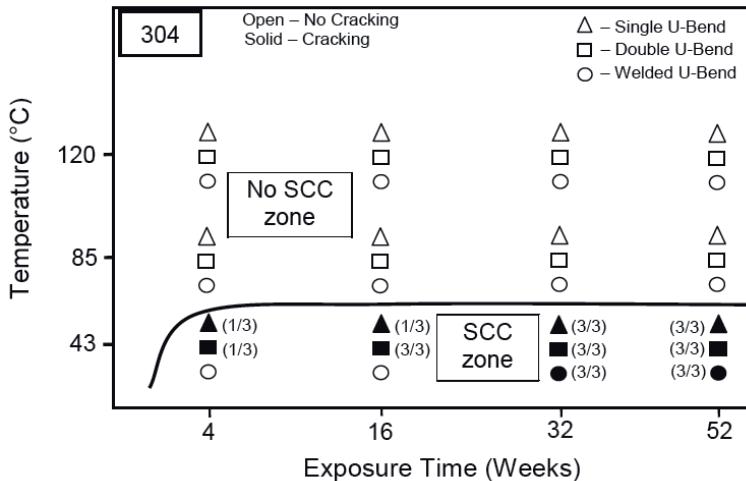
**January 14, 2014**

# 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

- 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

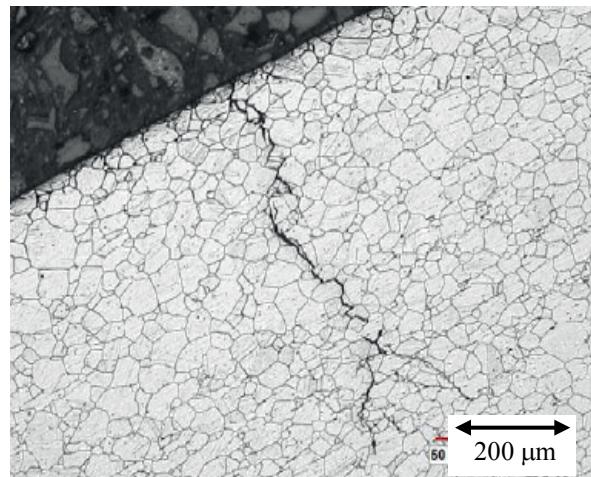
- Test objectives:
  - Limit absolute humidity (AH) to about 30 g/m<sup>3</sup>
  - Vary test temperature
  - Vary surface salt concentration and material condition
- Test methodology:
  - Deposited 0.1, 1, or 10 g/m<sup>2</sup> of sea salt on ASTM G30 U-bend specimens
    - Expose to salt fog for various times
    - Quantity determined by control specimen weight gain
  - Type 304 in as-received or furnace sensitized (2 hours at 650 °C) conditions
  - Exposed in test chamber to cyclic AH between about 15 and 30 g/m<sup>3</sup>

# Test Results

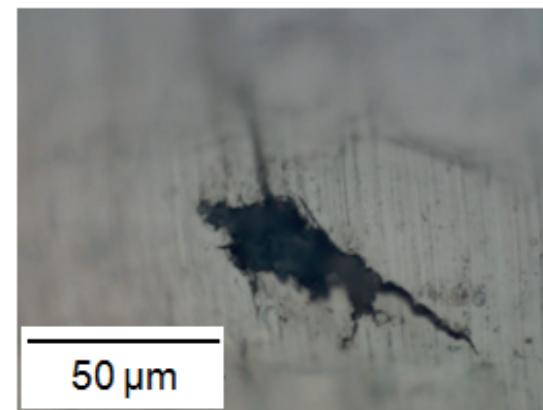
Specimen Temp. (°C)	RH Range (%)	Exposure Time	SCC Observed?	Lowest salt concentration at which SCC was observed
27	56-100	8 months	No	N/A – salt deliquesced and drained off
35	38-76	4 – 12 months	Yes	0.1
45	23-46	4 – 12 months	Yes	0.1
52	16-33	2.5 – 8 months	Yes	1
60	12-23	6.5 months	Yes	10



Pitting on specimens at 10 g/m<sup>2</sup> (top), 1 g/m<sup>2</sup> (middle), and 0.1 g/m<sup>2</sup> (bottom)



Cross section of sensitized,  
0.1 g/m<sup>2</sup> specimen at 45°C  
after 4 months



Top view of sensitized, 10 g/m<sup>2</sup>  
specimen at 60°C for 6.5  
months

# Elevated Temperature SCC Testing

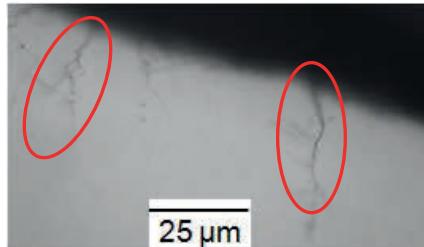
- Test objective: Evaluate SCC susceptibility at temperature up to 80 °C
- Test methodology:
  - Deposited 10 g/m<sup>2</sup> of sea salt on ASTM G30 U-bend specimens
  - Exposed specimens in test chamber at different humidity levels at 60 and 80 °C

Test Conditions				
Specimen Temp. (° C)	Relative Humidity (%)	Absolute Humidity (g/m <sup>3</sup> )	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	

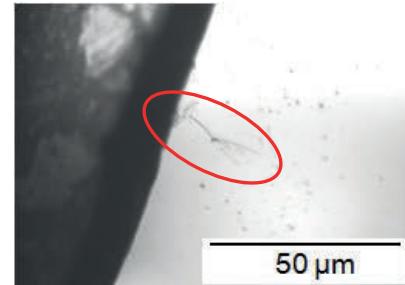
# Test Results

- SCC initiation observed at RH as low as 25% at 60 °C and 28% at 80 °C, though at AH above 30 g/m<sup>3</sup>
- Sensitized specimens showed greater extent of cracking

