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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

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UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

(ACRS)

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FUELS, MATERIALS, AND STRUCTURES SUBCOMMITTEE

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OPEN SESSION

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TUESDAY

JUNE 25, 2024

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The Subcommittee met via Video-Teleconference, at 10:00 a.m. EDT, Ronald G. Ballinger, Chair, presiding.

SUBCOMMITTEE MEMBERS:

RONALD G. BALLINGER, Chair

VICKI M. BIER, Member

VESNA B. DIMITRIJEVIC, Member

GREGORY H. HALNON, Member

CRAIG HARRINGTON, Member

WALTER L. KIRCHNER, Member

ROBERT MARTIN, Member

DAVID A. PETTI, Member

THOMAS ROBERTS, Member
MATTHEW W. SUNSERI, Member

ACRS CONSULTANT:
DENNIS BLEY
STEPHEN SCHULTZ

DESIGNATED FEDERAL OFFICIAL:
CHRISTOPHER BROWN

ALSO PRESENT:
MARKUS BURKARDT, EPRI
NATHAN GLUNT, EPRI
STORM KAUFFMAN, MPR Associates
FRED SMITH, EPRI

P-R-O-C-E-E-D-I-N-G-S

10:00 a.m.

CHAIR BALLINGER: This meeting will now come to order.

This is a meeting of the Advisory Committee on Reactor Safeguards, Fuels, Materials, and Structures Subcommittee.

I'm Ron Ballinger, Subcommittee Chair for this meeting. Members in attendance are Tom Roberts, Dave Petti, Bob Martin. Greg Halnon is on the Metro on his way. We have a number of people on the remote, not the least of which, let's see if I can get everybody.

I know Craig Harrington is on the line. Most of the people in here will recognize that he's a new member, will recognize that name from EPRI.

Who else? Vesna Dimitrijevic, Vicki Bier. Walt is not on; probably will be.

MEMBER KIRCHNER: I'm here, Ron.

CHAIR BALLINGER: Okay, got it.

Who else? Well, I'm sure I've missed somebody. Well, our consultants, Dennis Bley and Stephen Schultz, are also either here online. And, again, I probably missed somebody, but they'll correct me.

This is an information briefing.

EPRI, I'll say a little bit later, has submitted three topical -- three reports that are under review currently by the staff. And they all are related to what's called the ultimate licensing strategy. And the reports aren't out. I don't need to name them.

The ACRS was established by statute and is governed by the Federal Advisory Committee Act, FACA. The NRC implements FACA in accordance with its regulations found in Title 10 of the Code of Federal Regulations, Part 7.

This committee can only speak through its published letter reports. We hold meetings to gather information and preform preparatory work that will support our deliberations at a full committee meeting.

The rules for participation at all ACRS meetings were announced in the Federal Register on June the 13th, 2019. The ACRS section of the U.S. NRC public website provides our charter, bylaws, agendas, letter reports, and full committee transcripts of both the full and subcommittee meetings, including slides presented there.

The agenda for this meeting was posted there. A portion of this meeting may be closed to protect EPRI proprietary information pursuant to 5 USC 662(c)(b)(C)(4).

As stated in the Federal Register notice and in the public meeting notice posted on the website, members of the public who desire to provide or oral input to the subcommittee may do so and should contact the Designated Federal Officer, who happens to be Christopher Brown. A communications channel has been opened to allow members of the public to monitor the open portions of the meeting.

The ACRS now invites members of the public to use the Teams link to view slides and other discussion materials during these open sessions. We have not received any requests to make oral statements from the public regarding today's meeting.

Written comments may be forwarded to Christopher Brown, today's DFO. There'll be an opportunity for public comments and we have set aside ten minutes in the agenda for comments for members of the public during the meeting.

So, why are we have this meeting? There's an ongoing rulemaking to increase -- to allow increased enrichment. One of the directives from the Commission, as part of that rulemaking effort -- he made it, Greg Halnon is now here.

One of the requirements of that rulemaking was that fuel -- FFRD, fuel fragmentation, relocation, and dispersal, be addressed as part of that.

There's a Technical Basis Document that was produced that we have reviewed and a significant part of that Technical Basis Document was not present because there were comments related to so called Option 5 which dealt with ALS. That's the acronym that we'll use for that. And these documents are related to that Option 5 and so called ALS.

I might add that we have come a very long way. Some of us are old enough to remember that, in the early days, we used regulation and defense-in-depth much to our benefit. Appendix K covered an awful lot of things that we didn't know about.

You might recall that during the Second World War, the Liberty Ships decided that they'd use welding. And we lost as many welded Liberty Ships due to brittle fracture as we did the torpedoes, almost. And that resulted, ultimately, in what amounts to Section 11 of the ASME boiler and pressure vessel code.

So, inspection and repair -- excuse me -- inspection and repair in Section 11 has largely been derived because of our industry and efforts related to safety. Appendix K was the same way.

Our materials choices back in those days were made based on the best available information. I might add that Alloy 600 for steam generators, its major use before the nuclear side was in the dairy industry.

And so, we chose Alloy 600 and we have -- Section 11 has saved us a lot because of those materials choices.

So, all during this time for the last 20 years, much research has been ongoing related to inspection and repair and materials choices and prediction of materials behavior.

The ALS effort which includes inspection and repair, fracture mechanics, all kinds of the technology and data that's been generated all this time, the ALS is almost a product of that long standing effort.

So, we're about to embark on what amounts of a revolution, and not an evolution, in the way we do things regarding inspection and repair and materials behavior.

I might add, by the way, that Craig Harrington has recused himself for obvious reasons from this. He's online, but he can't participate in our deliberations.

So, with all of that rumination, who's going to go first? Fred, the floor is yours.

MR. SMITH: Thank you. Fred Smith from EPRI.

So, I'm going to go over an overview of ALS, highlight a few features, and then, we'll have deep dive or deeper dive into different reports as we go through the day.

So, as you mentioned, there are three reports that compose the topical report. The one in the center, which is a leak-before-break credit. It's a compendium of the others. It pulls them all together.

It also addresses several topics that are not addressed in either the fracture mechanics or the LOCA analysis. I'll walk through briefly the content of each of these reports.

One thing I want to point out is, in the increased enrichment rulemaking, there was a proposal that ALS be modified to convert large-break LOCA from a design basis event to a beyond-design-basis.

And we -- the industry took exception to that because we felt that like, while maybe have some merit, would really extend the period for review, complicate the review, and isn't necessary for -- to deal with FFRD.

So, any actions along that line separate and apart from this submittal.

CHAIR BALLINGER: I don't know about the other folks here, but I'm having a little trouble hearing you. Can you get a little closer to the mic?

MR. SMITH: Okay.

So, is that a little better?

CHAIR BALLINGER: Thank you.

MR. SMITH: Yes, sorry about that.

So, in the leak-before-break, there are several key elements. And we'll talk about one is a section on safety benefits. I won't go through all the details on the safety benefits, but they derive from three general areas.

The use of high enrichment, high burnup, is a much more efficient utilization of uranium. And so, the entire fuel cycle gets shrunk by the use of high enrichment, high burn-up. And so, that means that the front end has less mining impact, less transportation impact, and the fabrication is particularly impacted.

You know, the burnup increase is about a 20 percent increase. And so, the fuel insert fractions would be expected to be reduced by about 20 percent. And that means that on the back end, the high level waste discharge going forward would be reduced commensurate.

And so, there are a number of benefits associated with that, fewer dry cask loading campaigns, fewer casks on the pad, and then, ultimately, less transportation to a repository once one is developed and approved.

Overall, you know, the industry today is undergoing a very healthy growth period. When we started this, that was not necessarily the case and we hope it continues. But the economic benefits of the higher burnup and enrichment are sufficient that could make a difference in plants deciding to terminate their license early.

And so, that means that this supports international and national goals for low carbon emissions. While it's not necessarily an NRC directive, it is a national directive, I believe.

Also, the question subjects are complicated and there are relatively few experts in many of these areas. And particularly the dispersion area, there's a lot of research necessary to understand and address that.

The ALS approach eliminates dispersion. So, that eliminates the demand on those resources, both from an industry and for the Commission.

So, there's several pages in the report discussing safety benefits. I just wanted to highlight them here today.

The discussion on regulatory guidance, particularly about the history of leak-before-break. And while we don't suppose to enter into what the staff might choose to incorporate in new regulations, it obviously has an impact on the overall implementation of this topical.

There's a policy about leak-before-break and we would expect that that would be updated. And then, whatever downstream regulatory or other documents needed to be adjusted, we would be watching carefully with the staff as they finish the rulemaking process.

We will talk about defense-in-depth near the end of the day today, different perspectives on that, but we have included defense-in-depth mostly for all, in fact, all but one leak-before-break application that we reviewed did not address defense-in-depth, but we chose to do so as part of this.

And then, we talk about methodology and

the overall leak-before-break topic. So, the report summarized just results from the LOCA analysis report on the piping rupture results.

This is for large, intermediate break, and small break. Also, it evaluates the non-piping ruptures. It does not do a LOCA analysis as such, but it goes back and reviews the design basis for these kinds of non-piping components.

And just to confirm that there's no unexpected issues associated with them.

And then, there's the summary and conclusion section where we discuss the limitations of the analysis.

The first implementation of this is modular and it does -- it is applied directly to Westinghouse NSSS configurations with Westinghouse fuel is intended to be extendable with the supplemental analysis so that other NSSS configurations can apply it.

There are several that are interested in it. Other vendors can apply it and other fuel designs can it. And we have several people interested. And I think Paul Clifford is here from Framatome and if you would like to say a few words about your company's view?

MR. CLIFFORD: This is Paul Clifford, Framatome. Yes, even though we don't have a presentation, don't take that as to be a lack of interest or support for the EPRI ALS.

Framatome fully supports this robust technical and regulatory solution to fuel dispersal and we will work with our customers on a means to adopt it similar to the pilot program that Westinghouse is going to be presenting today.

And we will be closely monitoring the staff's review to really understand the areas of difficultly, the areas of concern with the staff, and any limitations and conditions that the staff may impose on the approval of these three reports.

And we will be adapting our methods to not only address those areas, but also, we will be closely monitoring the rulemaking to understand the extent to which risk would be allowed to be credited in the implementation of new LOCA methods, including LOCA methods that will be used to show compliance or to show implementation of the ALS.

Thank you very much.

MR. SMITH: So, while not every utility will elect to extend their burnup limits, not everyone has the same operational impact of the burnup limits.

Some have margin that they can use to achieve their other goals. We believe ALS can apply to every PWR in the country that elects to do so. And we're not here to talk about a BWR version, but EPRI is working on elements for BWRs as well.

So, the fracture mechanics report, as I'm sure you all know, the xPLRs are jointly developed. Probabilistic fracture mechanics analysis developed jointly by the NRC and EPRI.

And so, we will talk about the analysis and how it applies to this application. The report will -- I will warn you, the report is fairly comprehensive in that it does have cases that are not directly applicable to ALS.

So, it has smaller diameter piping, for example. And those are clearly annotated in the report. We are only applying the xLPR results to main cooling loop piping systems. But the report does and is comprehensive and covers a wide range of piping configurations.

There's a discussion on benchmark and validation comparison to 1829 as a figure of merit. And one of the key results for ALS is the time between a leak -- detectible leakage and a LOCA.

And so, we credit that as part of the

justification that operator response would be well inside that envelope and a LOCA would be included based on that operator response.

There's discussion on the degradation models that are in xLPR and why they apply to the application that's being used, and then, conclusions, of course.

And then, finally, Westinghouse has done a significant amount of LOCA work to support this. They've looked at all of their NSSS configurations and fuel types that we believe will be -- will most likely implement the soonest. And so, there's a comprehensive discussion on that analysis.

So, limitations and conditions in the end of the report. And then plant-specific requirements for implementing the LOCA analysis.

And just -- while it's not part of this submittal there is a reference that has been accepted for review that updates the Westinghouse LOCA methodology is also under review.

DR. SCHULTZ: Fred, one question association with application to other facilities.

You mentioned BWR and Paul talked about Framatome. What about combustion engineering plants and B&W plants? Is that something that the utilities are going to need to address or does EPRI have that in their forward plans -- forward looking plans?

MR. SMITH: There's been, particularly, the CE digital plants, what I call the CE digital plants, the large plants, there's a lot of interest there.

And we believe that that will occur, whether EPRI sponsors it or the vendors in conjunction with the individual utility sponsor it. The number of utilities -- the number of plants of that nature is fairly limited.

DR. SCHULTZ: Would it move into the owners groups, then? The PWR owners group, for example?

MR. SMITH: It could. We haven't gone that far to decide how to do it. But there are really only five plants like that in the U.S. and three of those plants are probably not that interested.

DR. SCHULTZ: Thank you.

CHAIR BALLINGER: Is there international interest in this?

MR. SMITH: There's a lot of international discussion about it. But the world is different in different places. Right?

So, the fuel costs and the back end costs are very different than the United States. And so, annual cycles are -- have been more the norm.

One of the main drivers in the U.S. is the PWRs into 24-month cycles. And while our engagement with international members have said they are looking at perhaps increasing their cycling, no one has yet said we're ready to go to 24-month cycles except the UAE.

CHAIR BALLINGER: I was going to say, there are a number of CE like plants.

MR. SMITH: Yes, that's right, that's right. So --

MEMBER PETTI: And how about Korea? Is there any --

MR. SMITH: Yes, yes.

MEMBER PETTI: That's what I mean, specifically.

MR. SMITH: Korea?

MEMBER PETTI: Yes.

MR. SMITH: We have -- we speak with them, we meet with them twice a year and they are very interested in what we're doing. But they haven't committed to doing anything yet.

MEMBER PETTI: So, is if fair to characterize it as, you know, there's a lot of interest. But from a licensing perspective, the U.S. is leading and people are watching?

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

PARTICIPANT: Well, I should add that, in 2014, ASN in France did redefine LOCA to follow TBS transition break size and everything above that.

So, I'm not sure U.S. is leading per se, I think what I see here is certainly the use of leak-before-break to strengthen the argument in the U.S. I think is significant.

So, certainly looking forward to seeing what you have to say there. It might put some meat on the bone where it probably needs to be.

MEMBER PETTI: I just -- I know you guys are going to get into the details. It would be helpful to talk a little bit about what topical listed fractured mechanics is on the record so people don't it's voodoo, you know, sort of stuff.

You know, what's the industry coming up with now? You know, give us that perspective.

MR. SMITH: Yes, I think we --

MEMBER PETTI: I'm sure your next presentation will cover that.

MR. SMITH: So, I'll turn this over to Markus or Nathan, okay.

MR. GLUNT: Perfect segue to that one, thank you. So, I'm Nate Glunt. I am from EPRI's Material Reliability Program.

I'll be starting off this presentation and then passing it over to Markus here, Markus Burkardt from Dominion Engineering. He worked with us on the XLPR work. And so, we'll be presenting on the xLPR probabilistic fracture mechanics analysis specifically for ALS.

As Fred mentioned, our analysis does include other line sizes other than ALS, what ALS is concerned about, but we'll just focus on ALS.

So, first of all, the outline, as I said, I'll take everyone through the background. I'll talk a little bit about xLPR and where we've used it. And then turn things over to Markus for the scope. And then he'll go through the summary of xLPR analysis cases and get into those key results that I know you all are really interested in. And then we'll finally finish off with some conclusions.

So, we do piping and fracture mechanics, so we have our own whole list of acronyms. And fuels has their own list of acronyms. I'm sure you all with your specialties have your own as well. So, we did include this list of acronyms here at the beginning so if anyone needs to refer back to, please feel free.

I'm pretty sure you all know what ACRS means. That's the first one on there. But please feel free to refer back. We know it can be quite confusing at times.

CHAIR BALLINGER: What makes you so sure?

(Laughter.)

MR. GLUNT: One more back, Fred. One more?

MR. SMITH: Backwards?

MR. GLUNT: Yes. So, this is actually our sixth time meeting in this building or the other building, I guess, to discuss xLPR and how it could be used for ALS.

So, we have the ML numbers, if anyone's interested in those other presentations. A notable one is just over a year ago. This was also presented, of course, to ACRS before. So, keeping track of those and just making sure everyone's aware of that.

So, now, we'll get more into the background and scope. And Fred stole my thunder a little bit before.

You know, xLPR is what we consider a state of the art probabilistic fracture mechanics code. But we do consider it state of the art, because we have benchmarked it with probabilistic fracture mechanics codes from all over the world.

What's unique is that it was jointly developed by EPRI, specifically, MRP, but it involved dozens and dozens of folks and NRC Research. And so, it's the industry working together with the regulators to solve a problem.

The code itself is specific for nuclear power plant piping. And it's -- the most important aspect of it, it gives you the ability to quantitatively analyze risks in piping.

When we speak about risk in piping, we're generally speaking about leakage, possibly rupture. But with the code, you can look at the probability of initiation of cracks in the first place and their growth. And so, risk is whatever you define it to be. There's thousands of outputs from the code.

Now, the code has been used in a few select areas already. Most notably, the NRC and EPRI worked together on analyzing the impact of primary water stress corrosion cracking on leak-before-break analyses.

This forms the basis for a lot of what we're going to discuss here today as well. And so, that is -- I consider it a separate project, of course, from ALS. It's totally separate. But we use a significant amount of what we've learned there in those analyses in our ALS work.

So, what xLPR is, it's not voodoo. So, it's fairly simple from a high level. Once you get into the inner workings of the code, it's very complex, of course. But what we have with xLPR is essentially a probabilistic structure or a probabilistic wrapper.

So, all of the -- there's thousands of inputs that can go into the code. And the vast majority of them, you can define as distributions.

So, you have a distribution of material properties, crack behavior, loads. So, you can -- the user chooses which inputs you want to define as a distribution. The code then samples and works through time-stepping before sending everything to a deterministic fracture model.

The deterministic fracture model is actually a set of different deterministic models that make up crack growth. So, you have crack initiation. Then you go into growth, transitioning that crack through wall, through-wall growth, and, finally, failure or rupture of the piping.

There's also deterministic modules on

leakage rates, in-service inspection, crack opening displacements.

So, the heart of xLPR is these series of deterministic models. We just have a probabilistic wrapper around it. But for a case, the user goes in and defines their input set. You can choose whether your inputs are constant or distributions.

The code samples the distributions for one single case, sends it to the deterministic models and you get an output. And the code starts again, sample again, run through the deterministic model, and you get an output.

By the end, you do this tens of thousands or hundreds of thousands of times and you have your statistical analysis at the end. You have your probabilistic fracture mechanics analysis. And so, you're just running many times through deterministic models by sampling what you put into them.

CHAIR BALLINGER: This may come later, but all of all the distributions, which one is the broadest? So, which model has the most uncertainty?

MR. BURKARDT: Maybe leak rate. I was going to say crack growth rate. Crack growth rate equations have a distribution that varies out towards the magnitude and crack growth rate. And likewise, crack initiation will still have --

CHAIR BALLINGER: I thought were going to say initiation.

MR. BURKARDT: Well, both have, you know, multiple orders of magnitude of variation within the input distributions. And so, you can get situations where you have cracks initiating very early and growing very quickly.

And also, ones where cracks, you know, initiate very late and grow very slowly, too. But that also accurately represents the level of variability that's in these materials as well.

And then there's substantial, you know, variability that's, you know, partially due to microstructure or other processing of the materials that influences the cracks, you know, susceptibility to PWSCC crack initiation or to crack growth.

And rather than trying to model those microstructural details, those are then, you know, basically captured by having a distribution on inputs associated with the crack growth or crack initiation models.

MR. GLUNT: Yes, and we have several different initiation models as well.

MEMBER KIRCHNER: Ron, this is Walt. A

corollary kind of question would be, do you find -- or maybe you're going to come to this -- do any of these, starting with the probabilistic inputs, does any one of those that you show here in this diagram dominate?

MR. GLUNT: It depends on the type of analysis. We find that welding residual stresses for have a significant impact, of course, with primary water stress corrosion cracking.

I mean, that generally dominates. And so, we look at -- the xLPR group has done a significant amount on the investigation into welding residual stresses for these weld types.

MEMBER KIRCHNER: So, if I may follow up, then, is that an issue that --

CHAIR BALLINGER: Excuse me, Vicki.

MEMBER BIER: Go ahead with the follow-up and then I'll ask mine.

MEMBER KIRCHNER: My follow-up would be, do you find this mostly at vessel to piping welds?

MR. GLUNT: So, the welding residual stress analyses that we have cover a number of different welds. So, the reactor vessel, nozzle to piping welds are significant.

But also, you know, we have done analyses for other lines with pressurizer, of course, that's below the limitations that we're looking at here. But even the steam generator has similar metal welds, we've investigated as well.

So, it's very particular to the design of the weld. And so, there's a lot of sensitivity analyses that have been done throughout the xLPR work on the welding residual stress analysis.

CHAIR BALLINGER: So, I'm to assume that the weld residual stress issue has been dealt with for years and years and years. And there are various -- all your acronyms have MSIP and all that kind of stuff. Does xLPR account for the fact that a weld may have been dispositioned in some way?

MR. GLUNT: You're one slide ahead. So, on the next slide, I'll discuss that.

CHAIR BALLINGER: Okay.

Oh, Vicki?

MEMBER BIER: So, before we get to the next slide, I'll ask my question which is, you have the fracture mechanics model being totally deterministic, which I understand.

And in generally known certainty analysis, there can be a wide range of how much uncertainty there is in the model itself.

You know, some analyses may be the, you

know, it really is just a matter of physics and all of the uncertainty is coming from the input parameters, other fields like climate change, for example, there can be different communities of scholars with different models and the model on uncertainty itself can be a big factor in the output.

So, I guess two questions. One is, where in that spectrum do you place your model, you know, are there a lot of modeling assumptions that are not reflected in your parameter uncertainty?

And second of all, just was there any attempt made to quantify or estimate the extent of model uncertainty?

MR. BURKARDT: So, I'll get to the treatment of uncertainty within xLPR for the different models and also the overall assessment in just a couple of slides.

But just kind of really quick preview of that, the models are intended to be, you know, best estimate type models with best estimate type inputs consistent with the probabilistic approach.

And, you know, by having xLPR developed by both, you know, NRC and industry on a collaborative basis, you know, we made sure to include, you know, all the subject matter experts in the various areas associated with each of the individuals models that were included within xLPR.

And also, had, you know, development and review from both sides just to ensure that, you know, everyone agreed that, yes, those are, in fact, the best estimate models to be included.

MEMBER BIER: Okay, thanks.

MEMBER HALNON: So, I wanted to follow up along the same themes, and so, I listened to you talk and Nathan are describing the user experience with the code and having this freedom to describe the uncertainties, the probability distributions functions of various parameters, it seems to me that this would be data driven, correct?

So, is the database or those sort of things that rich that we have the latitude to allow users to do anything they want with that information?

I mean, how easy is it to generate the kind of data that would otherwise supply a code like xLPR?

You know, I think of safety, a capital S in doing these kind of analysis, you know, you have to have pretty strict criteria on what, you know, the sources of information feeds the codes.

Is it really that much information out

there to deviate from, you know, some established set based on R&D that's been done already? And isn't it very expensive to go out and make the data that would otherwise feed a code like this?

MR. GLUNT: So, Markus is ready to jump all over this one, but I'll start with, you know, through -- yes, the code does allow you to select what you want. And the code is powerful and it is built for these special circumstances where you want to look at a very specific welding residual stress or a material properties one, you can do that.

However, the code also does come with standard properties already built in, database is full, thousands of pages of inputs already prepared by the industry and NRC together to select what we do consider the best estimates.

So, while the code can, and you can use it as you see fit, it can do all these different properties or whatnot. We do also provide what we consider the best estimates of the majority of the inputs.

MEMBER HALNON: Best estimates with, you know, best estimates like probability distribution functions or two best estimates -- we use the word best estimate when you are referring to a probabilistic input, it's a little confusing.

MR. GLUNT: That's best estimate distribution.

MEMBER HALNON: Thank you.

CHAIR BALLINGER: Member Harrington, within the limitations of your conflict of interest?

MEMBER HARRINGTON: Absolutely. I'm in an awkward place here. I would just like for Nate and Markus to speak to the uncertainty report in regard to Vicki's question.

MR. GLUNT: Yes, that's coming up in the presentation.

MEMBER HARRINGTON: Thank you.

MR. GLUNT: Continuing moving on, as I said, some of these questions will be asked in the slides and what's coming up next.

So, more about what the xLPR code actually has. So, as we said, it's for nuclear power plant piping, specifically, it is for piping butt welds. And it can analyze either dissimilar metal or similar metal welds with crack orientation being either axial, circumferential, or it can actually do both at the same time.

And it can also analyze multiple cracks around the circumference for a circumferential, for instance.

So, it's not limited to just a single crack, it's whatever the user puts in or the models initiate. The cracks that we do analyze are shown to the right in the middle, I'm not sure how to explain that, but we do have the ability to analyze a surface crack.

So, after either initiation or the user inputs a crack themselves, we have a surface crack which then grows until it reaches 95 percent through-wall, becomes a transitioning through-wall crack that defined more like a trapezoidal shape.

And then, finally, we grow directly into an idealized through-wall crack into continue to grow around the circumference.

So, we really start from crack initiation until it goes through-wall all the way around to failure.

And when we talk about initiation, we can have the crack initiate either by stress corrosion cracking, fatigue, or both, or we can actually have the user input whatever situation they want with cracks, multiple fracture on the surface, a single, that's up the user as well.

Crack growth is the same. You can look at stress corrosion cracking, fatigue, or both combined. And then we do have the ability to look at mitigation. So, we have built into the code, inlay, onlay, overlay.

We can include mechanical stress improvement process, so MSIP, through changing evolving residual stresses at whatever point in time you choose. And then chemical mitigation.

Now, a lot of the results that we're going to speak about today do not necessarily include mitigation because once you mitigate, we found that it's extremely effective.

If you change the welding residual stresses, the crack growth is going to stop. And that's the point of it and that's -- we're very happy to see that in the analysis. But it is part of it, so there were cases run with different mitigation strategies included as well.

And then the last two points I think are extremely important and they're going to lead into what Markus is going to discuss later.

We have the ability to include in-service inspection and we also have the ability to include leakage detection and how that impacts the results.

And I won't get into that too much now

because you will directly see that in some of the results that Markus will show later.

MEMBER HALNON: And as you read through all these different capabilities, and it struck me that it's almost the V.C. Summer crack exactly. Did you lay over that operating experience with this?

MR. GLUNT: Yes, the V.C. Summer, the stresses were directly used in early benchmarking.

MEMBER HALNON: And it showed good results?

MR. GLUNT: It did. I actually worked at V.C. Summer before coming to EPRI. And so, when I started on xLPR, that's the first case I ran.

MEMBER HALNON: And we may have run across each other because I was the guy that fixed it.

MR. GLUNT: Oh, there you go. Yes, we have, outside of ALS as part of the xLPR program overall, it was benchmarked against unknown circumstances.

CHAIR BALLINGER: By implication of what Greg's and your comment, the -- you can deal with a complex residual stress pattern as you go through the wall?

MR. GLUNT: Yes, you can. Yes, the welding residual stress pattern is defined as 24, 26 points through the wall. And so, you can get very complex and there's the ability of the code to actually sample that as well if you choose to do so.

So, it can look at very complex stresses. So, we've talked a lot about the inputs and what it looks like going into xLPR. This slide does a very brief discussion of what the results look like coming out of xLPR.

Now, again, this is overly simplified because you can pull out intermediate results throughout, but the easiest results to pull out, of course, are the probabilities of first crack, first leak, and rupture which is shown over here to the right just as an example.

You can also pull out individual crack results. So, when we talk about type, it's whether it's surface, transitioning, or idealized through-wall, the position around the circumference, leak rates associated with it, and then, of course, the growth, so the stress intensity factors that go with it.

The number of cracks is tracked along with the probability of non-repair and the stability ratios. That's all easy to get out of the code.

And then, finally, we'll talk a lot about leakage here today. So, you can pull leak rates from individual flaws or the total from all flaws.

And to your point earlier, you asked about mitigation, this is just an example for demonstration purposes, but that figure there to the right does show mitigation after 49 years. And you can see what the impact of mitigation and ISI have on the analysis as well.

CHAIR BALLINGER: I'm a gearhead in this, so you'll have to bear with me. Does it handle multiple initiation, multiple crack initiations which then coalesce?

MR. BURKARDT: It does, yes.

CHAIR BALLINGER: Because that's typically what we see.

MR. GLUNT: Coalescence is a lot of -- it is a big part of xLPR. But for some of the analyses, we just started with very long flaws to already get past the coalescence point, so very long flaws representative of multiple flaws coalescing as well.

MEMBER HALNON: And that's axial and circumferential?

MR. GLUNT: They don't combine together, they individually, you can.

MR. BURKARDT: So, we can model multiple

crack initiation of axial flaws, multiple crack initiation of circumferential flaws.

We allow multiple circumferential flaws to coalesce into larger circumferential flaws. But given that multiple axial flaws are out of plane of each other, we don't allow for those to coalesce with each other.

And we also don't treat coalescence of axial and circumferential flaws into some off axis sort of scenario, either.

CHAIR BALLINGER: I'm thinking of what's been happening in France with their multiple initiation, residual stress, thermally induced stuff.

MR. GLUNT: Yes, yes, we do have the ability to coalesce flaws and we have looked at that as well.

MEMBER ROBERTS: I'm just trying to go back to the -- just trying to understand how to interpret the red and the blue and the, you know, like in 20 years, the red and the blue are on top of each other. And then the blue takes off before the red does.

So, I would assume the blue take off before the red is the leak-before-break. How do you interpret when the red and the blue lines are on top of each other?

MR. GLUNT: For those cases, so, this output is -- I'm sorry, it's a little jagged, it's for demonstration purposes.

You don't have a significant number of leaking cracks in this case. And so, each time you see a jump, it's essentially another leaking crack or another crack leaking or going to rupture.

And so, these are cases when they've sort of caught up to each other.

MR. BURKARDT: You do also still see that the blue line corresponding to leakage is to the left of the red line corresponding to rupture. So, that shows, you know, leak prior to rupture.

But, yes, as Nate pointed out, if the probabilities are equal, that means that all of the cracks that have leaked have then, at that point, also ruptured as well. And so, that's what he meant with the one catching up to the other.

MEMBER ROBERTS: So, is there any meaning to the very left hand part of that curve, the 20 to 25 years or so where they just start on top of each other?

MR. BURKARDT: So, what I'm saying is, at that point, the blue line starts prior to the red line starting.

So, the meaning there is that the first crack that leaks, leaks for a couple of years from, you know, say, 20, 24 to 27 years and then, it ruptures at 27 years.

Then, you get the second crack that leaks at 30 years, the second crack ruptures at 32 years.

MEMBER ROBERTS: Okay, thanks. So, somewhere to the left of this curve, they would have diverged? Is that when the red would have been approximately zero at some point before the blue comes on scale?

MR. BURKARDT: That's correct, yes, they're all, you know, zero prior to that 1 minus 4 number.

MEMBER ROBERTS: Okay, thanks.

MR. GLUNT: Now, I'll turn everything over to Markus to walk you through some of the quality assurance that we discussed. And then through more details of the xLPR analysis.

MR. BURKARDT: Thank you, Nate. So, yes, so, xLPR, we developed under a very rigorous quality assurance program. And that quality assurance program was designed to use selected elements of ASME NQA-1-2008 as well as NQA-2008-1a-2009 Addenda, both of which are endorsed for meeting NRC's 10 CFR 50, Appendix B quality assurance requirements.

xLPR program has very extensive technical documentation with over 100 reports issued supporting documentation of the individual modules as well as the framework.

There's also very extensive verification and validation that we performed for the xLPR code with over 4,000 verification tests performed.

And for each individual module as well as the overall software being validated against operating experience, finite element analysis simulations and also other probabilistic fracture mechanics codes.

And so, the details of the quality assurance now is applied as part of the xLPR development process is documented in what we call like the top level report which is NUREG-2247.

As part of the development process also, we had an external review board that, you know, reviewed and provided input on, you know, the overall development approach.

Since then, xLPR is actually currently going through a global PFM benchmark that's being sort of jointly organized by the OECD, NEA, and CSNI.

And so far, this benchmark has found that xLPR represents a state of practice in terms of PFM modeling capabilities.

This is an international benchmark with 14 different PFM codes all around the world that are being used to model various different deterministic and also probabilistic problems as part of the overall benchmark.

There have been several conference publications on this word and the final benchmark report is expected to be published later this year.

All right, so on the -- go back, please, there we go. So, the right one, yes, thank you. To the uncertainty slide, please. Thank you.

All right, so the topic that everyone wants to hear about, uncertainty. So, first, I just wanted to talk about, you know, what we mean by uncertainty.

And in this case, we're talking about the knowledge of the knows and also the unknowns that affect model predictions. And so, Nate mentioned that we're using a probabilistic approach in the overall assessment. And so, what we mean by this is we're using best estimate models to describe a very complex system. Each of these models are linked together and integrated.

So, what we then do is, we quantify the uncertainties in the inputs, reduce them as best as we can to get best estimate uncertainties that accurately reflect the range of variation of that given input.

And then, account for the uncertainties by propagating them forward through each model using the Monte Carlo method.

So, with random sampling and then, working through a deterministic model, and then, aggregating the overall results and then, characterizing statistics on those overall results for each of the individual samples that are then propagated through that model.

Now, the xLPR program has an uncertainty report which summarizes and consolidates information on the sources of and also the treatment of uncertainties within every single one of xLPRs modules, crack initiation, crack growth, crack coalescence, solutions, leak rate, in-service inspection and so on.

And then, also within the overall framework as well. And so, this table here just kind of summarizes, you know, where certain details on that treatment is included both in the uncertainty report and also beyond that uncertainty report.

But regarding descriptions of specific uncertainties in the model reports, we speak to, you know, uncertainties associated with the basic model form that was selected.

The inputs that are, you know, the best estimate inputs that are recommended as well as the range of validity for those individual inputs.

We also assess individual assumptions that were made as part of the model development.

And then, also, you know, summarized the verification and validation efforts of those models. And we discuss any sort of uncertainty that's included or any sort of after uncertainty bias that the model and the either conservative or non-conservative direction.

And also, acknowledge that conservative and non-conservative may change depending on what sort of input you're -- or output you're considering.

We also speak to the limits of applicability for the models and if any sort of interpellation methods are applied and any acts thereof.

Within the model validation reports, we then also speak to any sort of model bias or uncertainty relative to, you know, laboratory data, field data, data from, you know, alternate models or from finite element analysis.

And then, in the scenario report, we then also speak to uncertainty associated with sampling the divergence of the results.

MEMBER HALNON: I just wanted to explore the uncertainty and the leak rate aspect. Because you're not just dealing with physics, you're dealing with operator performance, quality of procedures, historical ability of the plant, lots of different things.

What is the baseline assumptions for leak rate that gives you a reasonable uncertainty? Because that could be huge. Well, you just -- well, let's look at -- you just assume that it complies with the Reg Guide 1.45 or --

MR. BURKARDT: No, that --

MEMBER HALNON: -- is that actually go further?

MR. BURKARDT: So, for the leak rate, what we do is, we -- based on crack size, we calculate a crack opening displacement.

And then, you know, we basically calculate a leak rate through a crack of that size with the crack opening displacement at a given temperature and pressure.

MEMBER HALNON: Well, I get that that, you know, you can over this or whatever you want to do, but what about the detaching piece of it?

I mean, isn't that part of this is that you're assuming that very little leak rates are going to be detected, therefore, you have time?

MR. BURKARDT: So, in the xLPR analysis what we basically report out in our report and on our P480 is we assume a one gallon per minute detectability threshold for leaks. And then we also quantify time from one-gallon per minute to a large-break LOCA.

MEMBER HALNON: Okay, so you didn't have any uncertainty by being very conservative in how much or how little --

MR. BURKARDT: Exactly.

MEMBER HALNON: -- that can be detected?

MR. BURKARDT: And so, then, Storm, in his presentation will speak to the fact that, you know, although that might be a number that plants commit to in tech spec space, that in actuality, plants can detect much, much smaller leak rates.

MEMBER HALNON: Right, and that's where the variability comes from, that one PPMs well proven, so I get that, thanks.

MR. BURKARDT: And then, additionally, xLPR also applies uncertainty to the calculated leak rate as well, given that there's uncertainty in the crack morphology that could impact the calculated leak rates and applies that to leak rates below ten gallons per minute.

DR. SCHULTZ: Markus, an administrative question, the -- you described a very complex development program for this computer code and this development.

And many, many reports and a good QA program from the outset that sounds very good to have done. On the user side, how many users are involved with the application of the code? What's the training program associated with the use of the code? How is that controlled?

MR. GLUNT: So, the code itself is distributed by EPRI through an MOU with the NRC. And it is publicly available to anyone. The code comes with training documentation, significant documentation on the theory behind it, practical exercises and whatnot.

There's no dedicated training class to do the code. We have gone internationally as well as domestically to train folks who are interested in doing a similar analysis to this.

But to be quite honest, the user base is really generally EPRI, our contractors, NRC, their contractors, and a few others throughout the world that are trying things out.

So, it's publicly available. It's out there for anyone. But we do provide -- it's a very complex code. We provide as much as we possibly can to train them and then, we're also always available for questions and there's a specific xLPR@nrc emails and xLPR@EPRI emails where we do get a lot of feedback from folks and questions and work with them.

MR. BURKARDT: We have a user manual that's like 150, 200 pages long and then, beyond that, we have basically training material that's provided that is sort of the equivalent of like six days of -- six full days of training lectures.

Both on detailed training regarding the individual models that are included within the code as well as how to interface with the inputs, interface with the framework, how to run the code, and then, how to, you know, extract and manipulate results.

DR. SCHULTZ: Is there a need for version control of the code? In other words, are there several versions out there as its been developed? We hear results about applications, is it something we need to pay attention to?

MR. GLUNT: Yes, within the MRP-480, so there are several versions out there that are -- several versions during development when some of these analyses were done.

And then, we've released two versions since then and we're about to release another version as well.

With MRP-480, we have an entire session dedicated to the analysis of what are the differences in the versions and do the versions potentially change anything about the analysis?

So, we only have the latest available through EPRI's distribution. So, we take down the old ones and encourage people to get the latest and greatest.

So, yes, there are slight differences in the versions. But a lot of them are fixing well known bugs or enhancing the user experience by adding new capabilities to the code that makes it simpler or faster to run.

MR. BURKARDT: And so, the general recommendation is to, you know, apply the lasted release version of xLPR code to --

DR. SCHULTZ: So, there's not a user's group that you know how the users are?

MR. GLUNT: Yes, every user has to -- or the NRC actually has requirements.

We have to have everybody sign an end user license agreement, provide their country of origin, all that stuff to it because there are limitations on who can receive the code. So, we do track all that.

DR. SCHULTZ: Very good, thank you.

MR. BURKARDT: So on the topic of uncertainty quantification propagation, there's just a couple more items. In the inputs group report which is thousands of pages long, we document the recommended distributions on various inputs and parameters for I think 33 different sample cases, basically three different components and 11 scenarios that you might want to analyze for those components. And in the different module subgroup reports, again defining recommended distributions for input model parameters, and in the scenario analysis report discussing sampling strategies that are applied. So just very comprehensive discussion of all, you know, aspects of uncertainty for all of the details that go into every single input and model within the code.

MEMBER PETTI: Just a question about your validation test matrix, you know, there are people who make their living on this sort of stuff and making sure that all the modules are actively interrogated through the validation test matrix, so that you make sure you've got a validation case for stress corrosion cracking, thermal fatigue, all the pieces of the code get accurately exercised by a validation case. Is that, I mean is your validation data broad and deep enough to be able to make a statement like that?