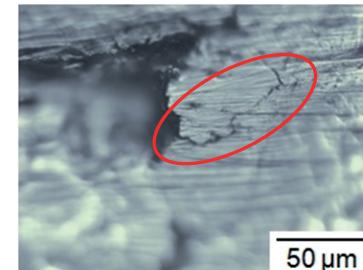
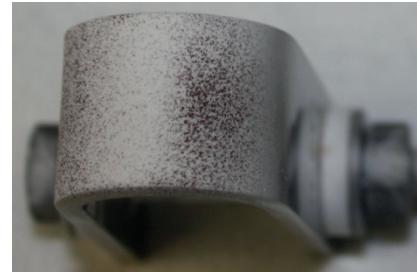
Sensitized, 60 °C, 30% RH



As-received, 80 °C, 35% RH



Sensitized, 80 °C, 28% RH



# C-Ring SCC Testing

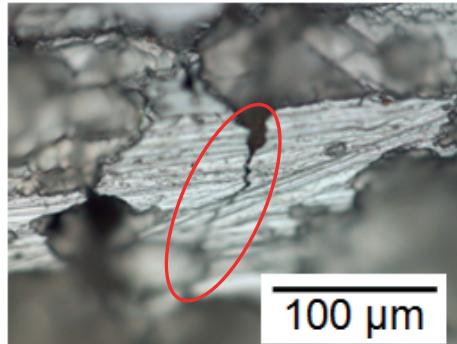
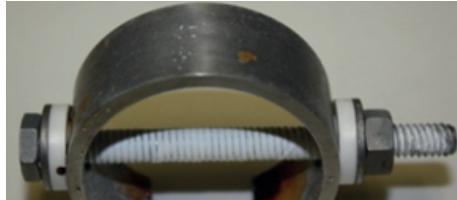
- Test objective: Evaluate lower strain condition relative to U-bend specimens
- Test methodologies:
  - Specimens fabricated following ASTM G38-01 and deposited with 1 or 10 g/m<sup>2</sup> of salt
  - Specimens strained to slightly above yield stress (~0.4% strain) or 1.5% strain, as measured by strain 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<sup>3</sup> at each temperature)



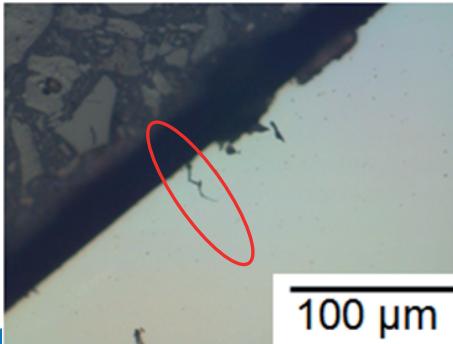
# Test Results

Specimen Temp. (° C)	RH (%)	AH (g/m <sup>3</sup> )	Salt Concentration (g/m <sup>2</sup> )	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

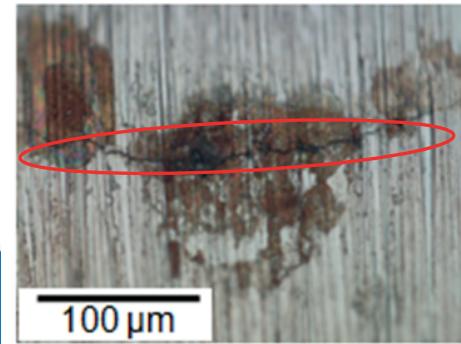
Sensitized, 35°C, 0.4% strain, 10 g/m<sup>2</sup> salt



As-received, 45°C, 1.5% strain, 10 g/m<sup>2</sup> salt



Sensitized, 52°C, 0.4% strain, 1 g/m<sup>2</sup> 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 –  $(\text{NH}_4)_2\text{SO}_4$
  - Ammonium bisulfate –  $\text{NH}_4\text{HSO}_4$
  - Ammonium nitrate –  $\text{NH}_4\text{NO}_3$
  - 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

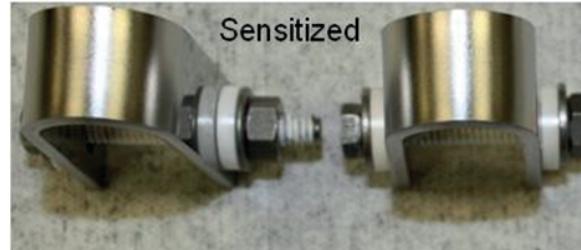
# Test Results

- 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  $\text{NH}_4\text{HSO}_4$ 
  - Deliquescent solution pH for most species is in range of about 4 to 5.
  - Deliquescent solution pH for  $\text{NH}_4\text{HSO}_4$  is about -1 to -2.

Specimens exposed  
to  $\text{NH}_4\text{NO}_3$



Specimens exposed to  
 $\text{NH}_4\text{NO}_3 + (\text{NH}_4)_2\text{SO}_4$  mixture



Specimens exposed  
to  $\text{NH}_4\text{HSO}_4$



# 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<sup>3</sup>.
- SCC initiation is observed at salt quantity as low as 0.1 g/m<sup>2</sup> 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**