MR. BURKHARDT: Yeah, so each individual model has its own validation report where basically with any available data that module is then validated, and in the absence of data, looking at alternative models, looking at results from finite element analysis, and if none of those were available, then in a couple of cases we did have to do some validation using expert judgement, but in general trying to lean as heavily as possible on validation with you know, either field or test data or alternative models.

CHAIR BALLINGER: Dennis?

DR. BLEY: Yeah, this is Dennis Bley. Just a historical question, lots and lots of years ago when NRC was doing its work on fracture mechanics they had Oak Ridge developing a probabilistic fracture mechanics code which was kind of interesting as we went week to week in working with them how things jumped around. Is this an extension of that work or is this done completely separate from that?

MR. BURKARDT: Are you referring to the FAVOR code, Dennis?

DR. BLEY: Huh, you're testing my memory now. I think that's right.

MR. BURKHARDT: This is yeah, unrelated to the FAVOR code, they're both probabilistic fracture mechanic codes but with pretty different applications. I think Oak Ridge was involved in some of the xLPR development process, particularly in the leak rate calculation aspect, they developed the LEAPOR module, and so that was their involvement there, but I think yeah, different from the FAVOR code.

DR. BLEY: Okay, thanks.

CHAIR BALLINGER: Is FAVOR pressure vessel related?

MR. BURKARDT: Yeah, FAVOR is pressure vessel related.

DR. BLEY: Yeah, that's right.

MR. BURKARDT: You know, similar metal levels in piping. So now we've talked about xLPR and Fred introduced the ALS overall, so how do the two fit together? So NUREG-1829 is a NUREG report that estimates loss-of-coolant accident frequencies, and in this case, the LOCA frequencies were estimated through an expert elicitation process. That report was developed a number of years ago now as part of an evaluation of the technical adequacy of redefining the design basis break size, which is the largest pipe break to which 10 CFR Part 50.46 applies to a smaller size.

And so as part of the ALS research work for FFRD, we applied xLPR to validate the NUREG-1829 LOCA frequency estimates for use in this high-burnup fuel licensing effort, and then also to evaluate the potential for leakage as a precursor to a LOCA rupture to be detected in a sufficient amount of time to allow for a reactor shutdown and to reduce decay heat levels before that LOCA rupture would potentially occur. And so as Fred noted, this work is published in MRP-480 which was published earlier this year, the document tells the gory details of this work.

So NUREG-1829 gives LOCA frequency estimates based on expert elicitation approach, and those are provided, the results that we'll be comparing against, are the ones in Table 1 of that report. And so in addition to that, 1829 considered

LOCA-sensitive piping systems that are associated, and their associated degradation mechanisms. Now the xLPR scope for the ALS is focused on piping welds greater than NPS 14, and so really what this means is that we're focused on the main loop piping components with these xLPR analyses, and so I'll be focusing on discussion specific to those here today. And so kind of in these tables, and then in later portions of the presentation kind of use like a blue box to indicate those. Now, although the focus of today's discussion is on the main loop piping welds, MRP-480 does document further analyses for a range of other piping systems that are covered in NUREG-1829 as well.

So the xLPR analysis cases that we considered here, they were developed to apply primary water stress erosion cracking and/or fatigue, as the material degradation mechanisms that were explicitly modeled. NUREG-1829 does consider additional material degradation mechanisms not included in xLPR, and in MRP-480 we reviewed those and dispositioned any such other degradation mechanisms and really identified that the PWSCC mechanism, which we assessed here was kind of the primary mechanism of concern and therefore the mechanism of focus in our assessment.

We either modeled flaws that were present at the start of the simulation, basically instantiated at time zero modeled as flaws of engineering scale with initial size of a couple millimeters, such that fracture mechanic principles apply, or we also considered cases where we used the initiation models for both PWSCC and fatigue to calculate the time to flaw initiation and to allow also the potential for multiple flaw initiation. We then performed an extensive set of sensitivity studies to determine the impact of changes to certain key analysis inputs with these sensitivity studies modeling different input selections for various parameters such as the geometry, loading, welding residual stress profiles, initial flaw sizes, or also seismic effects.

In this work as Nate kind of alluded to, we considered the results of recent NRCE technical letter reports documenting analyses that were developed to look at the leak-before-break issue in dissimilar metal piping butt welds in PWR plants. And so there were two technical letter reports that came out of this work. In that joint work, NRCE research and EPRI worked together to develop the overall case matrix, but then these reports reflect NRCE and their contractors own input selection and also then their own conclusions that they drew from those analyses that were performed.

And so these two reports, you know, we consider as part of the work, the kind of term, the first one, the piping system analysis report, which documented xLPR analysis for reactor vessel outlet nozzles and reactor vessel inlet nozzles in a Westinghouse four-loop PWR, and this report really included a very extensive set of sensitivity studies, as this was one of the earlier uses of the code, in probing a lot of different aspects of the code and its models. And the xLPR generalization study report, the second report, and took the learnings from the piping system analysis and extended that to other piping systems that contained alloy 2182 dissimilar metal butt welds that are received prior leak-before-break approvals from the NRC staff on a deterministic basis. And so this report then included a slightly reduced set of sensitivity studies for analyzed component, as was informed by the results of the piping system analysis, so here we really focused on the key sensitivity studies that we noted were more driving of the results as found in the piping system analysis.

So Nate touched on the results that you can get from xLPR, so there's a couple of particular interest for the ALS that I'll be reporting on here today. One is the time between one gallon per minute detectable leakage and rupture of a large-break LOCA, in this case large-break LOCA we're characterizing as 5,000 gallons per minute. Another is the probability of rupture conditional on crack initiation. Now I mentioned some of the cases we model using the initial flaw model rather than explicitly modeling crack initiation, and so there you already have flaws in every single realization at time zero.

In order to consider those results also for the comparison to NUREG-1829, we take those probabilities of rupture, given an initial flaw, and then scale those by the probability of initiation at 80 years to approximate the probability of rupture conditional on initiation. And we document some benchmarking in MRP-480 assessing the impacts of this sort of approximation, and so we found that the two approaches were within a factor of about 2.5 of each other. And then the final output that we discuss as well is the 80 year rupture LOCA frequency, in which case we calculate this from the probability of rupture 80 years by then dividing that by 80 years as well. So we have a question from Walt?

MR. KIRCHNER: Yes, thank you. Thanks, Ron. In your sensitivity studies, did you look at stress levels that you might see in a safe shutdown earthquake load on these critical areas that you identified of key interest? Like the example of both the outlet and inlet nozzle welds and such, did you look at the stresses that you might see for the safe shutdown earthquake kind of loads that might -- lead to a larger break LOCA in the piping systems?

MR. BURKARDT: Yeah, I believe for the reactor vessel outlet nozzle we had some sensitivity studies that looked at both loading and frequency associated with safe shutdown earthquakes, and changes to those inputs.

CHAIR BALLINGER: I've got a question, it's been gnawing at me when I saw 82, 182, it made me realize it. All of these welds that are less than, what, four inches, have been required to be dispositioned in some way, right? Am I correct? In other words stress improvement, some kind of thing has had to be done for these welds, not the least of which is to get the welds out and use 52 and 152.

MR. GLUNT: Right, or inspect them more frequently.

CHAIR BALLINGER: Or inspect them more -- so how many welds does what we're talking about, how many of the welds are there that this actually applies to?

MR. GLUNT: This is only the reactor vessel, the reactor vessel nozzles, steam generator nozzles, this is all --

CHAIR BALLINGER: Those have all been dispositioned.

MR. BURKARDT: So we have a figure actually in MRP-280, it's Figure 4-2, and so there we look at the number of dissimilar metal welds and their current status based on their cold leg temperature, hot leg temperature or pressurizer temperature. And so for all of the operating plants, all pressurizer temperature welds have been mitigated either using overlayer MSIP. The hot leg, large majority of them have been mitigated as well --

MR. GLUNT: But not all --

MR. BURKARDT: But not all, and then at the cold leg, actually, there's a decent number that have been unmitigated, but given that PWSCC is a thermally activated process, it progresses the disease, so to say, progresses more slowly at that colder temperature.

MR. GLUNT: So as significant amount of the hot leg, of course, as he just said are mitigated, those that are not mitigated are still inspected per

Code Case N-770 more frequently than other components, and so if they're not mitigated they're managed.

CHAIR BALLINGER: Are any of these results likely to affect the ten-year ISI? The code requirement?

MR. GLUNT: For the mitigated? Because the unmitigated hot leg is only five years.

CHAIR BALLINGER: Five years, okay.

MR. GLUNT: Yes, yes.

MR. BURKARDT: Yeah, and for many of these cases we actually modeled the xLPR analysis, body of xLPR analysis case is considered models inspections every ten years, even though inspections per N-770 are more frequent, such as the five years for the hot leg, as Nate noted.

MR. GLUNT: So yeah, any relaxation should not have an impact on these results.

DR. SCHULTZ: But we're not talking here about industry programs that may be related to extending the inspection frequency? Assuming that in this case the industry would be committing to retaining inspection frequency, is that correct?

MR. GLUNT: Or analyzing any impact of relaxing in inspection frequency. As Markus says, it's the unmitigated hot legs from N-770 is inspection every five years, we modeled every ten years, based on my probabilistic fracture mechanics, or based on my deterministic fracture mechanics experience, it'd be tough to ever get to ten years, so I don't think we would be challenged by that in reality, because --

DR. SCHULTZ: You modeled it for 10 years as a conservatism?

MR. GLUNT: That's correct. So we --

DR. SCHULTZ: How much impact does that make? Or you'll show that?

MR. BURKARDT: It's not shown here explicitly, but it's a substantial impact given that at hot leg temperatures, crack growth rates can be fairly quick, and you can have flaws just below the detectability limit grow through all in you know, under ten years, but the five year interval is designed to help manage that and detect those flaws prior to --

DR. SCHULTZ: So you do it not as a conservatism, but a demonstration as to what the difference would mean?

MR. BURKARDT: Yeah and I believe there's also a sensitivity study in the piping system analysis work that looks at the impact of changing the inspection frequency as well from five to ten years, so that's explicitly modeled in --

CHAIR BALLINGER: But N-770 resets the clock on some of the distributions to zero, right? Doesn't change the initiation time, but it just, if your inspection is designed to detect flaws or detect defects every five years, then the five years, that's time zero on the initial flaw, but not the initiation time, so how does that work?

MR. BURKARDT: So inspection within xLPR is handled sort of as a post-processing and inspection is also, rather than being handled on just a deterministic yes, no type of inspection, you're calculating a probability of detection as a function of the depth of the flaw, and then that corresponds to probability of non-repair and basically model the evolution of the flaw within xLPR assuming not inspections, no leak rate detection, and then after the fact you basically assess the impact that you would have from either an in-service inspection or leak rate detection on those results.

CHAIR BALLINGER: I'm just trying to understand the effect on ALS of inspections, and it's significant, I think.

MR. BURKARDT: Yes, it is, and we'll show the impact of inspections versus no inspections.

CHAIR BALLINGER: I see the reports, but I'm just thinking of the overall concept of ALS as it applies to the whole process of increased enrichment.

MR. BURKARDT: So diving into the comparison to NUREG-1829, I just first wanted to provide a little bit of context on the NUREG-1829 LOCA frequencies that I'll be showing on the next slide. As noted, those were based on expert elicitation and from those Table 1 results which show a median fifth and 95th percentile included from Table 1, and so those are total PWR LOCA frequencies after overconfidence adjustment using an error-factor scheme and our 40 year fleet average values. These considered the typical in-service inspection and leak rate detection resolution as required by tech spec limits as part of that expert elicitation process. Those results are also presented on a per-plant basis for each of the distinct LOCA categories, and consider both piping and non-piping passive system contributions.

So then here we're showing the xLPR LOCA frequency results for 80 years, and those are shown with the various different points on each of these charts, and I'll kind of speak through what each of them mean. On the left are the results where we credit leak rate detection but do not credit in-service inspection, and when leak rate detection alone is credited, the majority of the results are actually zero, but you know, we wanted to still consider those results overall in this comparison to NUREG-1829. So what we did is we developed a 95% upper bound based on a one-sided confidence interval using a binomial distribution. And this then considered the number of realizations that were run for a specific xLPR analysis case as well as the probability of initiation for cases that were modeling the initial flaw model rather than modeling probability of initiation explicitly. And so those are shown in the green open circles with the downward pointing arrows, with the downward pointing arrow implying that if more realizations were run, that you know, those probabilities would be even lower.

Now there are three cases which did have explicit ruptures with leak rate detection, and so those are shown explicitly with the yellow circles. But those three cases are all due to modeling that, you know, we looked into it and see that modeling not representative of plant conditions and operations, and it's common, and in a similar manner in the technical letter reports which initially performed those analyses, those cases are situations like where the overlay application caused a rupture, or the initial flaw was deeper than the inlay depth, resulting in atypical flaw geometries that xLPR really isn't capable of handling. All of those cases were also sensitivity cases, and then as relevant to ALS, you know we investigated those further, including the implications thereof.

Now the figure on the right, we then -- that shows what the results would look like if you additionally credit in-service inspection and as we noted those are corresponding to the 10-year in-service inspections which are actually less frequent than as required for these types of components. And so then when you consider both in-service inspection and leak rate detection, the LOCA frequency results that are estimated by xLPR are in a similar order of magnitude as the median NUREG-1829 LOCA frequency estimate. So further validates the LOCA frequency estimates from 1829 for application in the ALS work.

So then another key output is the time between detectable leakage and large-break LOCA. And so just to kind of help unpack what this output is and what it means and how we're considering it, I'd first like to kind of give an example of what this means for single xLPR realizations, so one, we'd just have one set of inputs that's then propagated through the xLPR model before we have the many, many realizations for a given case, and then the many different cases for different welds that we look at. And so this is really fundamentally a deterministic problem, where we're evaluating the evolution of a flaw growth from a part through-wall flaw to a transitioning through-wall flaw, and then an idealized through-wall flaw.

And so then in the chart, on the top right here, you see the leak rate as a function of time, and we're calculating this leak rate based on flaw size and parameters as discussed earlier. And so you see that the leak rate starts, and in this case it actually starts leaking at a leak rate just below on gallon per minute, then we reach a one gallon per minute threshold, in like 24 and a half years, continues leaking, transitions from a transitioning through-wall flaw, trapezoidal flaw, to an idealized through-wall flaw, and then continuous leaking as it grows, and then eventually a large-break LOCA and rupture then occurs in 31 and a half years.

And so when we're talking about the time from detectable leakage to large-break LOCA, those are the two time points that we're considering, and calculating the difference in times between those for a given realization. And so that's something that can only be calculated for realizations that result in a large-break LOCA or a rupture. In this case since we're looking at time between detectable leakage and large-break LOCA, it's for all realizations that have a large-break LOCA.

MR. GLUNT: And, obviously, for these cases you cannot have leak rate detection or ISI on for the component. You have to wipe those away for the sake of just getting results, because if you have leak rate detection on, you're obviously not getting anything, so.

MR. BURKARDT: So this is more to, you know, we assess the potential for LOCAs with leak rate detection in-service inspection in the comparison to NUREG-1829, but then to better characterize what the time from detectable leakage to LOCA would be, assuming no inspections and assuming no leak rate detection, you just start up your plant and run it for 80 years and look away the entire time, you know, that's really what we're trying to characterize here.

MEMBER HALNON: Well, I get this, I mean, you're just telling everybody don't worry about it, it's going to take over five years to have a real bad problem. I mean 100 gallons a minute is a bad problem, but clearly within the capability of the plant to deal with. And I realize this is not a pipe, but it was so -- fracture mechanics done for the Davis-Besse head event that caused additional problems, some of the mechanics that it could go as fast as 12 weeks before it ruptured.

Am I to take away from that, as an uninformed and very ignorant fracture mechanics guy that there's a lot of variability in the assumption, such that this is only one result that could occur, that there could be some that are quite more catastrophic and quicker?

MR. BURKARDT: Yes, so this is just an illustrative example realization, I just picked one where you can kind of see the nice progression, and then we'll speak more to the specific results for the full population of xLPR analyses up next.

MEMBER HALNON: So we'll get more detail this afternoon?

MR. BURKARDT: We'll get into more detail in the next 30 minutes.

MEMBER HALNON: Oh, okay.

CHAIR BALLINGER: I think we -- this is impossible, right? We do have leak detection, we do have inspections, and so for an uninformed member of the public to read this bothers me, because this is impossible, but you wonder sometimes --

MR. BURKARDT: So the basis for us really doing this --

CHAIR BALLINGER: I know why you're doing this, I'm just saying, this is your PhD against my PhD.

MR. GLUNT: But we're really trying to look into it whether, you know, we're not turning a blind eye to it for five years. The goal of this in the first place was to see if we had sufficient time to shut down the reactor and remove enough decay heat so that we would not experience an FFRD.

Now, what they need for that is significantly less than this, so all we can do is produce the statistics to show if it were worst case scenario, what would that actually look like? Even though we know that shutting down the reactor itself will remove the stresses that would likely cause the rupture, so we're removing the impetus behind any rupture in the first place, but it just feeds into the defense and depth of ALS itself.

MR. BURKARDT: So Storm will speak to detectability of leak rates in plants and time that operators need to shut down the plant, and then this is kind of input to that discussion, as it feeds into ALS.

MR. SMITH: In your summary, don't you characterize the probability of when you credit leak rate detection and --

MR. BURKARDT: Yes.

MR. SMITH: Yeah, and that characterization is what?

MEMBER KIRCHNER: To Ron's point on this view graph, what would be a typical tech spec for leak detection and hence shutdown of the plant and inspection of where the source of the leak is? How many gallons per minute?

MR. GLUNT: For pressure boundary leakage there is no allowable, the allowable is zero. You find it, you shut it down and fix it. Traditional leak-before-break uses generally one gallon per minute, because that is the tech spec limit for unidentified leakage, so it's conservative. So yes --

MEMBER KIRCHNER: Would it be useful to put that -- some dotted line on this diagram to indicate that this would be an unacceptable operating condition?

MR. BURKARDT: Yes, it would be useful to include in this FAVOR.

MEMBER ROBERTS: Can you speak to the second to last bullet, the ore seismic effects? So the other three I think you turned off, or it would help the story, but doing seismic effects would worsen it?

MR. BURKARDT: So it would, now seismic effects are more considered in the rupture calculations for xLPR, when it's a safe-shutdown earthquake and it doesn't feed directly into the leak rate calculation. What the generalization study does consider is when it calculates probability of rupture and also time between detectable leakage and rupture, it considers the seismic loads on a non-probabilistic basis and every one month time step, in basically more and more conservatively assessing when the rupture would occur, assuming that whatever the seismic loads are would occur every time step rather than just at whatever the input earthquake's frequency is.

MEMBER ROBERTS: So on this curve, the vertical part would move to the left, presumably?

MR. BURKARDT: As I mentioned, it's not tied to the leak rate calculation, but if anything, like if for the rupture time, it would maybe, you know, the time on the right would shift to the left just slightly, where this curve ends. Yeah, but we didn't see a big impact in the cases where we did look at that.

CHAIR BALLINGER: But if you had a safe-shutdown earthquake or even a design-basis earthquake, the plant would be shut down, that's a onetime event and they would re-inspect everything.

MR. BURKARDT: Yes.

CHAIR BALLINGER: So the clock gets reset to zero again.

MR. BURKARDT: Yes.

MR. GLUNT: We find that we reset the clock a lot on this, to be quite honest, and so that's the problem.

CHAIR BALLINGER: Somebody ought to say that.

MR. GLUNT: Yes, we are having to look at cases that are highly, highly, incredibly improbable, for the sake of having any results at all, because if we came in here and honestly said well it already has deterministic leak-before-break, so we know it's not going to, that's not enough. We're trying to add the meat on the bone as we said earlier.

MEMBER ROBERTS: Did you use NUREG-1903 in your benchmarking?

MR. BURKARDT: I'm not sure that I'm familiar with NUREG-1903.

MEMBER ROBERTS: That was the adjunct study -- for the 1829 was still valid for seismic loads, called Seismic Considerations for the Transition Break Size. His conclusion was that the seismic spectrum wouldn't really effect the results from 1829, but it also talks about a lot uncertainties in that, I was wondering if you'd look to that and concluded that that conclusion was still valid based on what you'd done. Your response to Walt's question I think basically said yes, but I was just wondering if you'd looked at that study.

MR. BURKARDT: Yeah, I don't know if I looked at 1903 too closely, Storm, did you in your investment?

MR. KAUFFMAN: I would need to take that as a look-up. I looked at a lot of references. 1903 sounds familiar, I don't remember what I got out of it.

MEMBER ROBERTS: Okay, thank you.

MR. BURKARDT: So that was kind of the picture for one individual realization. Now within a single xLPR analysis case, remember we ran multiple cases for given welds and then cases for multiple different welds. Basically within one case you run, you know, at least 10,000 or up to several hundred thousand realizations, you may then have multiple realizations that then have a large-break LOCA. And so then what we did is we characterized the distribution of times from detectable leakage, one gallon per minute detectable leakage to a large-break LOCA for that individual case. And so this figure just kind of illustrates what that looks like for one such case.

As Nate pointed out, for these points to even exist, we need to not credit in-service inspection or leak rate detection which is unrealistic, right, but again, we're just trying to conservatively assess what this time would look like if for some reason your in-service inspection or leak rate detection were ineffective. And so then yeah, we considered the distribution of results for each of these analyses as part of the overall assessment of the time between detectable leakage and large-break LOCA for each analyzed component. We then used these distributions for each individual case as a sort of screening exercise, basically looking at the most limiting cases for further review, so we really understand what's happening in those more limiting cases.

I mentioned we performed some further investigation, both of the three point that have non zero occurrence of rupture with leak detection is those three yellow points on the comparison to NUREG-1829 figure, as well as for the cases that have minimum times, so of all of the realization that had large-break LOCA, the very most limiting ones of those, if the time between detectable leakage and rupture was less than three months we looked into those in more detail also to better understand them. All of these cases that we looked into further were sensitivity studies, and they were defined to inform the understanding of the base case results by investigating inputs that were known to have influence in the overall xLPR results, but they were also less constrained by maintaining fidelity to realistic plant conditions as well.

And so then in these re-investigations, you know, kind of depending on the case, in some cases we re-ran those with refined time-stepping to better understand what's happening, and in other cases considered updated input model parameters, including as recommended in the NRC technical letter reports that reported out on those cases. So really we wanted to further investigate the inputs, the intermediate variables and the outputs to better understand the overall applicability of that scenario as being modeled. We then, once that was complete, we then reviewed the details of the lapsed time results for all xLPR analysis cases as applicable to each of the main loop piping components that we modeled.

And so this then considers the full population of cases that results in realizations resulting in large-break LOCA, and kind of summarizing the conclusions for each of these in the table below, and I'll just run through these very quickly. For the reactor vessel outlet nozzle, there were like 27,000 realizations that resulted in large-break LOCA, and as we evaluated those further and did some statistics to characterize that distribution. The reactor vessel inlet nozzle, which is at cold leg temperature showed no occurrence of cracking, leakage, large-break LOCA or rupture. The reactor coolant pump nozzle, which is also at cold leg temperature, for the xLPR analysis cases that modeled flaw initiation showed no occurrence of leakage whatsoever and therefore no significant probability of large-break LOCA. But then the cases that did model initial flaws in every single realization starting at time zero did have some large-break LOCAs, but the minimum time from detectable leakage to large-break LOCA was 25 months. For the steam generator inlet nozzle, so in this case, all steam generator inlet nozzles in the U.S. PWR fleet have been mitigated and xLPR results showed no leaks or ruptures in those mitigated components. For the steam generator outlet nozzle, there were two realizations where the time from detectable leakage to large-break LOCA was zero months, but then when we considered in-service inspections, these two scenarios are very unlikely, and I'll explain why we conclude this in the next couple slides.

And again, all of these cases consider unmitigated components, and as we discussed earlier, right, at the hot leg temperature a majority of the components are mitigated at this point as well. So again, just further conservatisms baked into the overall assessment of how the results are being used, although attempting to use best estimate inputs for the individual analyses consistent with the probabilistic approach. So for the reactor vessel, we have a question from Walt, so we'll go ahead and take that before I start the next slide.

MEMBER KIRCHNER: Yes, I was struck on your previous slide where you were indicating no predictions of breaks for the cold leg loops. Is it that temperature sensitive between the cold leg and the hot leg that on the hot leg nozzle you actually had realizations of large break LOCA and you had none for the cold leg nozzles?

MR. BURKARDT: Yes, substantially so.

MEMBER KIRCHNER: And it's just a function of temperature?

MR. BURKARDT: Yes.

CHAIR BALLINGER: The rule of thumb for stress corrosion cracking and baking a cake is that for every 15 degrees C it's a factor of two.

MEMBER KIRCHNER: Okay, so it's that sensitive, so there's a threshold. So do you see any cliff-edge effects then, with that kind of phenomenon?

MR. BURKARDT: No cliff-edge effect, it's just a continuous function of temperature, and just as the temperature goes up, crack initiation rates, frequencies, and crack growth rates increase accordingly to the activation energies that define that distribution, or define that by way of the Arrhenius effect.

MEMBER KIRCHNER: And to Ron's introductory remarks when this session started, so you don't see any potential brittle facture kind of events?

MR. BURKARDT: No, we do not.

MEMBER KIRCHNER: Thank you.

MR. BURKARDT: Thank you. So for the reactor vessel outlet nozzle, as I mentioned there were some 27,000 realizations that had large-break LOCAs, and so we're showing all 27,000 of those in the upper right figure. What we wanted to do was define a 95/95 one-sided tolerance interval and so we define that such that there's a 95% probability that the constructed limit is less than 95% of the population of interest for the surveillance intervals selected. So for this distribution of times, the 95/95 one-sided tolerance interval lower bound is 19 months, and so we calculated this considering the distribution-free assurance-to-quality criterion that's described in Chapter 24 of NUREG-1475 for F-1.

Now in the bottom right figure I show the lower tail of this distribution that depicts the subset of data that would fall outside of this 95/95 one-sided tolerance interval lower bound. And so you can see there are a couple points with slightly shorter times than the 19 month time, but again, I want to remind folks that all of these results do not credit leak rate detection or in-service inspection, and if leak rate detection or in-service inspection are credited, no large-break LOCAs are modeled to occur.

And for the steam generator outlet nozzle, so there's just one case that modeled an unmitigated steam generator outlet model which is the Generalization Study Case 4.1.4, and so this case had 54 realizations out of 100,000 that resulted in a large-break LOCA, and of those there are two realizations where we did see leak rate going from less than one gallon per minute to greater than 5,000 gallons per minute in a single time step, time step being one month, and so that corresponds to time from one gallon per minute detectable leakage to large-break LOCA of zero months.

Both of these cases occurred due to multiple large flaws coalescing, which then resulted in very, very long flaws, that once they grew through-wall had extremely high leak rates right from the get-go. In this case, we think about in-service inspection, because those are being applied also for these types of components, and the scenarios are highly unlikely once the in-service inspection is credited. You then basically have a probability of non-detection on the order of 1E minus five or less, given that the flaws are present with depths exceeding 10% through-wall for multiple inspection intervals.

And so on the two figures on the right I show that crack depth is a function of time for these two realizations, and for each of these, like for the first one you see flaws exceeding 10% through-wall at about 21, 22 years, and the flaw doesn't even go through-wall until after 60 years, even after coalescing. And for the second one, flaws again kind of get past 10% through-wall, maybe at 24 years or so, and then you know finally grow through-wall at like 72, 24 years. So there's many opportunities to perform in-service inspections, and these are modeled every 10 years for this case, and those in-service inspections, right, we use a probability of detection curve that's a function of depth as calibrated to data from the EPRI Performance Demonstration initiative program where inspectors are basically using mock-ups to characterize detection rates for different flaws.

And so when we consider these two realizations among the overall population of 100,000 realizations for this case and the 80 year simulation time, when you credit in-service inspection, the annual occurrence of this scenario is then on the order of 1E minus 12 per year. And then furthermore, this is only applicable to one U.S. PWR, which has an unmitigated steam generator outlet nozzle.

So then moving on to the conclusions, so we looked at NUREG-1829 LOCA frequency estimates, and so when we credit in-service inspection, leak rate detection, the occurrence of rupture results were on a similar order of magnitude as the LOCA frequency estimates from 1829. The only non-zero results that we even saw were for cases that included modeling that's not representative of plant conditions and operations, and for cases with zero ruptures with leak rate detection we then used a 95% upper bound based on a one-sided confidence interval to allow for comparison to the NUREG-1829 LOCA frequency estimates.

CHAIR BALLINGER: And these are for unmitigated welds, right?

MR. BURKARDT: That's correct.

CHAIR BALLINGER: So if you have mitigation -- gone.

MR. BURKARDT: It's even lower, yeah. For components relevant to the ALS, large-break LOCA did occur when not crediting in-service inspection or leak rate detection for the reactor vessel outlet nozzles, and considering those cases we developed a distribution of times that's characterized by 95/95 one-sided tolerance interval lower-bound of 19 months, but then when you do credit in-service inspection, leak rate detection, large-break LOCA does not occur for the reactor vessel outlet nozzle. For the unmitigated steam generator outlet nozzles, which is applicable to only one U.S. PWR, it's highly unlikely when crediting in-service inspection, and large-break LOCA does not occur for the reactor vessel inlet nozzle, reactor coolant pump nozzle, and mitigated steam generator inlet nozzles.

And so these results overall demonstrate that there's sufficient time between detectable leakage and large-break LOCA to shut down the reactor and prevent the large-break LOCA from occurring, following detection of the leakage, and they also further demonstrate the significant benefits of in-service inspection and leak rate detection in precluding large-break LOCAs. So MRP-480, which I mentioned, contains all of the gory details, it also includes applicability criteria for each of these conclusions to the ALS.

CHAIR BALLINGER: Where do we sit? I'm trying to --

MR. SMITH: About 10 minutes before we're done.

CHAIR BALLINGER: Oh, is that what you're -- I was looking for the -- I'm trying to figure out where we are with respect to the agenda.

MR. SMITH: We're in section two.

MR. GLUNT: Four more slides.

CHAIR BALLINGER: Okay, all right. Okay, good.

MR. GLUNT: Okay, so I'm going to transition the next few slides in a bit of a different direction. You've heard about everything with xLPR and how we're looking at the time from detectable leakage to rupture, but I do want to go back, and since the ALS mentioned so much about leak-before-break, what does traditional leak-before-break actually look like? And so these slides will take you through at a very high level of traditional deterministic leak-before-break and where the conservatisms lie.

So great oversimplification, leak-before-break can essentially be set up into four individual steps. You start by postulating a through-wall crack, I'm going to mess up and say flaw at some point, but in this case, flaw and crack and synonymous, so I apologize ahead of time, but you start by postulating a through-wall crack and then you grow that crack until it reaches your leakage detection threshold limit, and that is your leakage crack size. You further look at the size that crack would need to be to reach failure, and that is your critical crack size calculation, and then finally this fourth step is you go back and compare them. You compare your critical crack size, so the crack size that causes failure, compare that to your leakage crack size, the crack size that would occur that produces your leakage threshold. Now each of these have their own conservatisms embedded within them, and the next three slides will go through that.

So I'll start with the first and the last steps, because the conservatisms are kind of similar. As you can see, we totally ignore the role of crack initiation when it comes to traditional leak-before-break, we go directly to a through-wall flaw, so there's no crack initiation and there's no crack growth accounted for, which kind of throws ISI out the window if you're going straight to a through-wall crack. Beyond that, it only looks at idealized through wall cracks, and so in xLPR we have crack initiation, surface growth, into a transitioning through-wall crack, but again, traditional LBB you start with idealized through-wall crack, so you're missing the entire life cycle of that crack up until that point.

Similarly, on the last step when you're doing a crack size comparison, you're ignoring the role of crack growth between the leakage crack size and the critical crack size calculation. Time is not accounted for in any way in this analysis, instead you're doing a margin calculation, so you just want to make sure your critical crack size is twice the size of your leakage crack size. And so whether it takes 100 years to grow from one to the other, it doesn't matter, it's simply a margin. There's also an additional margin for the stresses that you are applying on your leakage crack size, so if you apply 1.4 times the stresses and make sure it still doesn't fail as well. So those are the conservatisms on the first and last point.

Next slide is the conservatisms in the second part, which is the leakage crack size calculation. We've already talked about it quite a bit on here, but the leakage crack size calculation is basically what produces leakage representing your leakage detection threshold. With traditional LBB, with a factor of 10 applied to it, so for the majority of leak-before-break applications you start with a one gallon per minute leakage threshold, because this corresponds with the tech spec limit for unidentified leakage. You then apply a factor of 10 to it, so you're actually looking at what crack would cause 10 gpm leakage, which is quite conservative, but that does account for uncertainty on the leak rate. And then finally, the next slide is our critical crack size calculation.

The conservatism that lies within here is inherent to a general deterministic fracture mechanics. So when you're doing limit load or elastic plastic fracture mechanics there's safety factors included, which is no different in this case. The technical basis for LBB also includes the suggestion of including conservative inputs, which is followed throughout this process of course, so your inputs that you're selecting are conservative in the first place, especially when you think about design basis versus operating basis calculations. Finally, you are ignoring the pipe-end restraint effects. So this is something we've been doing a bit more work in lately.

In a vacuum, if you have two pipes connected by a butt weld and you have loading on it, it will eventually experience double-ended guillotine break. But in reality, we do not have two pipes out in space, we have large restraints on either end of the piping, vessels, steam generators, pumps, branch lines in between, everything like that, and we've found that in reality as the flaws or cracks grow, the moments actually reduce, and that the moments reduce make it even more unlikely that you'll have a double-ended guillotine break. Now none of that is included within a traditional leak-before-break evaluation, because it is a simplified analysis trying to demonstrate an extremely low probability of rupture. So there are four steps in it, and each step has inherent conservatism built in, where we can go look at xLPR and use it to quantify some of those conservatisms and fill in some of the blanks that aren't available in traditional LBB. And that was my quick overview of traditional LBB.

MR. SMITH: So some of the takeaway with this is that all the pipes credited in ALS have been evaluated through this traditional, deterministic LBB process, and part of the conclusions of that process is that the probability of rupture is exceedingly small, and so the LBB process reinforces what we already have heard about 1829 and xLPR, so it's kind of an additional, independent evaluation of the integrity of the large bore piping system.

CHAIR BALLINGER: And you have confirmed the wisdom of the people that wrote Section 11. Okay, this is where we're supposed to break. We should ask the members if there are any questions right now, any questions from the members or members that are online, consultants, Dennis, any questions before we recess for lunch? Hearing none, thank you very much, we will recess until 1:00, according to our schedule. Thank you very much.

(Whereupon, the above-entitled matter went off the record at 11:54 a.m. and resumed at 1:00 p.m.)

CHAIR BALLINGER: Okay. We're back in session now. I'll remind folks that you'll have an opportunity for closed session after this. So I'm not sure who's up next. So Storm?

MR. KAUFFMAN: Thank you. I'm Storm Kauffman with MPR Associates supporting EPRI in assessing burnup extension an FFRD. I'm going to pull some of the material that you've already heard this morning together into hopefully a big picture that you can understand why we have a number of individual parts to what we're doing. Next slide. Thank you.

This is an outline of the presentation

slides I'll be using. Fundamentally, the purpose of the report in this meeting is to cover how the industry proposes to address fuel fragmentation, relocation, and dispersal in a somewhat nontraditional manner. The presentation I'm giving will provide an overview of the alternative licensing strategy, then talk about some precedence associated with parts of the ALS, address leak detection and response, non-piping assessment because what you've heard about with xLPR is limited to piping failures. And finally, provides a summary.

My section will be followed by closed session to talk about fuel -- by Fred talking about defense-in-depth and then the fuel thermal analysis. Next slide. Why do we need an alternative licensing strategy? Traditionally for handling the situation we find ourselves with FFRD would be to gather a lot of data, develop computer models, and obtain everybody's agreement that the computer models were a conservative representation of what's going on.

We did an evaluation in 2020 and concluded that that was not a near term process to bring to conclusion, that we needed to work on some alternative. The 2020 report, if you look in the ADAMS database actually lays out several alternatives.

And it's been overtaken by events. So be careful that you get current 2024 report if you're referencing what we're doing, not the 2021.

CHAIR BALLINGER: Do we have that?

MR. KAUFFMAN: The 2024 one? Both? Yes, the 2021 was submitted but not reviewed by the NRC. It was submitted to --

CHAIR BALLINGER: I'm looking for Chris. Yeah, we'll check.

MR. KAUFFMAN: Okay.

CHAIR BALLINGER: Okay.

MR. KAUFFMAN: It's just I know that sometimes when you do a search in ADAMS, you may not get the hit you expect. Anyway, the purpose of the ALS process is to provide a technical justification to be able to exclude FFRD so we do not have to justify a model that conservatively predicts the consequences. To do that, we needed to piece together several different analyses.

We initially looked at a single approach and decided and it would be best to use a combination of leak-before-break and low probability of occurrence for large break and protruding analysis for smaller breaks. And that's what I'll be explaining how they all fit together. The advantage -- next slide, please. The advantages of Alternative Licensing Strategy is it lets us consider risk insights by providing possible generic approach for the industry. It minimizes licensee and NRC effort.

In other words, every licensee doesn't have to develop their own justification for extending burnup. And NRC doesn't have to review all those individual justifications. In addition, the ALS is largely consistent with the NRC Alternative 5 or the increased enrichment rulemaking.

When I say largely consistent, the NRC regulatory basis actually went beyond what we're proposing. And that's discussed in EPRI's response or NEI's response to the increased enrichment basis document. Finally, the advantage ALS also lets NRC --

(Simultaneous speaking.)

MEMBER ROBERTS: Hey, Storm. Fred mentioned briefly earlier this morning about the main motivation was schedule. Did not go all the way to Alternative 5. I was wondering if you can comment on that. It seems like there's more issues with Alternative 5 like other parts of the safety basis that are tied to the large-break LOCA, the containment design such as leak rate assumptions, the containment testing, ECCS sizing, availability requirements, redundancy, all those things are tied to the existing large-break LOCA.

And it just seems like going farther is more than just a scheduler. But there's an awful lot of the existing fundamental safety basis that need to be reconsidered. And maybe that's a burden of schedule because it will take a long time to reconsider those individually. But I wondered if you had any perspective on just the implication of going all the way to Alternative 5.

MR. KAUFFMAN: You drew the correct conclusion in that try to extend all the way to Alternative 5 involves many collateral issues and would not be readily done in a short time frame. If you look at the history of assessing large breaks and dealing with them, it's only been limited applications. And I'll talk about some of those as examples, but only limited applications of modifying the design basis -- assumptions that have been accepted. And part of the reason why you can do that is there's very low likelihood of occurrence. And there's a high assurance that we will have margin and defense-in-depth which Fred will talk about. Okay.

MEMBER ROBERTS: Yeah, thanks, Storm. And all of that would require more evaluation, whether there's some actual loss of defense-in-depth or safety margin that will go along with all the things that I mentioned. Again, that may be another way of saying schedule. It'd be a long time to go through that. But it may also end up potentially affecting actual margins that are maintained now for a large-break LOCA that actually provide margin in other ways that -- I just wanted to say that and to see if that was part of your thought process.

MR. KAUFFMAN: Well, right now, there's not an explicit requirement to analyze for FFRD. So we're trying to establish the appropriate approach. And I wasn't trying to shortchange you on the answer. I get to a few points on subsequent slides that will help.

CHAIR BALLINGER: You say there's no specific requirement to analyze FFRD. It's in the rule. It's in the draft rule.

MR. KAUFFMAN: Yes, we're headed there.