# 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

	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)	<ul style="list-style-type: none"> <li>• xLPR pilot study NUREG - 2012</li> <li>• ACRS xLPR presentations 2012/2013</li> <li>• ACRS WRS Presentation 2013</li> <li>• WRS NUREG 2013</li> <li>• WRS validation</li> <li>• Emergent Support for LBB &amp; Flaw Evaluations</li> <li><input type="checkbox"/> CRDM/BMI work</li> <li>• ASME Code Support</li> </ul>	<ul style="list-style-type: none"> <li>• V6444- Emc2 - LBB Reg guide</li> <li>• V6411 - PNNL - xLPR inspection</li> <li>• V6375 - Battelle - Piping integrity</li> <li>• V6260 - SNL - xLPR V2</li> <li>• Internal efforts on xLPR, WRS Validation, LBB support, flaw evaluation support</li> </ul>
	NRR-2013-xxx	Implementation Of Probabilistic Methods For Evaluating Leak-Before-Break Of Nickel Based Alloys Exposed To Primary Water Environments			
	NRR-2013-yyyy	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	<ul style="list-style-type: none"> <li><input checked="" type="checkbox"/> Appendix H to NRR/NRO</li> <li>• RG199R3/TBD NUREG</li> <li>• Appendix G revision TBD</li> <li><input type="checkbox"/> 50.61a Reg guide/NUREG under review</li> <li>• ASME Code Support</li> </ul>	<ul style="list-style-type: none"> <li>• N6438 - ORNL - RPV</li> </ul>
NDE	NRR-2013-009	Evaluating The Reliability Of Nondestructive Examinations Of Vessels And Piping	NDE VP (2013) NDE (2011)	<ul style="list-style-type: none"> <li>• 50.61a RPV Inspection review;</li> <li>• VT of RPV Internals;</li> <li>• UT in lieu of RT for fabrication,</li> <li>• Assess Industry Actions re: DMW, HPDE, CASS,</li> <li>• Inspector training/qualifications (PDI)</li> <li>• Effectiveness and reliability of field NDE</li> <li>• NDE modeling</li> </ul>	<ul style="list-style-type: none"> <li>• V6323 - PNNL - Capabilities and Reliability of NDE</li> <li>• V6411 - PNNL - xLPR inspection</li> <li>• V6097 - PNNL - Effect/Reliab of UT in lieu of RT</li> <li>• N6593 - PNNL - Assess Emerging NDE Methods</li> <li>• G6022 - ASME Grant - Convergence of International Codes</li> </ul>
HDPE	NRR-2010-014	Volumetric Examination of Vessels and Piping (NDE VP)			
EAF	NRR-2010-120 NRO-2010-008	Request for NDE of Polyethylene Piping and Fittings			
	NRR-2006-007	Development of a Technical Database on the Use of HDPE in Safety Related Piping Systems	HDPE (2011)	<ul style="list-style-type: none"> <li>• HDPE piping in buried class 3 safety systems</li> <li>• Assess industry efforts</li> <li>• ASME Code Support</li> </ul>	<ul style="list-style-type: none"> <li>• V6245 - Emc2 - HDPE testing</li> </ul>
	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)	<ul style="list-style-type: none"> <li>• Draft revision to NUREG/CR-6909 - June 2013.</li> <li>• Finalize NUREG/CR-6909 Rev. 1 for public review -- December 2013.</li> <li><input type="checkbox"/> Revise Reg. Guide 1.207 for public review -- January 2014.</li> <li>• Issue NUREG and Reg. Guide - December 2014</li> <li>• ASME Code Support</li> </ul>	<ul style="list-style-type: none"> <li><input type="checkbox"/> V6069/V8269 - ANL - completed 9/30/2013</li> </ul>

# 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

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?	<ul style="list-style-type: none"> <li>Evaluation deferred in 2010</li> <li>Renewed effort to complete technical review and forge staff consensus</li> </ul>	X		
10 CFR 50 App. H (Surveillance)	1984	<ul style="list-style-type: none"> <li>Is it still adequate to reference a 1982 ASTM standard?</li> <li>Augmented guidance on integrated surveillance</li> <li>Changes to reporting requirements</li> </ul>	<ul style="list-style-type: none"> <li>Reviewed adequacy in 2008. Deferred.</li> <li>Support NRR in renewed rulemaking push (SECY paper)</li> </ul>	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	

# 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

- **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<sup>2</sup> (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<sup>2</sup>(V6444), Battelle(V6375), PNNL(V6411), ORNL(N6438)

# Code Development

## Team Members

### 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

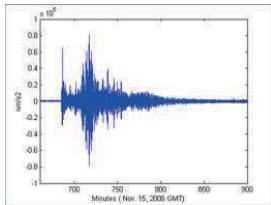
xLPR Team



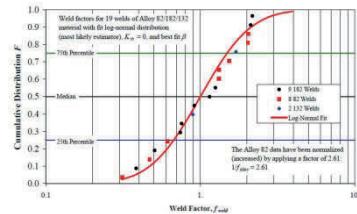
**Cooperative effort between NRC and EPRI through Memorandum of Understanding**