CHAIR BALLINGER: Okay.

MR. KAUFFMAN: But right now, it's still a draft rule. Next slide. So what's the basis for ALS? Well, we had a discussion on leak-before-break and why that makes it very likely that you'll have a large break LOCA. We actually start in ALS with the fact that a large-break LOCA inducing FFRD is not a credible event.

Why is that? Well, first of all, the rupture -- large rupture of the main loop piping is highly unlikely. It's extremely unlikely. The main loop piping is already approved for leak-before-break.

NUREG-1829 which has been discussed some this morning shows that the frequency of those large breaks in the loop piping on a plant basis with allowance for expert overconfidence factor is less than one in a million per year. Then xLPR as we've heard about this morning supports the order of magnitude that is given in 1829 and extends the validity of the extremely low likelihood of occurrence to plant life of 80 years. If you look back at 1829, most of the analysis was done at 25 and 40 years as there were a couple of components that were looked at for 60 years.

But we wanted to assure that our approach worked to 80. And then there's a question about time for operator action. We didn't have an established method for calculating or estimating how long you have for the operator to respond.

The xLPR analysis as described this morning shows if a leak -- a detectible leak were to precede rupture, you're still 19 months away from that rupture when the leak first becomes detectable. So you have a long time for the operators to respond. And I'll get to that in more detail in a minute.

The ability for the operator to respond depends on the angle to detect a leakage. And we evaluated the methods for detectable leakage or detecting leakage. I'll talk about those in more detail.

Finally, the main loop piping is crucial before break. And some clients do not have smaller piping approved. We needed to come up with an alternative approach to justify the acceptability of breaks for smaller lines. That's what Jeff will talk about in his session. Next, please. Next again.

Okay. So there's different components that we have to look at as the source of possible primary leaks or ruptures. And I'm careful -- try and be careful not say loss of coolant because loss of coolant is actually defined in the regulations as a piping break. But for completeness in defense-in-depth purposes, we'll look to other component failures to assure there is not an unexpected risk of somewhere other than piping.

When looking at the non-piping -- can I

get some water? Thank you. All right. When looking at the non-piping, there are a number of existing evaluations that have been done for license renewal, life extension, and other reasons. We divided up the territory into several different categories.

There are locations that are screened for extremely low probability. In other words, the break is not expected to occur, reactor pressure vessel. There are bolted connections which fail in a somewhat different way. It has to be looked at in accordance with how bolts fail, their component bodies, and active component failures.

Active component failures are pretty easy to rule out. There isn't any active component that can cause the loss in the quantities that can cause FFRD. Next slide. There are a number of regulations that deal with preventing large-break LOCAs.

And Professor Ballinger, this goes back to something you've mentioned a couple of times which is the importance of the ASME code requirements, namely having ductile materials and instructional analysis in accordance with the code. And there's also procedural requirements that are imposed in the plant or in the plant design that help minimize the chance that you'll have a pressure transient that might lead to damage to the reactor coolant pressure boundary. So those all go together as part of the picture that supports ALS.

Also, you may be aware there's always consideration of changing existing procedures or making design changes. When a licensee references ALS, any design changes will subsequently have to be addressed as part of the overall licensing basis which would then include ALS presumably if the NRC accepts it. Next slide, please. Leak-before-break has not always existed.

Leak-before-break originated as a response to the unresolved Safety Issue 2 in the 1980s which had to do with asymmetric pressure blowdown loads and had the possibility of basically distorting the plant geometry. The NRC worked through that and subsequently concluded that the process of leak-before-break could be used to justify excluding the asymmetric break. Then in the subsequent years, the NRC and the industry went back and forth on several other extensions of leak-before-break. Next slide, please. Oh, sorry. Back up, yeah. That's it.

I've talked about the fact that we've looked at component failures in addition to piping failures. There was actually a comment in a SECY in 1988 that noted that other breaches in the fluid system boundaries such as failed manways or value bonnets must be examined to determine whether they control EQ profiles. So that was about EQ as if FFRD didn't exist as a problem then.

But we considered that was an indication that we needed to address bonnet failures in addition to piping failures. Next. In addition, what I've already discussed, there'd been a couple of cases where leak-before-break has been more broadly applied. In this particular reference, the comment was made that all Westinghouse PWR primary coolant piping has been qualified before leak before break and that the success criteria applied for baffle bolting can be applied to this new fuel design to enable the exclusion of several phenomena which are shown over in the green box on the right, namely, no fuel fragmentation caused by blowdown, hydraulic loads, and 10 CFR 50.46 limits must be met.

That failure mechanism is different than FFRD. But it does involve fragmentation and the acceptance eventually by NRC of leak-before-break as a way to exclude that phenomena. Next slide. I just went over a couple of examples.

There are a number of places where leak-before-break has been used to justify excluding large piping breaks for certain purposes. First row is the USI A-2 I mentioned. Then there's more traditional ones of pipe whip and control rod. Sorry.

And finally, there's baffle bolting and the NGF fuel structural analysis. Note there is one place where NRC has not accepted applying leak-before-break, namely, GSI-191. In that case, the NRC identified a number of criteria that they were concerned about and decided that leak-before-break was not a suitable solution.

MEMBER HALNON: I expected to seal package, the RCP seal package. Is that on this? Because that's a component of failure.

MR. KAUFFMAN: The RCP seal package won't result in a rupture or loss rate that's equivalent to larger than a 14-inch pipe break.

MEMBER HALNON: A small break? All right.

MR. KAUFFMAN: It's taken care of by the poor cooling analysis as opposed to being excluded by leak-before-break or other evaluations.

DR. BLEY: Storm, it's Dennis Bley.

MR. KAUFFMAN: Yes.

DR. BLEY: Can you go back to that slide? Yeah, I don't remember this coming up actually during GSI-191, did it? Did they made a decision or did it just not come up?

MR. KAUFFMAN: Well, there were several letters from both NRC and the licensees that were exchanged that I think extended over a period of two to three years. I'd have to go double check. But I guess the best way to answer it is there is stuff in the files. I don't know to what extent it was brought to the ACRS' attention in discussions with GSI-191.

DR. BLEY: Okay. So some people objected to part of GSI-191 because the low probability of a large break was what was going on?

MR. KAUFFMAN: No, I think what you said, I got turned around. Namely, GSI-191 resolution was not allowed to credit leak-before-break to resolve it. So GSI-191 was not dependent on leak-before-break.

DR. BLEY: Okay. That's interesting. I just don't remember that discussion coming up at all, but okay.

MR. KAUFFMAN: Next slide. Leak detection, leak detection has always been required. The most applicable guidance document is Reg Guide 1.45. And there are technical specifications that limit continued operation with a leak from the primary system.

We'll talk about some of that this morning mainly. Unidentified leakage, you don't know where it's going. It's limited to one gallon per minute. If it exceeds that, then the plant has to be shut down in accordance with this tech spec.

As you can see, this is from the standard BWR -- PWR. I was going to say BWRs are different. But PWR standard tech specs for Westinghouse show that in general you got a limit of one gallon per minute.

And then you have to be in Mode 3 within 36 hours and Mode 5, although there are a few plants that go to Mode 4 instead within 36 hours. I need new glasses. The leak detection that you depend on for those technical specifications includes a number of diverse instruments.

There are requirements in Reg Guide 145 for how to meet diversity requirements. But they include everything from containment sump level to radiation level in the containment, airborne radiation, humidity, containment pressure and temperature. Some plants have acoustic emission to basically hear a leak.

In the limit where you've got months as xLPR predicts to detect a leak, eventually the guy in the warehouse calls up and says, you've used up all my boric acid. What's going on at the plant? Because there are lots of peripheral effects that a large amount of time will bring or make obvious.

The important thing about what was discussed this morning on the many months for operator detection is this is not something that if you were doing a PRA would be subject to a human-error factor because of urgency, because of environment. This is something that the operators on multiple shifts in multiple indications have the ability to detect. So it's incredible that operators will not detect a 1 gpm leak which is what we've assumed for xLPR in the period of time before it would rupture.

I'd note that experience has shown that you can actually detect leaks down to about 0.05 or about 1/20th of tech spec limit. And in general, plants shut down considerably before 1 gpm is reached because they don't want to be in a situation where they're in violation of the tech spec because they didn't act fast enough. Next slide.

In addition, there are a number of different ways that indications of leakage are supposed to be interpreted. And this is discussed in the WCAP that's referenced here, the idea being to have different metrics to evaluate leakage indications against. So if you've got some confusion indications, this detailed guidance helps the operators wade through and determine whether or not there's possibility of leakage that may be infused or otherwise massed by other things going on.

MEMBER HALNON: Storm, to be clear, there's no annunciator alarm that says you have greater than something leakage in the RCS. This is usually at least a four-hour if not a full shift procedure of taking the readings and watching tank levels and humidities and everything else. So I just want to make sure that this is not misunderstood that there's a leak annunciator. There may be some that are somewhat similar if you will like charging tank levels or something to that effect.

MR. KAUFFMAN: Or I believe there's some sump.

MEMBER HALNON: Probably computer monitors maybe. But --

MR. KAUFFMAN: Yes. And --

MEMBER HALNON: -- again, it's an algorithm, a calculation of many different things.

MR. KAUFFMAN: Different clients have different methods. Historically, it was a manual process once every 72 hours. A lot of plants have automated it. But I agree. I do not intend to imply that there's an alarm that says you've got unidentified leakage.

MEMBER HALNON: And in fact, containment radiation has become more and more moot since we've got such clean fuel.

MR. KAUFFMAN: Right.

MEMBER HALNON: You're really just throwing water into the atmosphere. So cooler discharge, sump levels, those are all solid. Some of these things are a little bit more ambiguous.

MR. KAUFFMAN: And that's part of the reason why we wanted to make sure we had adequate time as shown by the xLPR analysis to evaluate. Thank you. Next.

MEMBER BIER: Hi. If I can go back. This is Vicki Bier. I have a question on, I think, the previous slide. I was having trouble finding my mic on my phone.

You mentioned that there are numerous other things that would go wrong if there was a significant leak like the guy in the warehouse saying, hey, I'm running out of boric acid. What's going on? I agree that at a plant with good safety culture, that would absolutely happen.

But we already say with Davis-Besse that the people responsible for changing filters were saying, hey, why are we going through so many filters and they're all full of rust? It seemed unusual. But it never got raised to a level of, hey, where's all this rust coming from and what should we do about it?

So I don't know. I don't think you necessarily need to comment on that. But I just wanted to raise that point if you want to address it.

MR. KAUFFMAN: I was very conscious of Davis-Besse. It's kind of the poster plant for primary leakage attentiveness. And there are a number of things that were done following Davis-Besse that help address those concerns.

But that's why it's so important to show that there's a long time available for other personnel to note the problem, even if there's a culture. Nineteen months is enough time for INPO to come in. And there's quarterly reporting, not the sort of things that you can take credit for in the safety analysis.

But in the real world, there's a lot of eyes on primary leakage as a performance indicator. And if they've got continual loss of water at one gallon per minute, that's equivalent to one of those not biggest but medium sized gasoline trucks that deliver fuel to gas stations, equivalent in about a week. You're putting that much water in containment, somebody is going to notice.

MEMBER BIER: Okay. Thank you. I appreciate the answer.

CHAIR BALLINGER: There's always --

MEMBER BIER: Go ahead.

CHAIR BALLINGER: -- a claim that for Davis-Besse at no time did they exceed the unidentified leakage rate during the thing. But that's kind of a misnomer because the identified leakage at the time was very high. And so nowadays, that kind of identified leakage would never be defined as identified leakage. And there's a bare metal walkdown --

MR. KAUFFMAN: Yes.

CHAIR BALLINGER: -- that has to be done. And that happened after South Texas.

MR. KAUFFMAN: And if you go back to the WCAP criteria, I think it's -- no, sorry, that. So those criteria are also designed to give you different perspectives so you don't ignore the fact that the leak rate is creeping up very slowly or you recognize that the baseline leak rate is different from your last shutdown.

MEMBER HALNON: There's some corroborating data. I feel like what happened at V.C. Summer, it was about a third of a gallon a minute for the cycle. And we had hundreds of pounds of boric acid in containment. And the initial lockdown after the outage, it made it painfully clear that there was an RCS leak somewhere.

Eventually, we found it in this place. So it happened in one cycle, but it stayed very small to the point where it didn't really ring any bells on the leakage or radiation monitoring. But it was slow enough that you were able to see visually very simply it was a problem.

MR. KAUFFMAN: And the process where you make sure that the leak rate is not increasing gives you the ability to separate what the cause is from just the indication. So the criteria here requires the operating staff to address increased leakage. The only example I found in operating experience where this didn't work reasonably well or very well was one place where they actually had two leaks.

And one was, I think, a seal. And they fixed that and said, aha, we're good. And within a few days thereafter, they found they still had a leak. So that shows that there's an ability if you've got some reasonable period of time for operators to recognize more than one leak or follow up more.

MEMBER HALNON: And the other piece of all this that we're not talking too much about is that if it's unidentified, you don't have very much margin. But if it's determined that you identify it as part of the pressure boundary leak, you're shutting down immediately. So all these are pressure boundary leaks. It sounds like you can identify it and go up to 10 gallons per minute. You've got to go shut the plant down immediately to comply with tech specs.

MR. KAUFFMAN: I agree with you, but we're looking at it from the standpoint of knowing we've got a pressure boundary leak and we want to do something about it. But the operators have an indication maybe leakage. And --

MEMBER HALNON: And it's a great incentive to try to identify it. When you're talking about a half a gallon or 0.05 gallons per minute, you can probably go find a drip somewhere and say, okay, that's a packing leak. I'll identify it and put it in a 10 gallon per minute. There's a lot of different things that go on relative to leakage. I think the point you're trying to make is it's slow enough so that any one of those probably will be found out in a cycle during the next refueling outage, not before.

MR. KAUFFMAN: Correct. The idea is there are multiple indications available to multiple personnel over many months. And if this were in a PRA, you could probably justify the group human error rate of 10 to the -6 of this.

MEMBER HALNON: The surveillance, like you said, is done every 72 hours. That's a tech spec also because you have to go look. It's not somebody notices an increase in leakage. You have to look. It's tech spec surveillance. So you have to benchmark against your previous readings.

MR. KAUFFMAN: Thank you. Next slide. Non-piping, so there are components in the loops that are big. And if they broke in two or broke into a significant rupture, the leak rate could exceed what was shown. Core cooling can be assured.

However, the assessment in NUREG-1829 included in the statistics that Markus showed this morning the component failure rate too. So where he was comparing the piping results from xLPR, he was comparing that to NUREG-1829 where the number is piping failures, active failures, component failures. In general, 1829 predicts the component failures or about equivalent probability piping failures.

Component failures are not, however, normally considered in most design analysis. They're excluded. And if we can go back to the slide with the picture. Keep going. Thank you.

So the colors here show the different regions of the plant. And the ones that are in the right purple or magenta are places where the rupture is excluded based on design margins and other criteria. So there are quite a few components that are taken off the table at the start.

We looked at the other components that had the potential to cause large loss of coolants and referenced a number of studies and also considered leak analysis or leak prevention associated with license renewal and life extension and concluded that those processes provide high assurance that the components will not rupture. Even if a leak developed in a component, it's highly unlikely that we get an opening large enough to be equivalent to a double-ended guillotine break. Next slide. We're all the way back to where we were.

Okay. So we have assessed non-piping ruptures, although again 10 CFR 50.46 defines LOCAs as being caused by a piping failure. And I think this is -- I just said all of these. Licensee then reports a number of the references we looked at had detailed assessments of prior operating experience.

But most of them were of a visage like 2010, 2005, 2000, or earlier. So using NRC's licensee event report database, we looked at whether or not there were any events that had occurred since those other references were written and didn't find any indications that there were vulnerabilities that weren't being addressed. In general, leaks are detected somewhere in between 0.05 gpm and about 0.5 gpm, so with a margin to what ALS xLPR analysis considered. Next.

So in summary, the alternate licensing strategy is an assemblage of different justifications for different portions of the plant or different conditions to justify treating FFRD as not credible. It's not credible because large LOCA will not occur. And those portions that I've talked about include NUREG-1829, extremely low likelihood of occurrence, xLPR analysis, leak-before-break, justifies that will not have a main loop piping rupture, assessment of non-piping components or cooling analysis for small breaks, operating experience which shown anything that will be of concern that we missed.

And we will need obviously to have

criteria for implementation at individual plants. That's discussed in an appendix in the EPRI report. But we think that for a non-traditional solution, this provides a fairly comprehensive justification to exclude FFRD from the design basis based on it not being credible. Any other questions?

CHAIR BALLINGER: Why are you using the word, non-traditional? What you're describing is the use of results, analysis, and history which is anything but non-traditional.

MR. KAUFFMAN: Correct. I was using non-traditional as a shortcut for saying we're not going to develop a model and show that FFRD has acceptable consequences. Instead, we're going to justify that FFRD will not occur.

DR. SCHULTZ: It's the dispersion that won't occur.

CHAIR BALLINGER: Yeah, that's what I was about to get at.

DR. SCHULTZ: No fragmentation will occur to some level in performance. But it's the dispersion --

MR. KAUFFMAN: Yes.

DR. SCHULTZ: -- portion of it. I just wanted to make a comment when we bring up Davis-Besse that I don't want to leave the impression that's anything in the industry's experience that wasn't addressed. And that comprehensive and extensive safety culture program was instituted not just by utility industry and the manufacturing industry and the NRC. It was pervasive through the industry. And it has made a difference in industry performance over the last many years.

MR. KAUFFMAN: If there are no other questions, then Fred Smith will talk a little bit more about defense-in-depth.

MR. SMITH: So we've said it several times. I'll reiterate it again that LOCA induced FFRD is extremely low likelihood. You have three independent indications supporting that.

1829, the xLPR analysis, and the LBB piping qualification process all align to say this is an extremely low likelihood. The layers of defense as you began the meeting begin with the design. And so piping system design has specific requirements for material selection, geometry, stress, and any number of factors that are providing, promoting the performance that we're seeing.

The fabrication is another layer where welding procedures qualify welding training programs, QA, material qualifications, welding inspection, et cetera. So that's another layer of defense. The abnormal and normal operating procedures prevent severe stresses in piping systems from occurring.

The ISI program and leak rate detection program all are layers of defense to preclude large-break LOCA -- to keep large-break LOCA at a low frequency of occurrence. And then the ECCS is a mitigating action that is credited for the small and intermediate-break that we're doing but not for the large-break LOCA and describe why that is acceptable. So if we look at these and consider two scenarios, one where if we had a short time between detectable leak and LOCA, we have a different story.

So if the xLPR analysis was the time to detectable to LOCA was a week, we would probably have a very different story to tell. But at 19 months or even a tenth of that, it's very different. So those first three layers are in place all the time per a scenario.

If we had a small period of time, then the operator response liability on there, responding might be less. And that might be a contributor to risk. But with very long period for detection, it's not credible, I don't think, in anywhere close to 19 months that this could be not detected and the plant would not shut down.

And so that's a big increase in our knowledge of performance of the plants. We didn't have ECCS actuations of small, very short periods of time. You would probably have to rely upon ECCS systems.

But with such a long time and rely upon the operator shutting the plant down, the plant is shut down. And anywhere close to -- within weeks or perhaps even months, the stored energy is all but gone. Decay heat is gone. The motive force for forcing a flaw to failure is gone. And even if you did have a failure, which there's no mechanism for that to occur, then there's not enough energy in the fuel to cause clad rupture and fuel dispersal. So --

MEMBER HALNON: If we can go back to your leak detection, I actually think you might -- I can make an argument that you've got the operator response swapped. If you have a short time between leakage and LOCA, it means it's probably increasing. Or it gets a lot of operator attention. Believe me. It gets a tremendous amount you do a leak rate probably almost continuously, snapping a line every four hours.

MR. SMITH: That would be a change in the system you mean.

MEMBER HALNON: Yeah.

MR. SMITH: Yeah.