# PFM Technical Flow

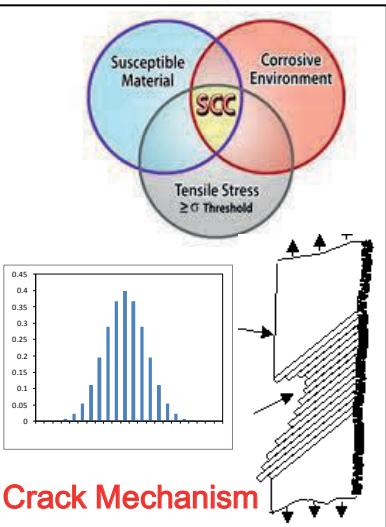
## Loads



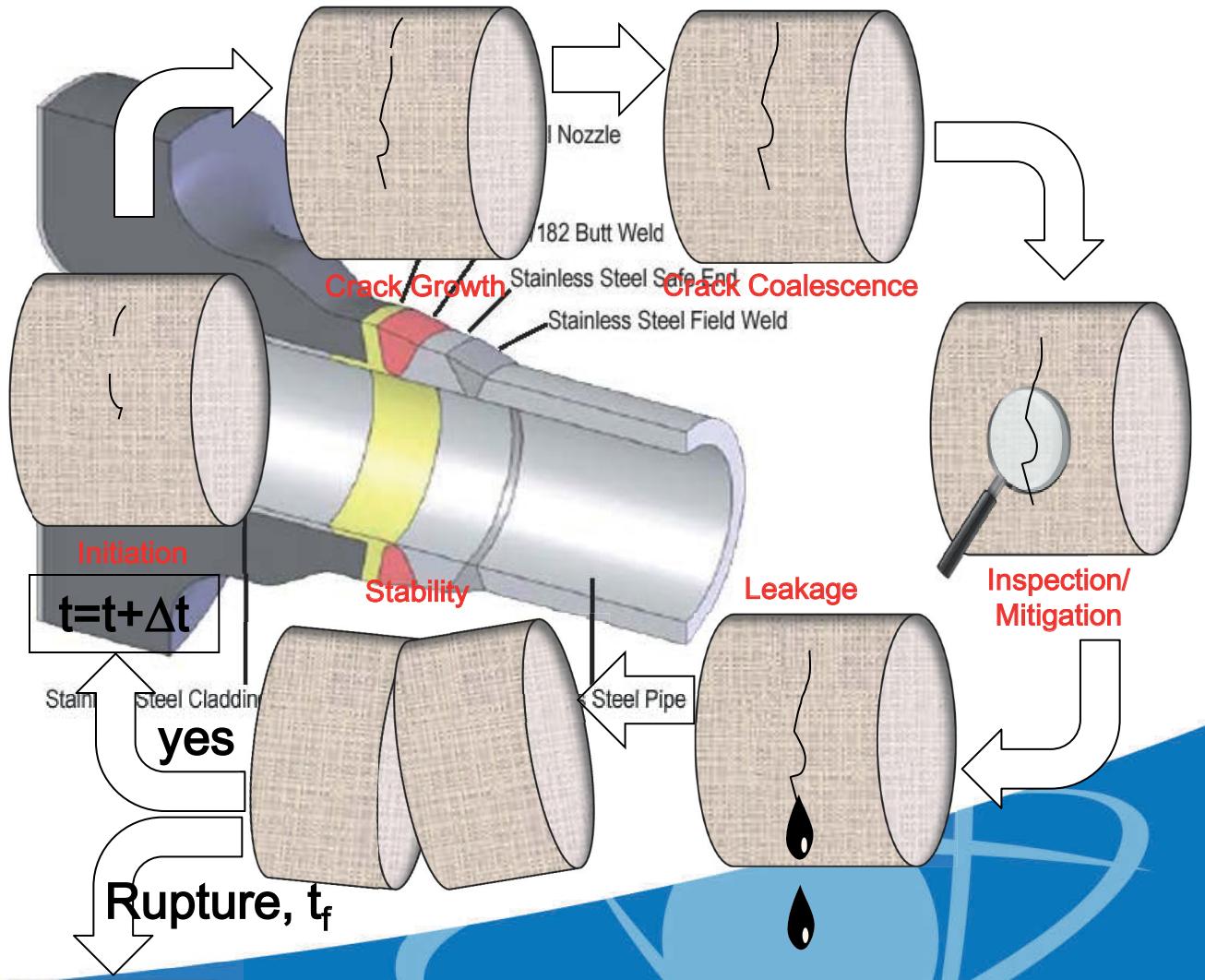
## Material Properties



$t=t_i$



## Crack Mechanism



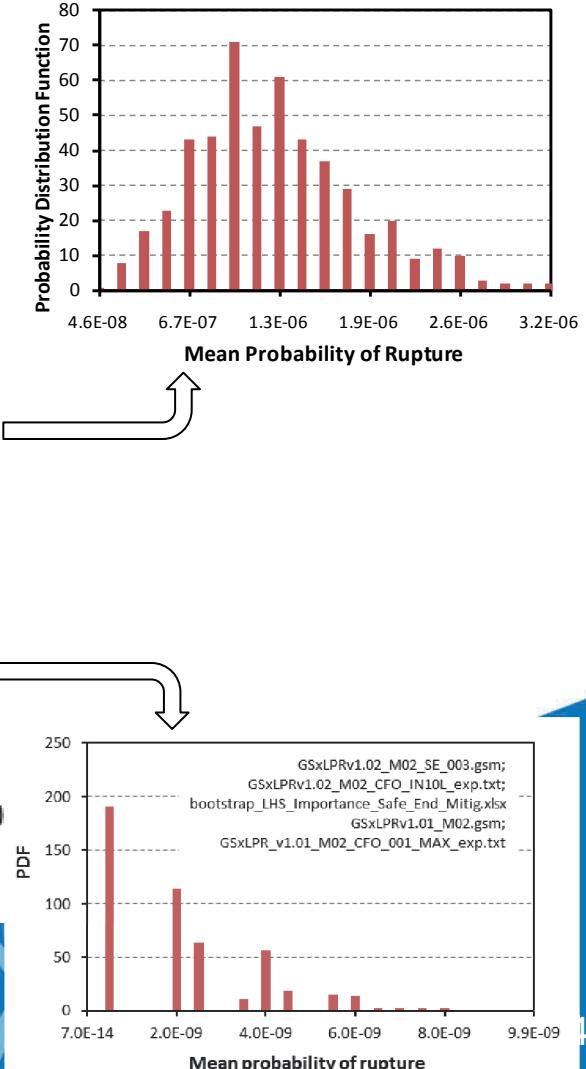
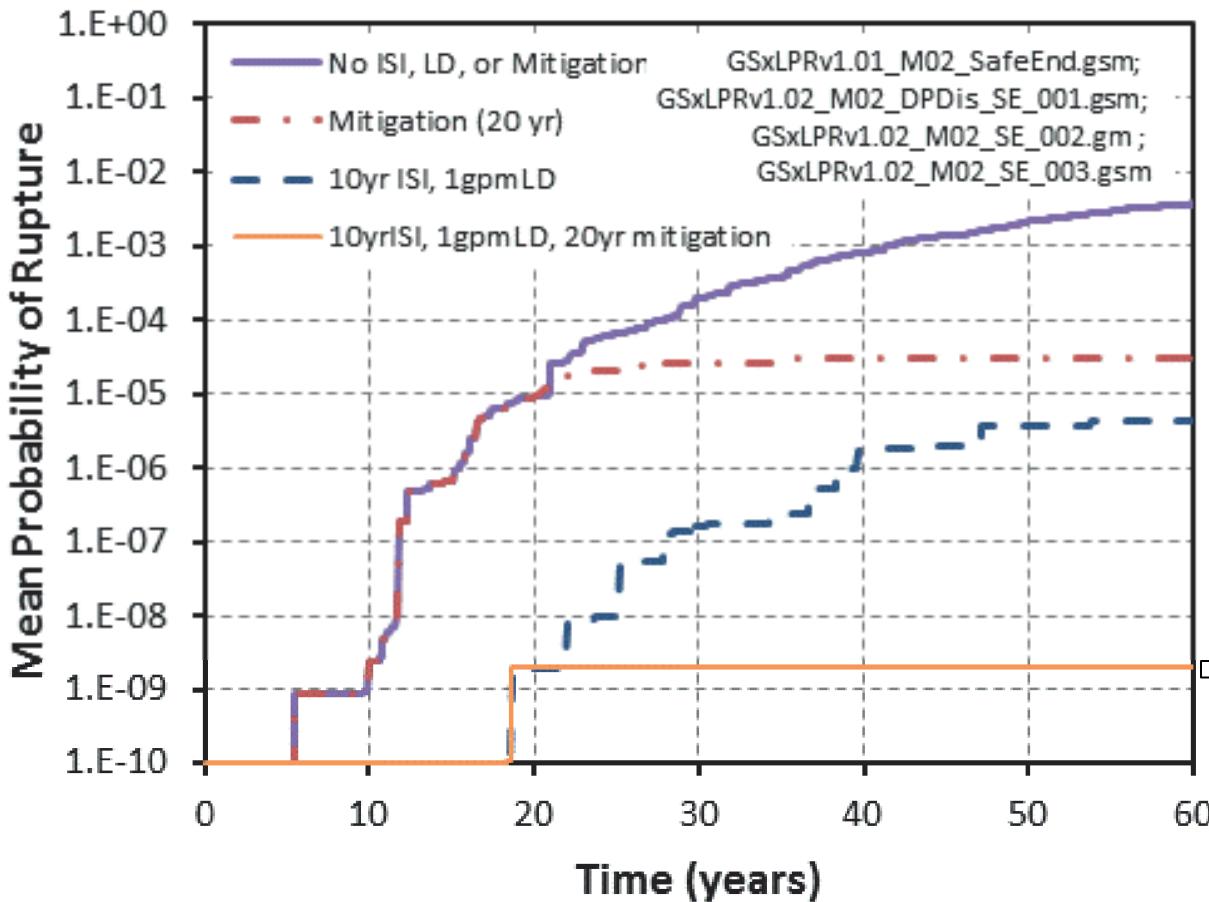
**EXIT**

# 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 **it is feasible** 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



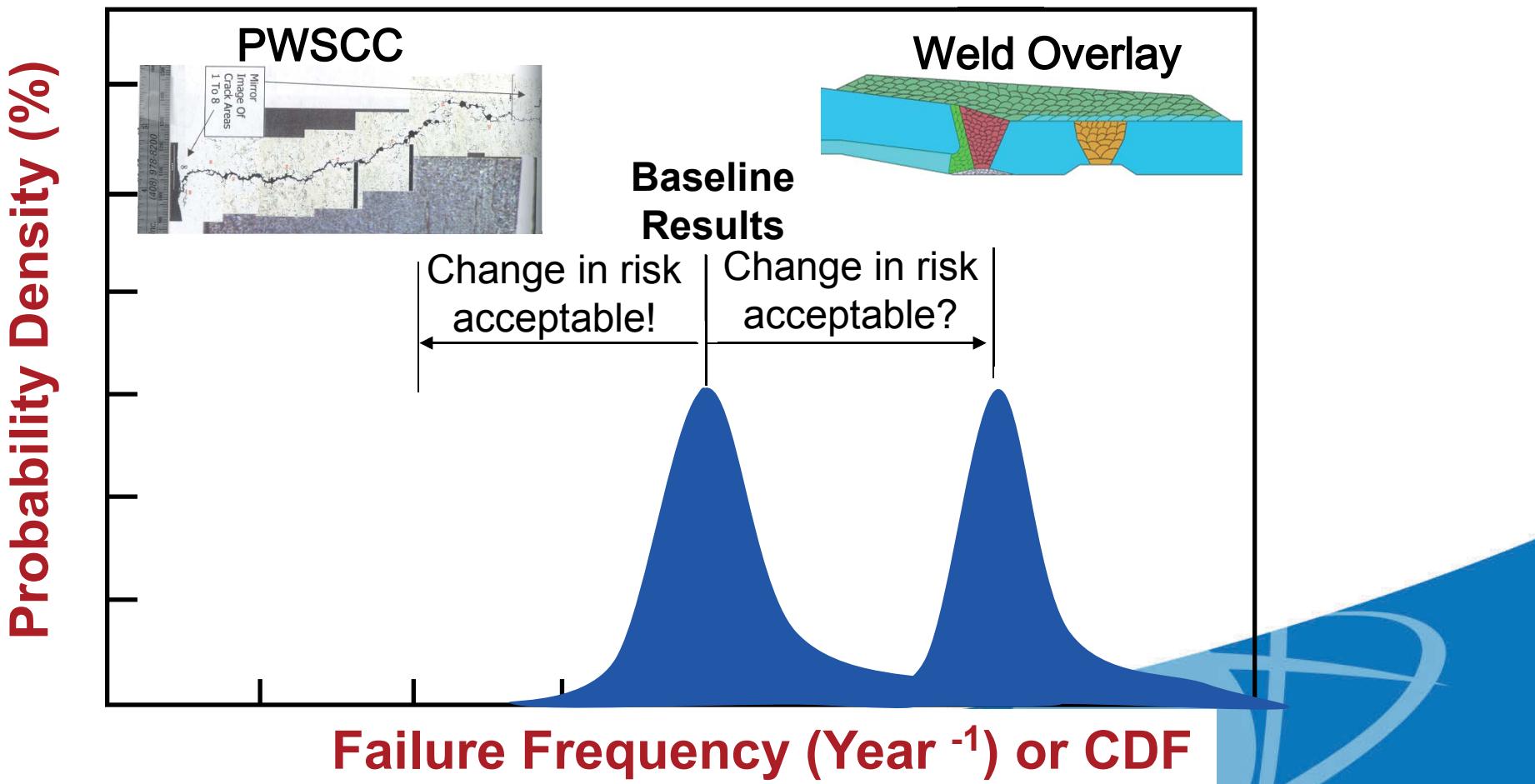
- Quantified solution to LBB issue
  - Regulatory Guide
  - Update to SRP3.6.3
- Fully QA'ed modular probabilistic fracture mechanics code for reactor pressure boundary integrity
  - LBB including evaluation of mitigation for DM welds
  - Research tool for prioritization
  - TBS – 50.46a
  - Risk informed 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 ( $\Delta$ -Risk)
  - Intent is to use existing acceptable risk values