MEMBER HALNON: I would say that you got much more reliable operator response if it's a shiny object on the wall in the control room --

MR. SMITH: Yeah.

MEMBER HALNON: -- as opposed to a complacency of that's only increased to 0.05.

MR. SMITH: Yeah, I didn't mean to intend that. The scenario I was trying to address is you do have highly qualified, highly proceduralized activities by the control room. And they do an incredible job. If they were to miss once, then the consequence of that for a short period of time would be higher potentially, higher risk, than if you have 200 shots on goal.

MEMBER HALNON: The operator response has a much higher impact in a short time --

(Simultaneous speaking.)

MR. SMITH: Yeah, that was what I was trying to communicate.

MEMBER HALNON: Okay. I can buy that.

MR. KAUFFMAN: There are fewer opportunities for operator recovery if the time period is shorter. So if somebody makes a mistake, then your assurance that that mistake will be corrected is reduced.

MEMBER HALNON: Okay. So the reliability of the operator has a much higher impact in the short period of time versus the long term because of the single mistake made.

MR. SMITH: So in the short time scenario --

MEMBER HALNON: Yeah, I got it.

MR. SMITH: -- you might expect ECCS system actuation. ECCS system is not perfect. It's highly reliable. But there are equipment variations and equipment issues that are in the analysis side that are accounted for. In reality, they may or may not occur. And so --

MEMBER HALNON: I get it now. I think I know what you're trying to say.

CHAIR BALLINGER: My experience as an actual operator is that when -- not in this world but in another world was that when something bad is happening quickly, it really gets your attention in a hurry.

MR. SMITH: Yes.

CHAIR BALLINGER: So you don't miss it.

MR. SMITH: Right. That's right. You don't --

CHAIR BALLINGER: You don't miss it.

MR. SMITH: Yeah.

CHAIR BALLINGER: And if you do miss it, there's somebody crawling over your back.

MR. SMITH: Yeah, I agree. I agree with that. So from a risk perspective, having the long time between detectable leakage and a LOCA makes you less dependent upon the ECCS. And not having to rely upon it as we're doing does not increase the risk of an unfortunate consequence.

So if you have multiple shots on goal, high, high assurance that you're going to shut the plant down. And there will not be any fuel dispersal consequences. And so in the very short period scenario here, like I said, if xLPR told me the time was two weeks, I'm not at all sure that we would be able to make the arguments that we are making. But even if it's a factor of 10 less than the results we have now, there's high confidence that operators will shut the plant down and mitigate any dispersal consequences. So --

MEMBER ROBERTS: Could I clarify the last row on the previous table? Could you back to the table? The last row, second column says, some dispersal may occur impacting containment.

This ties back to what Storm was saying. That's based on the RIL, I assume, and the research has been done to date which is not conclusive in terms of its results. I mean, the RIL would imply that's the case.

If you had RIL, impact is that you put more activity in containment. But people can make up other stuff too. It's a whole lot more significant. So is that basically a judgment that's likely the case? Is that the way to read that?

MR. SMITH: Well, the NRC part on dispersal consequences said this is a potential consequence. And so we don't know how much because there's a lot of research that has not been done to quantify the mobility of dispersed material among other things. But certainly dispersed material would find its way in the containment, and it would require some evaluation.

MR. KAUFFMAN: I think the reason we focused on containment was it's the third barrier to fission product release. We've already damaged the fuel clad and the RCS. So it was a little bit different perspective than you're thinking. That's your last barrier. You don't want FFRD and dispersal to fail it.

MEMBER ROBERTS: Okay, thanks. I understand. That does presuppose some of the things that are uncertain. And the research information letter won't have them. But ultimately, containment is the last barrier that would be the last line of defense for things like criticality if that were possible or loss of cold -- and that kind of thing. Okay, thanks.

MR. SMITH: So kind of summary that from a potential risk for the ALS approach, the biggest potential consequence would be the first operator does not detect the leak rate exceeding the tech spec. Now that's very unlikely considering the importance of how it's proceduralized or how they train or have a skill to do this at least every three days but really more often than that. So the likelihood of that operator missing this is very small.

But if they did, then there are -- the next guy on the next shift is going to come up and detect it. The symptoms will become increasingly obvious as the flow slowly increases or the volume and temperature accumulates. It will be easier to detect.

So we believe it's not credible that given the time frames that we are talking about that we won't be detected. So we believe that shutting the plant down is a credible barrier and a very reliable barrier. So the other potential risk is the reliance upon xLPR.

And so while it's a very important element of this, we have well qualified code just like we have in the LOCA area. And we understand the uncertainties. We understand how it performs, and we have large amounts of margin to address any potential gaps of that understanding.

So we don't believe that's a critical element of defense-in-depth. So that was the last of my slides. If you have any other questions.

CHAIR BALLINGER: Questions from members or consultants?

Hearing none, this constitutes the end of the open session. So by -- yeah, that's what I was about to do. You're way ahead of me. So we need to go out for public comment. Are there any members of the public that would like to make a comment? If there are, would you state your name and then provide your comment?

Hearing none, this is the end of the open session. I'm assuming we're going to have a closed session. There's another set of slides.

And so what we need to do is to take a, I don't know, ten-minute break while we get set up and verify that we have people in the room that should be here to hear this. So let's take a ten-minute break so we get sorted out. And who's going to be the gatekeeper for the online?

You'll do that? So Chris Brown will be the gatekeeper. And we'll have to rely on the EPRI folks if there's somebody that we don't see. So let's recess until -- well, let's call it 2:15.

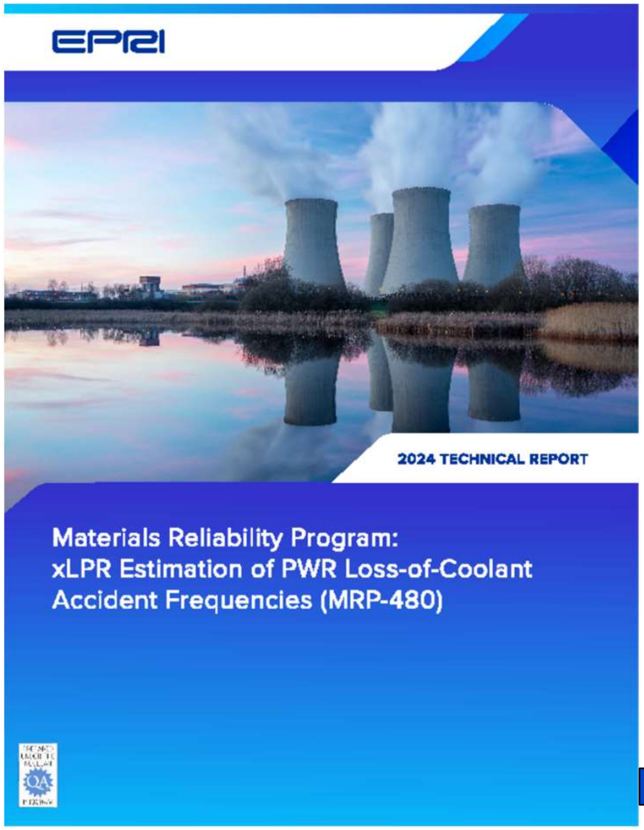
(Whereupon, the above-entitled matter went off the record at 2:03 p.m.)

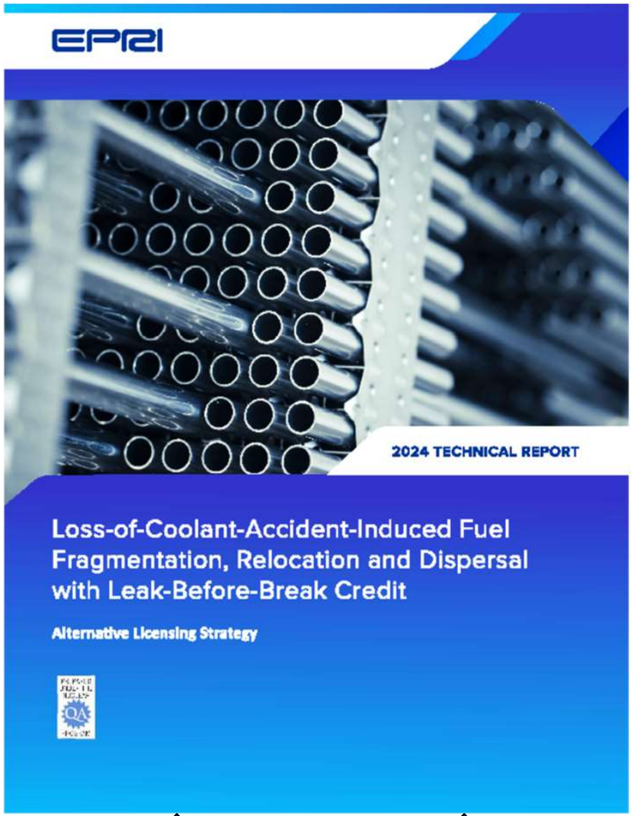
Introduction to EPRI's Alternative Licensing Strategy to Address LOCA induced FFRD

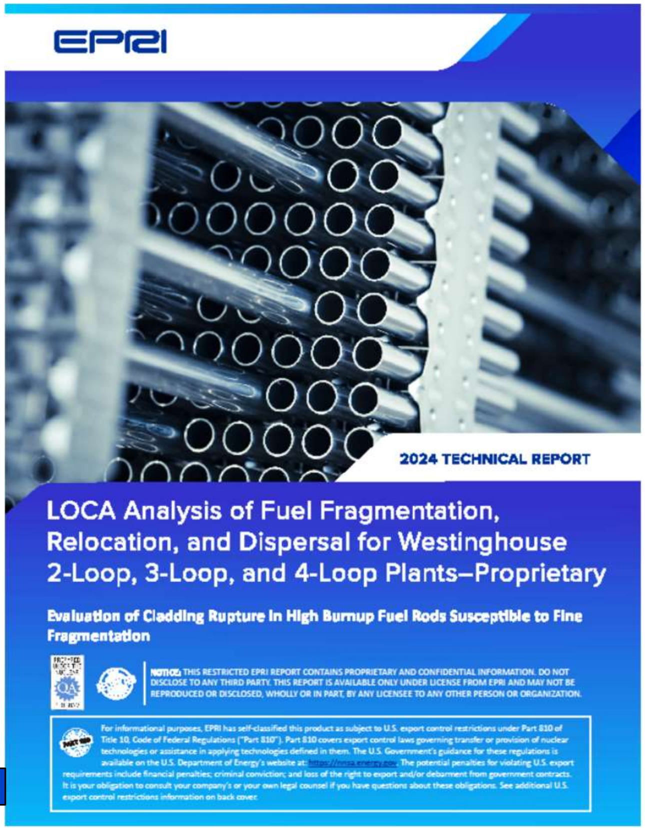
Fred Smith
Sr. Technical Executive

ACRS Meeting of the Fuels Materials, & Structures Subcommittee
June 25, 2024

ALS Submittal Introduction*



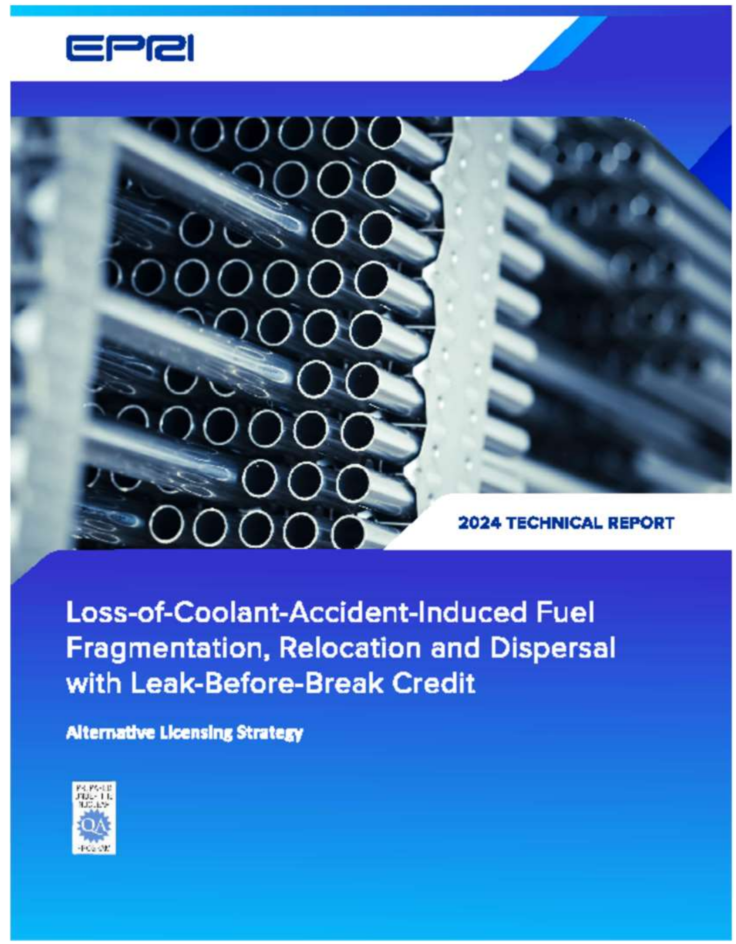




*Does not include removal of LB-LOCA from design bases

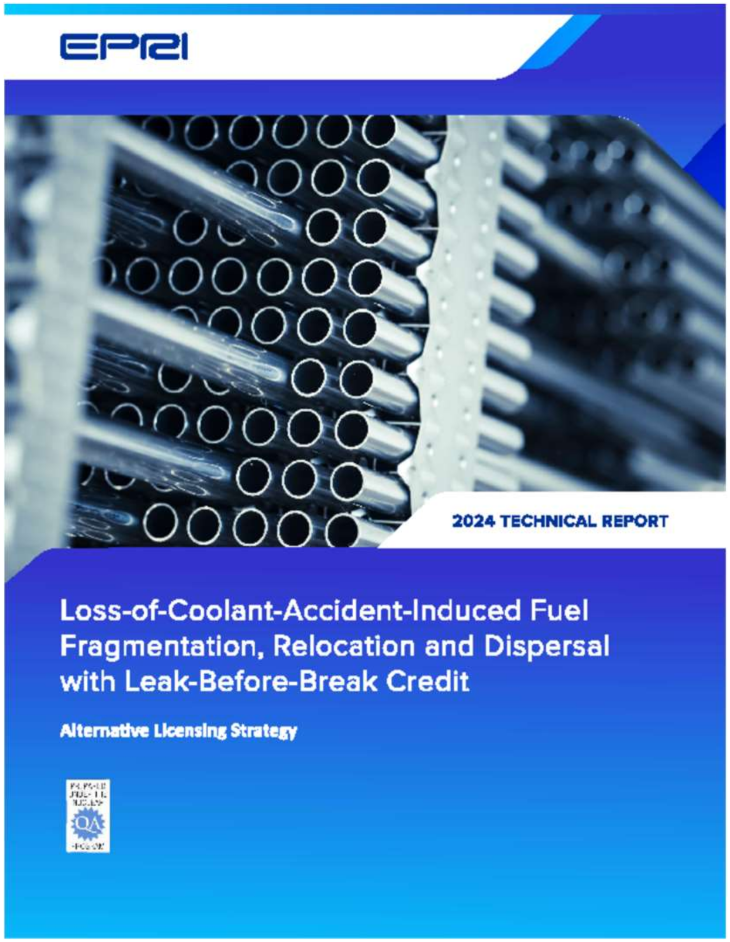
Key Features – Leak-Before-Break

- Introduction
  - Safety Benefits
    - Reduced Fuel Cycle Impacts including High Level Waste and other Radiological Impacts
    - Support Nuclear Plant Low Carbon Emissions
    - Reduced industry and NRC demand on scarce specialized resources
- Regulatory Guidance
  - Current Guidance and potential changes to Regulations
  - Defense-in-Depth
- Methodology
- Leak-Before-Break



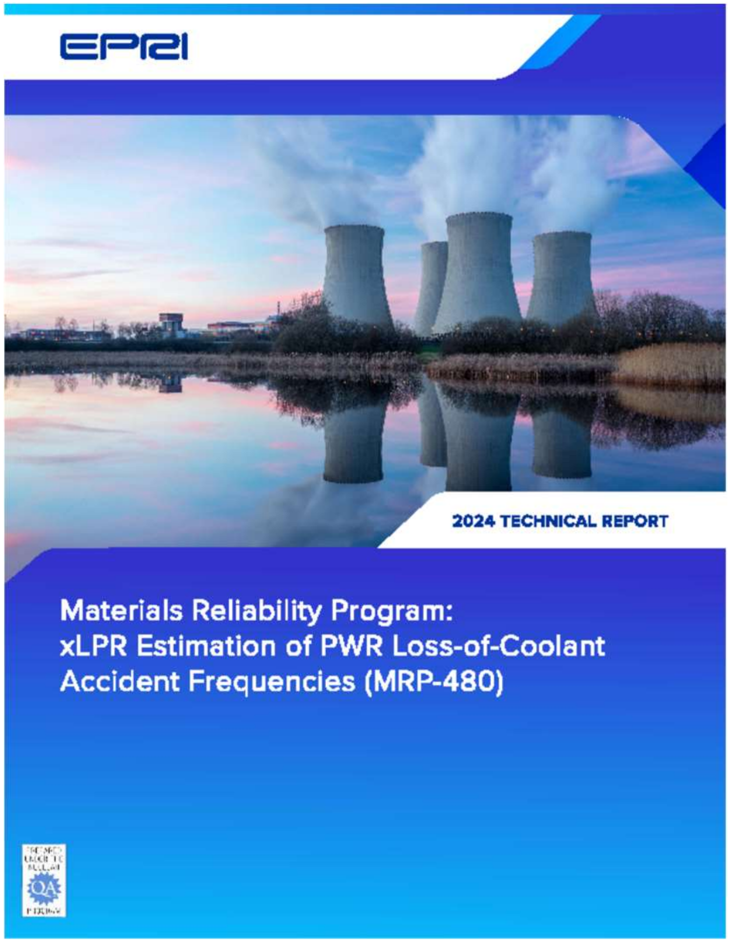
Key Features

- Piping Ruptures
- Non-Piping Ruptures
- Summary and Conclusions
  - Initial Application – Westinghouse NSSS Systems using Westinghouse fuel
    - Extensions to other PWRs with appropriate small break and intermediate break LOCA analysis
    - Other NSSS systems
    - Other fuel designs
    - Other vendor’s analysis methods
  - Appendix A Requirements to Apply ALS to Specific Plants



Key Features - xLPR

- Introduction
- xLPR Probabilistic Fracture Mechanics
  - Evaluated Case Matrix – Full case matrix includes non-primary loop coolant piping which is not applicable to ALS scope
  - Benchmarking and validation
- Comparison to NUREG-1829
- Time between detectable leakage and LOCA
- Evaluation of applicable degradation mechanisms
- Conclusion

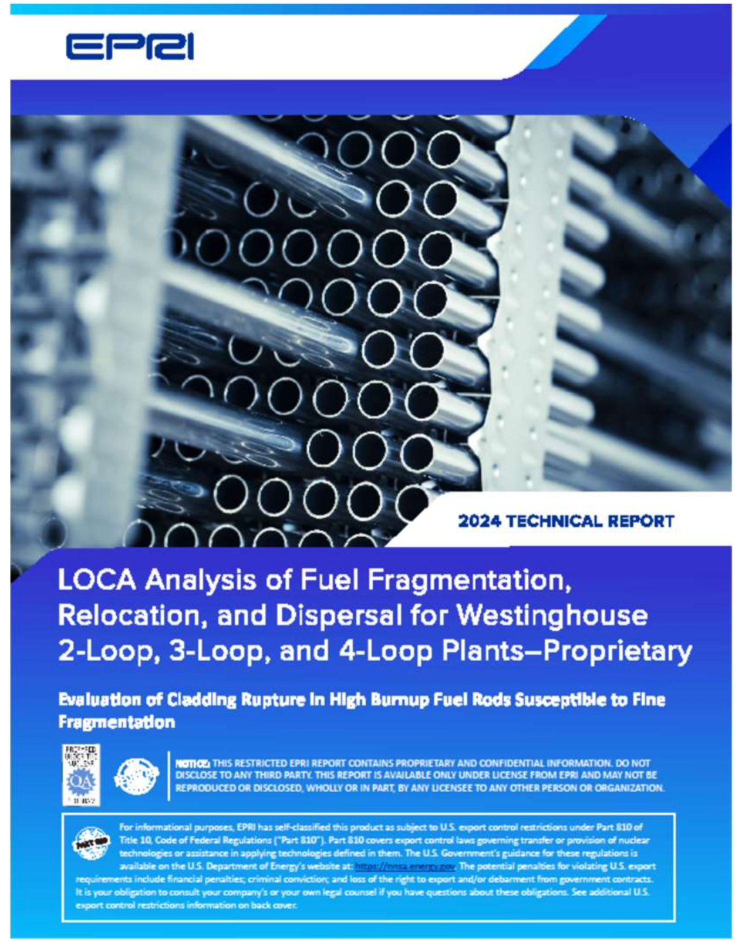


Key Features - LOCA

- Overview of Cladding Rupture Analysis
- Methodology
- Bounding Model development
- Cladding Rupture Results
  - 2-Loop
  - 3-Loop
  - 4-Loop
- Summary and Implementation
  - Evaluation of Limitations and Conditions
  - Plant-Specific Implementation Requirements

Relies on previously submitted Methodology Report:

WCAP-18850-P, “Adaptation of the FULL SPECTRUM LOCA (FSLOCA) Evaluation Methodology to Perform Analysis of Cladding Rupture for High Burnup Fuel,” February 2024.