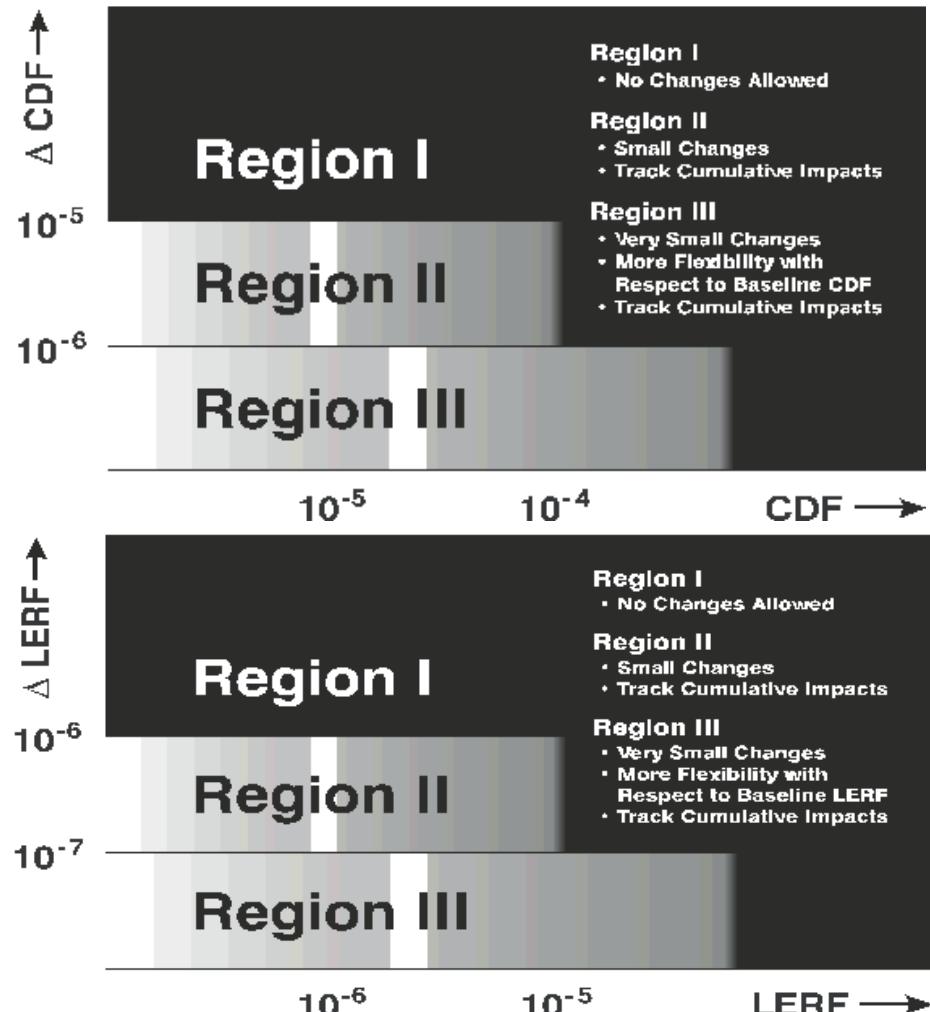
# Using xLPR for LBB

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  $\Delta$ CDF
  - Large Early Release Frequency (LERF) and  $\Delta$ LERF
- 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



- **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<sup>2</sup>, 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

- **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 ( $\sim 10 \text{ mm}^2$ )
  - 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 PWSCL 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.)

- **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/m<sup>2</sup>
  - 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.)

- **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 dissimilar 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

- **Purpose:** Identify 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

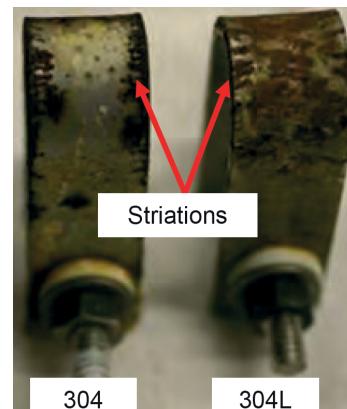
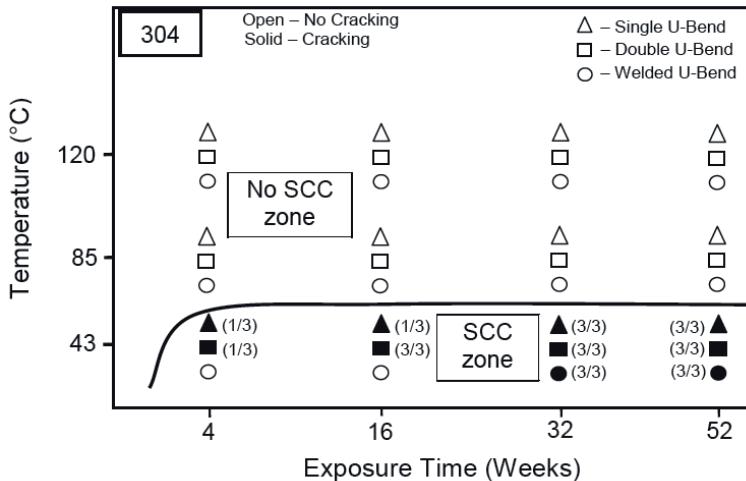
**Meeting with the ACRS Subcommittee on  
Materials, Metallurgy, & Reactor Fuels  
January 14, 2014**

# Background

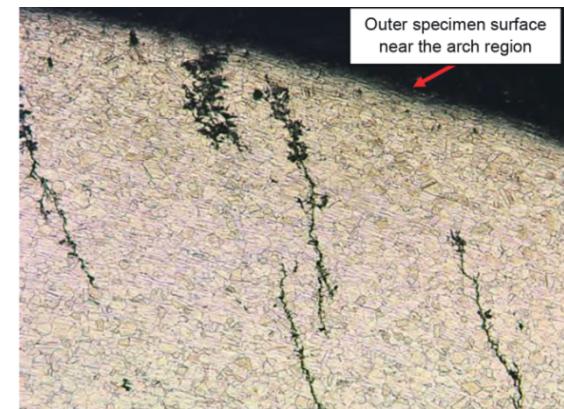
- Austenitic stainless steel is susceptible to stress corrosion cracking (SCC) in chloride-rich (i.e., marine) atmospheres
- Japanese studies at Central Research Institute for the Electric Power Industry (CRIEPI) since early 2000s
- Electric Power Research Institute (EPRI) topical reports in the mid-2000s
- 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



- 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

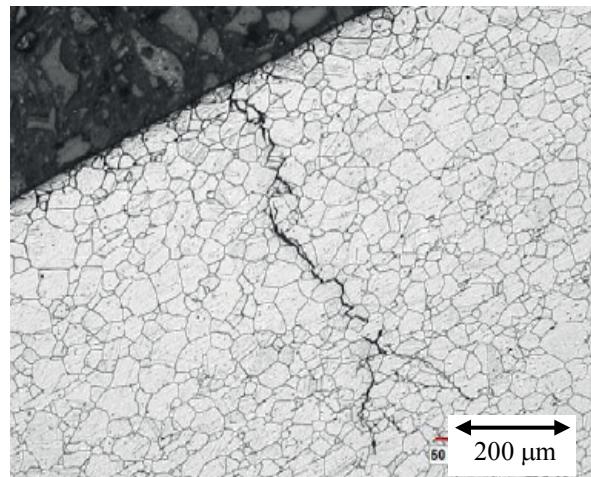
- Test objectives:
  - Limit absolute humidity (AH) to about 30 g/m<sup>3</sup>
  - Vary test temperature
  - Vary surface salt concentration and material condition
- Test methodology:
  - Deposited 0.1, 1, or 10 g/m<sup>2</sup> of sea salt on ASTM G30 U-bend specimens
    - Expose to salt fog for various times
    - Quantity determined by control specimen weight gain
  - Type 304 in as-received or furnace sensitized (2 hours at 650 °C) conditions
  - Exposed in test chamber to cyclic AH between about 15 and 30 g/m<sup>3</sup>

# Test Results

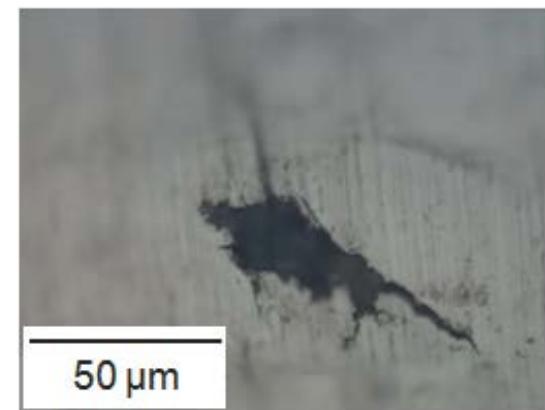
Specimen Temp. (°C)	RH Range (%)	Exposure Time	SCC Observed?	Lowest salt concentration at which SCC was observed
27	56-100	8 months	No	N/A – salt deliquesced and drained off
35	38-76	4 – 12 months	Yes	0.1
45	23-46	4 – 12 months	Yes	0.1
52	16-33	2.5 – 8 months	Yes	1
60	12-23	6.5 months	Yes	10



Pitting on specimens at 10 g/m<sup>2</sup> (top), 1 g/m<sup>2</sup> (middle), and 0.1 g/m<sup>2</sup> (bottom)



Cross section of sensitized,  
0.1 g/m<sup>2</sup> specimen at 45°C  
after 4 months



Top view of sensitized, 10 g/m<sup>2</sup>  
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<sup>2</sup> 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 <sup>3</sup> )	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 °C and 28% at 80 °C, though at AH above 30 g/m<sup>3</sup>
- Sensitized specimens showed greater extent of cracking