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xLPR Probabilistic Fracture Mechanics Analysis for the ALS

Overview and Key Analysis Results

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ACRS Meeting of the Fuels Materials, & Structures Subcommittee
June 25, 2024

Outline

- Background
- Scope
- Summary of xLPR Analysis Cases
- Key Results
  - LOCA frequency compared to NUREG-1829
  - Time between detectable leakage and LOCA
- Conclusions

List of Acronyms

ACRS	Advisory Committee on Reactor Safeguards
ALS	Alternative licensing strategy
CE	Combustion Engineering
CL	Cold leg
DMW	Dissimilar metal weld
DN	Diametre nominal
FFRD	Fuel fragmentation, relocation and dispersal
HL	Hot leg
ISI	In-service inspection
LBB	Leak-before-break
LBLOCA	Large-break loss-of-coolant accident
LRD	Leak rate detection
LOCA	Loss-of-coolant accident
MSIP®	Mechanical Stress Improvement Process
MDM	Materials Degradation Matrix
NPS	Nominal pipe size
NRC TLR	US Nuclear Regulatory Commission Technical Letter Report
PFM	Probabilistic Fracture Mechanics
PWR	Pressurized water reactor
PWSCC	Primary water stress corrosion cracking
PZR	Pressurizer
RCP	Reactor coolant pump
RCS	Reactor coolant system
RVIN	Reactor vessel inlet nozzle
RVON	Reactor vessel outlet nozzle
SCC	Stress corrosion cracking
SGIN	Steam generator inlet nozzle
SGON	Steam generator outlet nozzle
WRS	Weld residual stress
xLPR	Extremely Low Probability of Rupture

Previous NRC Interactions

Date	Event	NRC ADAMS Accession Number
06/14/2022	NRC Public Meeting to Discuss Use of the Extremely Low Probability of Rupture Code for LOCA Frequency Estimates	ML22166A345
01/19/2023	NRC Public Meeting to Discuss Use of the Extremely Low Probability of Rupture Code for LOCA Frequency Estimates	ML23019A148
05/18/2023	ACRS Fuels, Materials, and Structure Subcommittee Meeting	ML23164A190
11/08/2023	Pre-Submittal Meeting to Discuss the Use of the ALS to Address LOCA Induced FFRD	ML23312A003
06/06/2024	Introduction to Alternative Licensing Strategy; LOCA-Induced Fuel Fragmentation, Relocation and Dispersal	ML24156A244

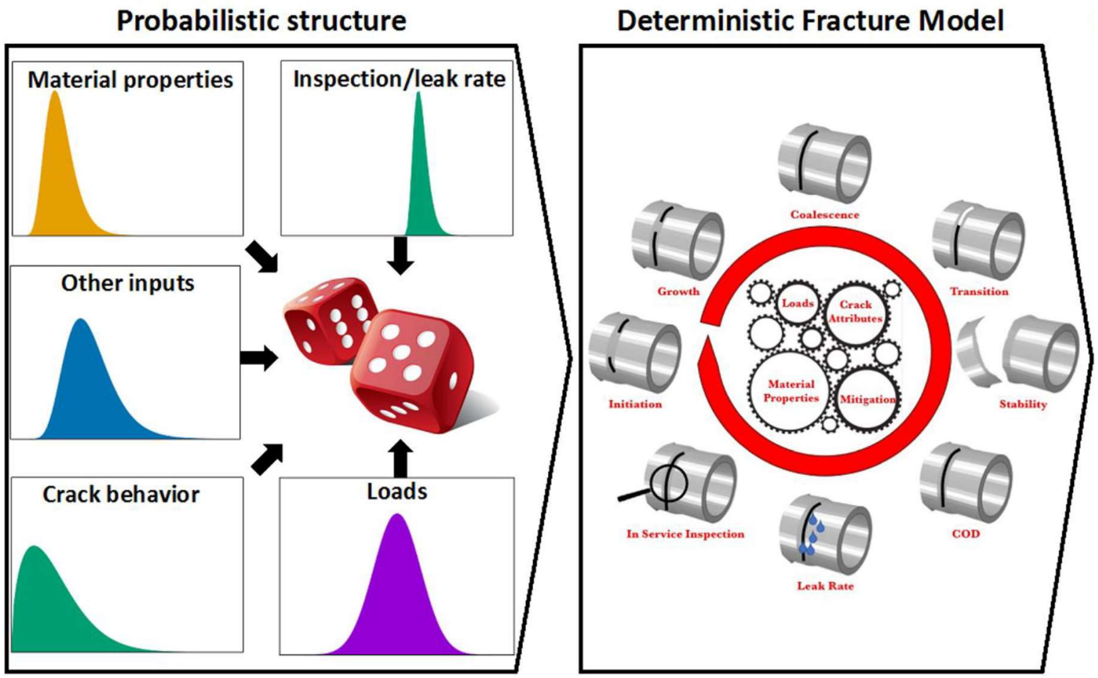
Background and Scope

Background

- xLPR is a state-of-the-art **probabilistic fracture mechanics code** jointly developed by the NRC's Office of Nuclear Regulatory Research and the Electric Power Research Institute (EPRI)

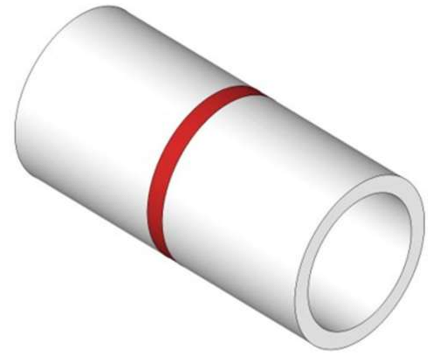
- Provides new quantitative capabilities to analyze the risks (e.g., leakage or rupture) associated with nuclear power plant piping systems subject to active degradation mechanisms

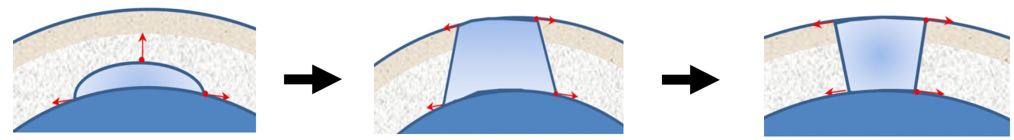
xLPR Overview



xLPR Model Attributes

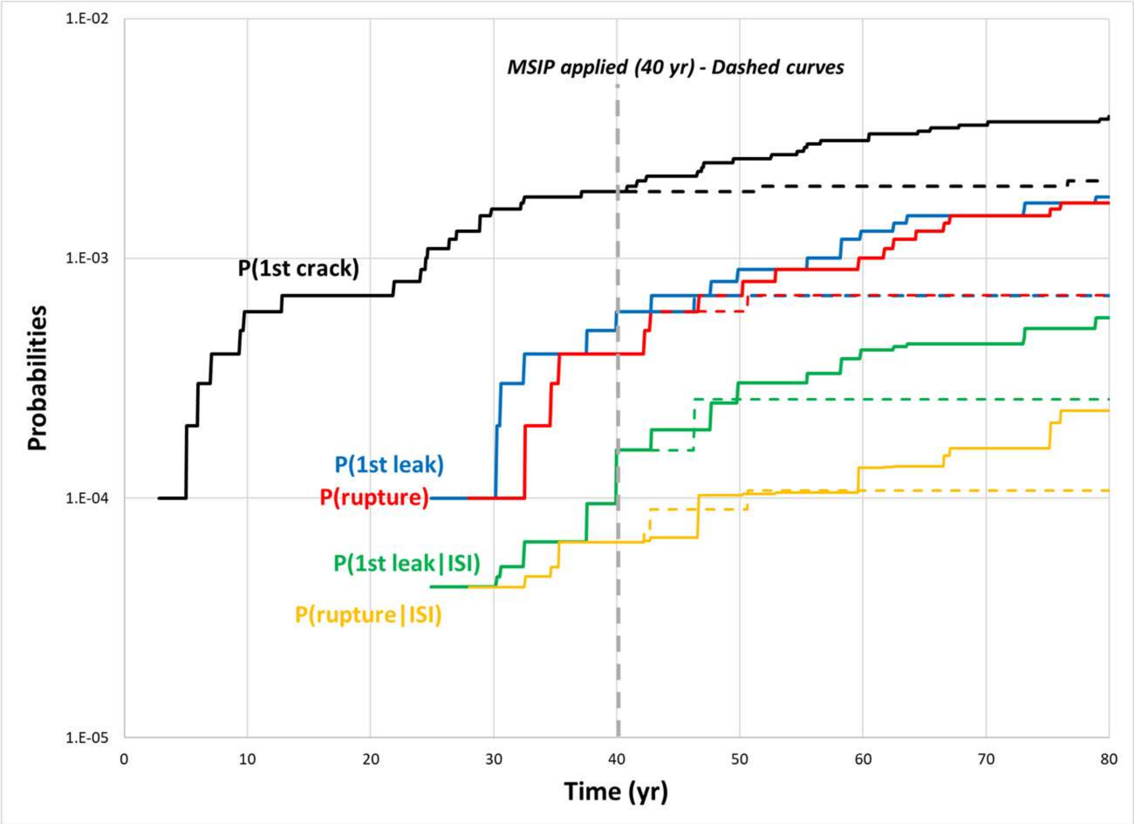
- Geometry
  - Piping butt-weld
- Materials
  - Dissimilar metal weld
  - Similar metal weld
- Crack orientations
  - Circumferential and/or Axial
  - Multiple cracks
- Crack initiation
  - SCC, Fatigue, Both
- Crack growth
  - SCC, Fatigue, Both
- Mitigation
  - Inlay, Onlay, Overlay, Mechanical Stress Improvement Process (MSIP®)
  - Chemical
- Inservice inspection (ultrasonic testing)
- Leakage detection





Direct Results from xLPR

- Probabilities
  - First Crack
  - First Leak
  - Rupture
- Individual Crack Results
  - Type
  - Position
  - Leak rate
  - Growth
  - Stress Intensity Factors
- Number of cracks
- Probability of non-repair
- Stability ratio
- Leakage rate
  - Individual flaw
  - Total for all flaws



xLPR Quality Assurance

- Built under rigorous quality assurance program
  - Selected elements of ASME NQA-1-2008 and NQA-1a-2009 Addenda, which are endorsed for meeting NRC's 10 CFR Part 50, Appendix B, quality assurance requirements
  - Extensive technical documentation
- Verification and validation
  - 4,000+ verification tests
  - Validation of each physical model and of complete software against operating experience, finite element analysis simulations, and other probabilistic fracture mechanics codes
- Externally reviewed
- Quality Assurance in xLPR development process documented in NUREG-2247
- Participated in OECD/NEA/CSNI global PFM benchmark
  - Finds xLPR represents the state-of-the-practice in terms of PFM modeling capabilities
  - Several conference publications; final benchmark report to be published in 2024

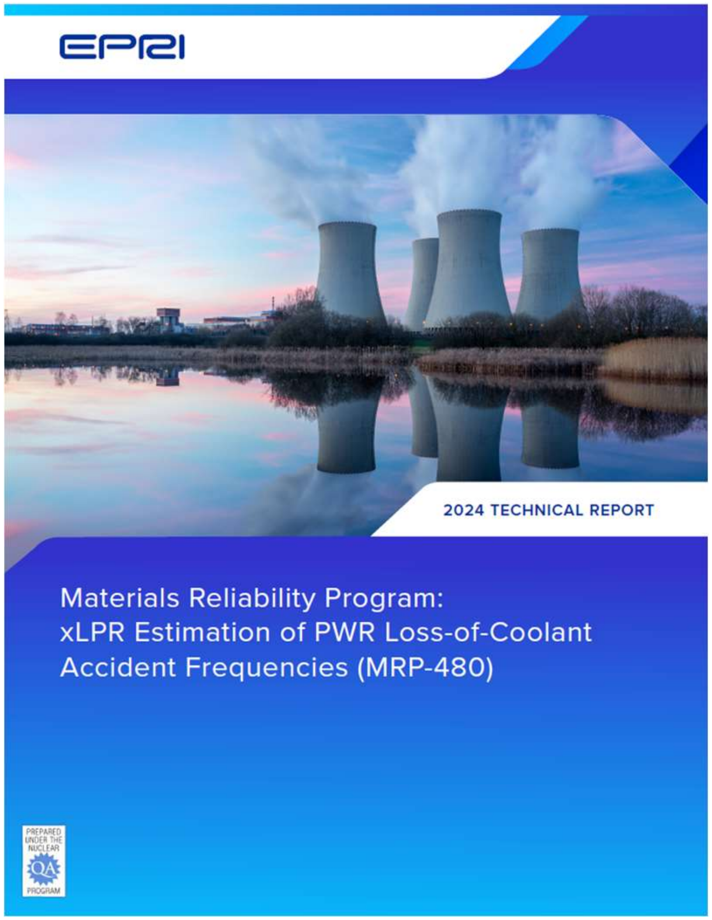
xLPR Treatment of Uncertainty

- **Uncertainty:** Knowledge of the knowns and unknowns that affect model predictions
- Probabilistic approach:
  - Use of best-estimate models to describe complex system
  - Models linked and integrated
  - Uncertainties quantified, reduced (best estimate), and accounted for by forward propagation through each model using the Monte Carlo method
- xLPR Uncertainty Report [ML19337C165] summarizes and consolidates information on sources and treatment of uncertainties within the xLPR modules and Framework

What	Where	Specifics
Uncertainty descriptions	Module reports	Basic model form, inputs, range of validity
		Assumptions and summary of verification/validation efforts
		Uncertainty/bias factors
		Limits of applicability, interpolation methods
	Validation reports	Model bias and uncertainty relative to lab or field data
	Scenario report	Sampling and convergence uncertainty
Uncertainty quantification and propagation	Inputs report	Distributions on inputs and parameters
	Module reports	Distributions on model parameters
	Scenario report	Sampling strategies

Study Scope within the Fuels Alternative Licensing Strategy

- NUREG-1829, Vol. 1 estimates Loss-of-Coolant Accident (LOCA) frequencies
  - Evaluated the technical adequacy of redefining the design-basis break size (largest pipe break to which 10 CFR 50.46 applies) to a smaller size
  - Estimated LOCA frequencies through an expert elicitation process
- As part of research into an alternative fuel licensing strategy (ALS) for fuel fragmentation, relocation, and dispersal (FFRD), xLPR was applied to:
  - Validate NUREG-1829 LOCA frequency estimates for use in high burnup fuel licensing
  - Evaluate probability that leakage as a precursor to a LOCA / rupture will be detected in sufficient time to allow for reactor shutdown and reduce decay heat levels before a LOCA / reactor coolant system (RCS) piping rupture occurs
- MRP-480 (EPRI 3002023895, freely available) has been published, documenting the details of this work



Line Size Considerations

- NUREG-1829 gives estimates of LOCA frequencies based on expert elicitation (Table 1)
- The expert elicitation considered LOCA-sensitive piping systems and associated degradation mechanisms (Table 3.5)

Table 1 Total BWR and PWR LOCA Frequencies
(After Overconfidence Adjustment using Error-Factor Scheme)

Plant Type	LOCA Size (gpm)	Eff. Break Size (inch)	Current-day Estimate (per cal. yr) (25 yr fleet average operation) 5th Per.	Median	Mean	95th Per.	End-of-Plant-License Estimate (per cal. yr) (40 yr fleet average operation) 5th Per.	Median	Mean	95th Per.
BWR	>100	½	3.3E-05	3.0E-04	6.5E-04	2.3E-03	2.8E-05	2.6E-04	6.2E-04	2.2E-03
	>1,500	1 7/8	3.0E-06	5.0E-05	1.3E-04	4.8E-04	2.5E-06	4.5E-05	1.2E-04	4.8E-04
	>5,000	3 ¼	6.0E-07	9.7E-06	2.9E-05	1.1E-04	5.4E-07	9.8E-06	3.2E-05	1.3E-04
	>25K	7	8.6E-08	2.2E-06	7.3E-06	2.9E-05	7.8E-08	2.3E-06	9.4E-06	3.7E-05
	>100K	18	7.7E-09	2.9E-07	1.5E-06	5.9E-06	6.8E-09	3.1E-07	2.1E-06	7.9E-06
	>500K	41	6.3E-12	2.9E-10	6.3E-09	1.8E-08	7.5E-12	4.0E-10	1.0E-08	2.8E-08
PWR	>100	½	6.9E-04	3.9E-03	7.3E-03	2.3E-02	4.0E-04	2.6E-03	5.2E-03	1.8E-02
	>1,500	1 5/8	7.6E-06	1.4E-04	6.4E-04	2.4E-03	8.3E-06	1.6E-04	7.8E-04	2.9E-03
	>5,000	3	2.1E-07	3.4E-06	1.6E-05	6.1E-05	4.8E-07	7.6E-06	3.6E-05	1.4E-04
	>25K	7	1.4E-08	3.1E-07	1.6E-06	6.1E-06	2.8E-08	6.6E-07	3.6E-06	1.4E-05
	>100K	14	4.1E-10	1.2E-08	2.0E-07	5.8E-07	1.0E-09	2.8E-08	4.8E-07	1.4E-06
	>500K	31	3.5E-11	1.2E-09	2.9E-08	8.1E-08	8.7E-11	2.9E-09	7.5E-08	2.1E-07

Table 3.5 PWR LOCA-Sensitive Piping Systems

System	Piping Matls.	Piping Size (in)	Safe End Matls.	Welds	Sig. Degrad. Mechs.	Sig. Loads.	Mitigation/ Maint.
RCP: Hot Leg	304 SS, 316 SS, C-SS, SSC-CS CS – SW	30 - 44	A600, 304 SS, 316 SS, CS	A82 304 SS, 316 SS, CS	TF, SCC, MA, FDR, UA	P, S, T, RS, DW, O, SUP	ISI w TSL, REM
RCP: Cold Leg/Crossover Leg	304 SS, 316 SS, C- SS, SSC-CS, CS – SW	22 - 34	A600, 304 SS, 316 SS, CS	A82 304 SS, 316 SS, CS	TF, SCC, MA, FDR, UA	P, S, T, RS, DW, O, SUP	ISI w TSL, REM
Surge line	304 SS, 316 SS, C-SS	10 - 14	A600, 304 SS, 316 SS,	A82 304 SS, 316 SS	TF, SCC, MA, FDR, UA	P, S, T, RS, DW, O, TFL, TS	TSMIT, ISI w TSL, REM
SIS: ACCUM	304 SS, 316 SS, C-SS	10 - 12	A600, 304 SS, 316 SS,	A82 304 SS, 316 SS	TF, SCC, MA, FS, FDR, UA (FAC)	P, S, T, RS, DW, O	ISI w TSL, REM
SIS: DVI	304 SS, 316 SS	2 – 6	A600, 304 SS, 316 SS,	A82 304 SS, 316 SS	TF, SCC, MA, FS, FDR, UA (FAC)	P, S, T, RS, DW, O	ISI w TSL, REM
Drain line	304 SS, 316 SS, CS	< 2"			MF, TF, GC, LC, FDR, UA	P, S, T, RS, DW, O, V, TFL	ISI w TSL, REM
CVCS	304 SS, 316 SS	2 – 8	A600 (B&W and	A82	SCC, TF, MF, FDR, UA	P, S, T, RS, DW, O, V	ISI w TSL, REM