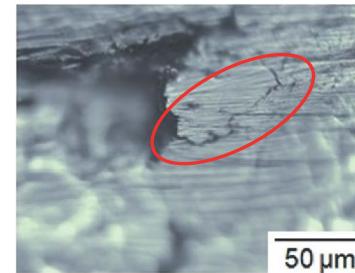
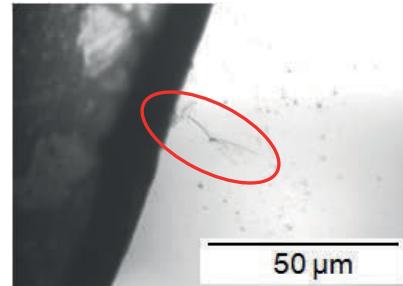
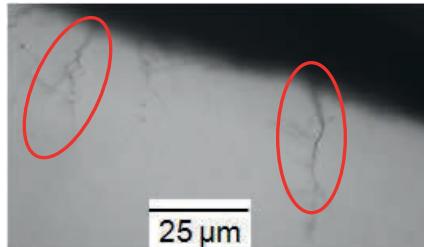
Sensitized, 60 °C, 30% RH



As-received, 80 °C, 35% RH

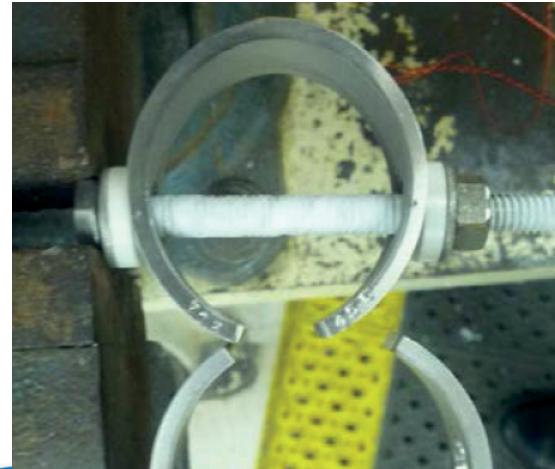


Sensitized, 80 °C, 28% RH



# C-Ring SCC Testing

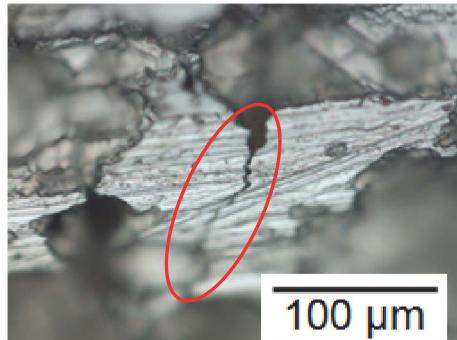
- Test objective: Evaluate lower strain condition relative to U-bend specimens
- Test methodologies:
  - Specimens fabricated following ASTM G38-01 and deposited with 1 or 10 g/m<sup>2</sup> of salt
  - Specimens strained to slightly above yield stress (~0.4% strain) or 1.5% strain, as measured by strain 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<sup>3</sup> at each temperature)



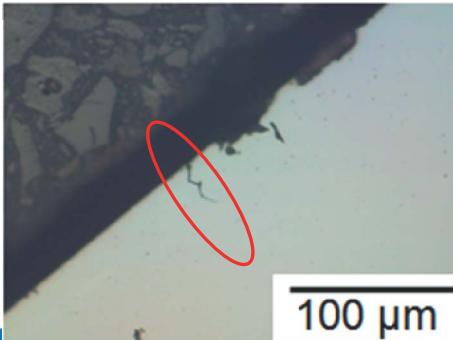
# Test Results

Specimen Temp. (° C)	RH (%)	AH (g/m <sup>3</sup> )	Salt Concentration (g/m <sup>2</sup> )	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

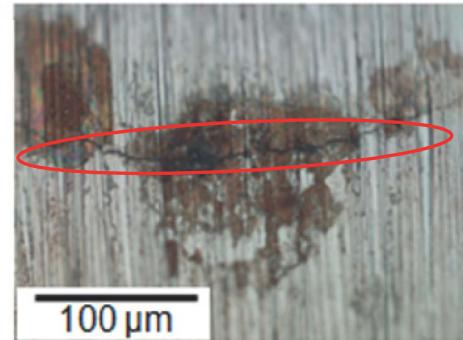
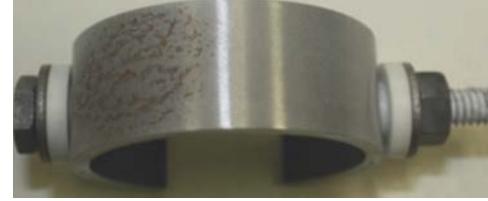
Sensitized, 35°C, 0.4% strain, 10 g/m<sup>2</sup> salt



As-received, 45°C, 1.5% strain, 10 g/m<sup>2</sup> salt



Sensitized, 52°C, 0.4% strain, 1 g/m<sup>2</sup> 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 –  $(\text{NH}_4)_2\text{SO}_4$
  - Ammonium bisulfate –  $\text{NH}_4\text{HSO}_4$
  - Ammonium nitrate –  $\text{NH}_4\text{NO}_3$
  - 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

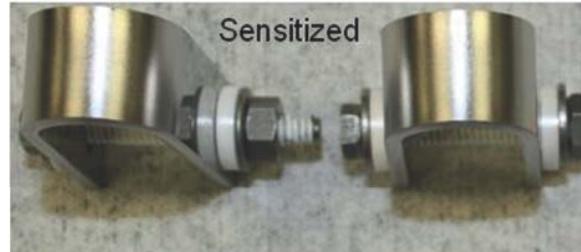
# Test Results

- 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  $\text{NH}_4\text{HSO}_4$ 
  - Deliquescent solution pH for most species is in range of about 4 to 5.
  - Deliquescent solution pH for  $\text{NH}_4\text{HSO}_4$  is about -1 to -2.

Specimens exposed  
to  $\text{NH}_4\text{NO}_3$



Specimens exposed to  
 $\text{NH}_4\text{NO}_3 + (\text{NH}_4)_2\text{SO}_4$  mixture



Specimens exposed  
to  $\text{NH}_4\text{HSO}_4$



# 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<sup>3</sup>.
- SCC initiation is observed at salt quantity as low as 0.1 g/m<sup>2</sup> 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