The goal of the current study is to analyze piping welds > NPS 14 (> DN 350) in support of alternative licensing strategy (ALS) for FFRD

Summary of xLPR Analysis Cases

Summary of xLPR Analysis Cases

- xLPR analysis cases were developed applying Primary Water Stress Corrosion Cracking (PWSCC) and/or fatigue as the material degradation mechanisms
- Either modeled flaws as present at the start of the simulation or used initiation models to calculate the time to flaw initiation
  - All flaws at initiation were modeled as flaws of engineering scale
- Sensitivity studies were performed to determine the impact of changes to analysis inputs
  - Sensitivity studies modeled alternate inputs for parameters such as geometry, loading, weld residual stress profiles, initial flaw sizes, or seismic effects

Summary of xLPR Analysis Cases

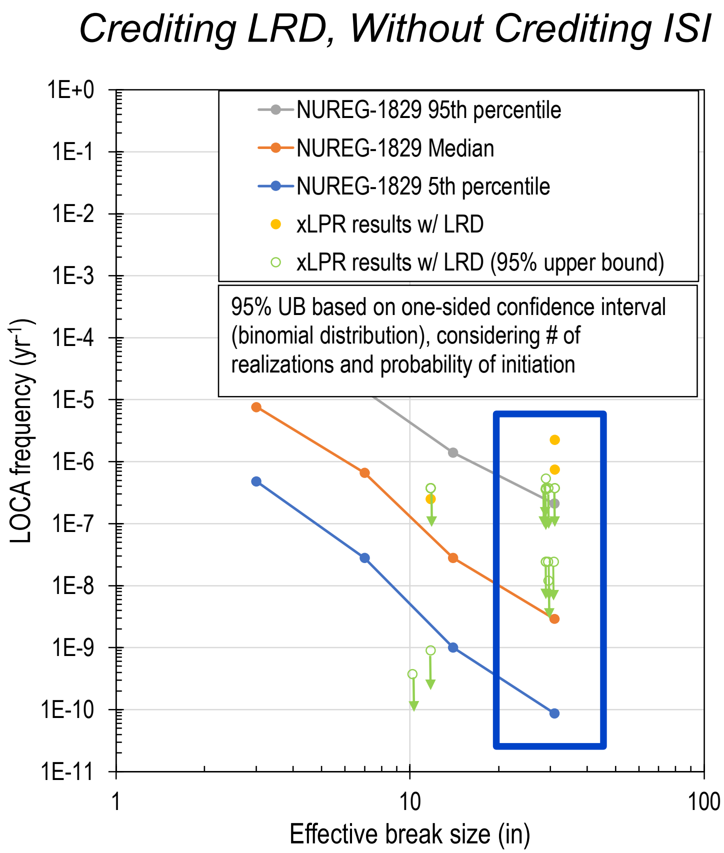
- The results of recent NRC analyses are used where possible and supplemented with additional xLPR analysis cases as needed
  - TLR-RES/DE/REB-2021-09 (ML21217A088)
    - Referred to herein as "xLPR piping system analysis"
    - Documented xLPR analysis of representative reactor vessel outlet and inlet nozzle welds in a Westinghouse four-loop PWR
    - Includes extensive set of sensitivity studies
  - TLR-RES/DE/REB-2021-14 R1 (ML22088A006)
    - Referred to herein as "xLPR generalization study"
    - Documented xLPR analysis of other piping systems containing Alloy 82/182 dissimilar metal piping butt welds which had received prior LBB approvals from the NRC staff
    - Includes reduced set of sensitivity studies per analyzed component, as informed by "xLPR piping system analysis"
  - Shorthand numbering #.#.## is used to refer to specific xLPR analysis cases
- Results of Interest for ALS
  - Time between 1 gpm detectable leakage and rupture or LBLOCA ("lapse time")
  - P(Rupture|Initiation) ≈ P(Rupture|Initial Flaw) × P(Initiation)
  - Average 80-year rupture (LOCA) frequency = P(Rupture) / 80 yrs

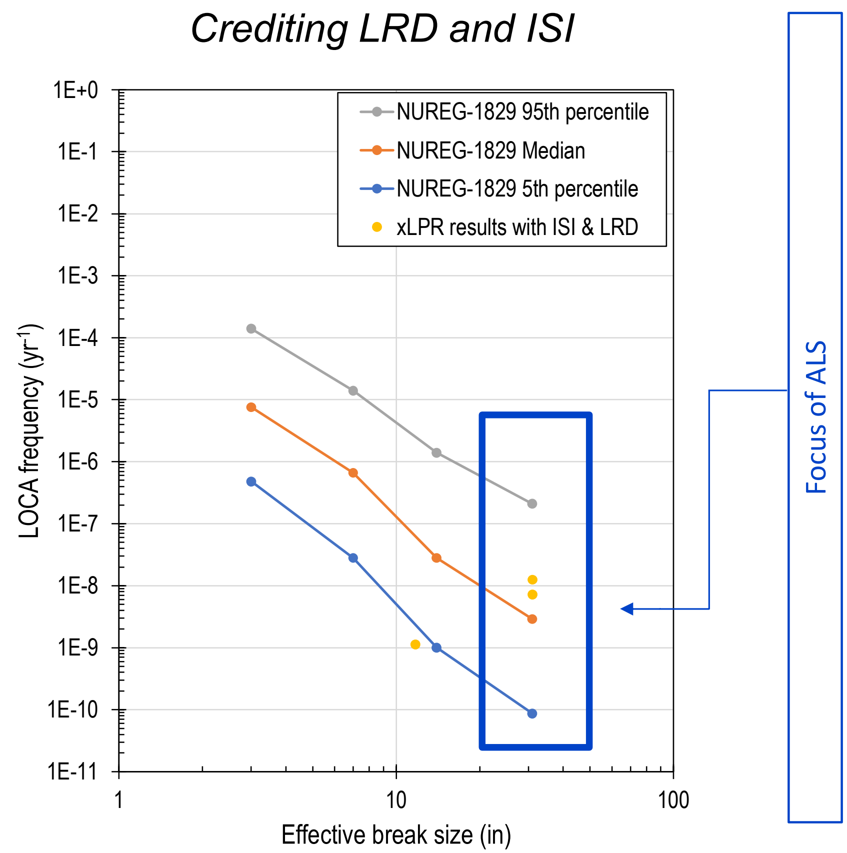
LOCA Frequency Compared to NUREG-1829

LOCA Frequency Results from NUREG-1829 Table 1

- NUREG-1829 LOCA frequencies used for comparison are:
  - Based on expert elicitation
  - From Table 1
    - Median, 5th percentile, and 95th percentile
    - Total PWR LOCA frequencies after overconfidence adjustment using error-factor scheme
    - 40 yr fleet average values
    - Consider typical ISI with LRD resolution as required by tech spec limits
  - Results are presented on a per plant basis, for each distinct LOCA category
  - Considers piping and non-piping passive system contributions

xLPR LOCA Frequency Compared to NUREG-1829 Table 1





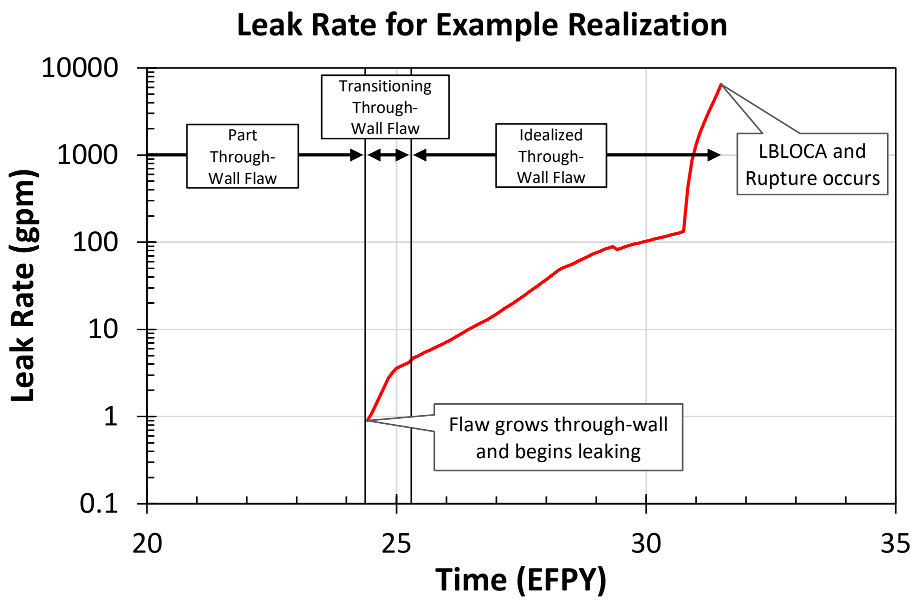
When considering ISI and LRD, LOCA frequencies estimated from xLPR are on a similar order of magnitude as median NUREG-1829 LOCA frequency estimates

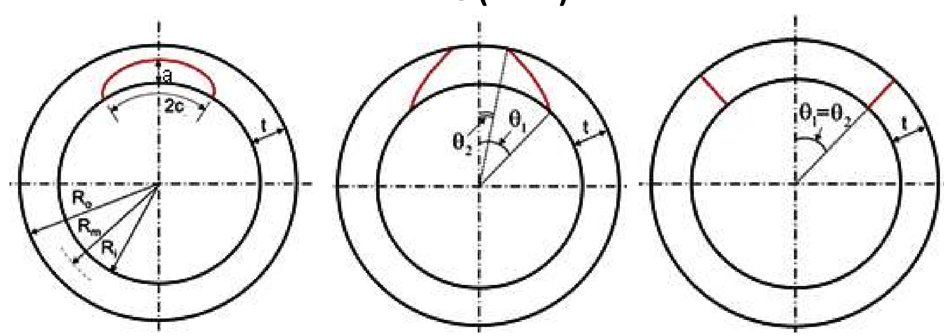
Time Between Detectable Leakage and Large-Break LOCA

Time from Detectable Leakage to LBLOCA

For a Single xLPR Analysis Case Realization

- Results shown depict example leak rate time history for one realization modeled in xLPR
  - Component modeled: Unmitigated Alloy 82/182 reactor vessel outlet nozzle dissimilar metal weld
  - Key modeling options selected:
    - Initial flaw model (i.e., initiation at time = 0)
    - PWSCC growth only
    - One circumferential crack
    - No inservice inspection, leak rate detection, mitigation, or seismic effects
    - LBLOCA = 5,000 gpm leak rate

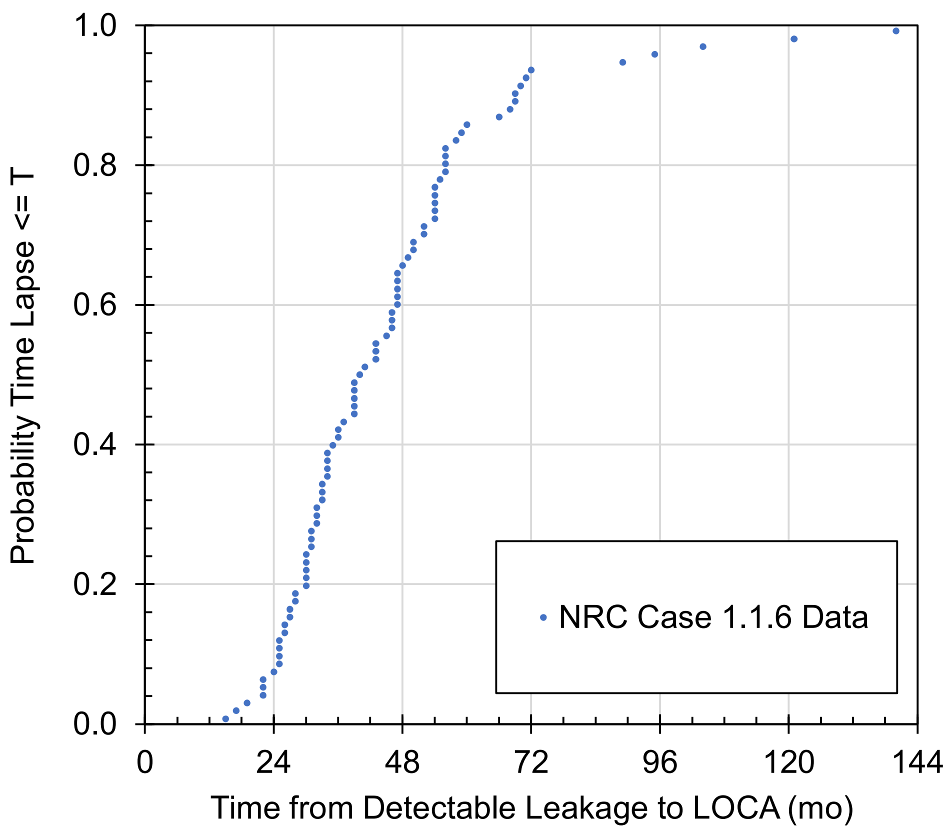




Distributions of Time from Detectable Leakage to LBLOCA

For a Single xLPR Analysis Case

- Results for one xLPR analysis case produce a distribution of lapse times
- Each data point corresponds to one realization which resulted in LBLOCA (without crediting ISI or LRD)
  - Note that the lapse time result distributions are truncated at 12 years in NRC TLRs
- The distribution of results for each xLPR analysis was considered as part of the overall assessment of lapse times for each analyzed component
- These results do not credit ISI or LRD



Investigation of Limiting Cases

- Considering the distributions of times from detectable leakage to LBLOCA/rupture for each xLPR analysis case, limiting cases were identified for further review
- Performed further investigation for limiting cases with realizations exhibiting:
  - Minimum time between detectable leakage and rupture < 3 months, or
  - Nonzero occurrence of rupture with LRD
- All limiting cases were sensitivity studies, which were:
  - Defined to inform understanding of the base case results by investigating inputs known to have influence on xLPR results
  - Less constrained by maintaining fidelity to realistic plant conditions
- Some of these limiting cases were then re-run with:
  - Refined time-stepping
  - Updated input model parameters

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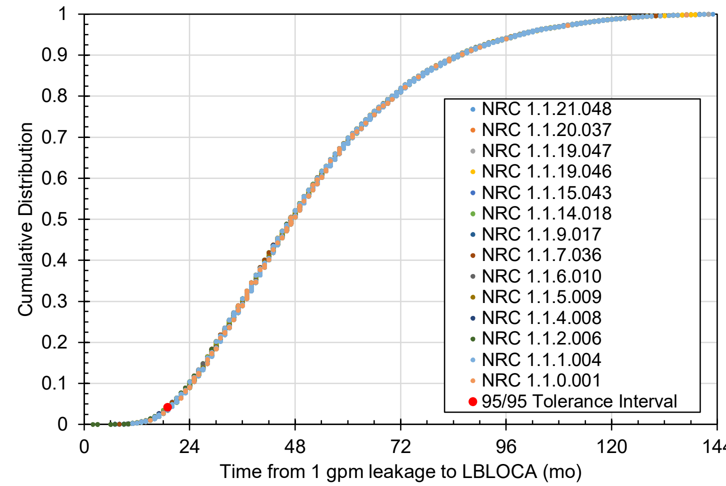
Summary of Time from Detectable Leakage to LBLOCA

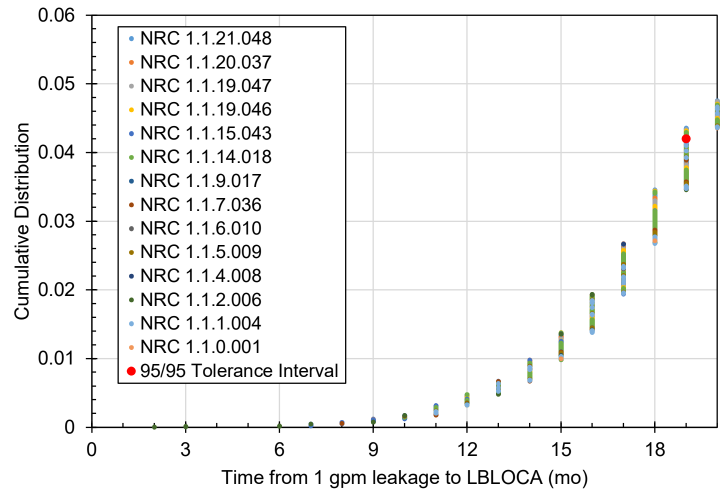
- Considers full population of cases with realizations resulting in LBLOCA
- Summary below reflects results including re-runs of cases (as noted on prior slide)

Component	Summary of Time from Detectable Leakage to LOCA
Reactor Vessel Outlet Nozzle (RVON)	Data for all realizations resulting in LBLOCA (~27,000 realizations) were evaluated further. [See following slides]
Reactor Vessel Inlet Nozzle (RVIN)	This component is at cold leg temperature. xLPR results showed no occurrence of crack, leak, LBLOCA, or rupture.
Reactor Coolant Pump Nozzle (RCP)	This component is at cold leg temperature. xLPR results in cases modeling flaw initiation showed no occurrence of leakage (and therefore no significant probability of LBLOCA). Cases modeling initial flaws did have ruptures, but the minimum time from detectable leakage to LBLOCA was 25 months.
Steam Generator Inlet Nozzle (SGIN)	All SGINs in the US PWR fleet have been mitigated, and xLPR results showed no leaks or ruptures in mitigated components. (Includes results from re-runs of two cases with a more realistic initial flaw size, based on suggestions in the xLPR Generalization Study)
Steam Generator Outlet Nozzle (SGON)	There are two realizations where the time from detectable leakage to LBLOCA is zero months. When ISI is credited, these scenarios are highly unlikely. [See following slides]

Time from Detectable Leakage to LBLOCA: RVON

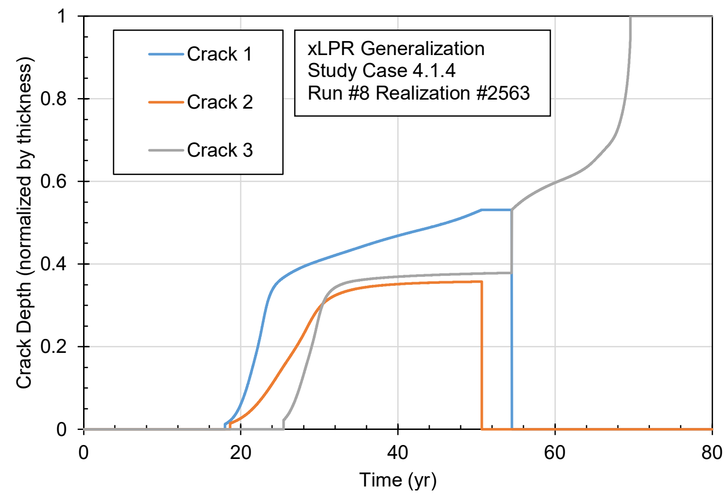
- The distribution of time from detectable leakage to LBLOCA for all ~27,000 realizations is shown in the upper right figure
- A 95/95 one-sided tolerance interval is defined such that *"there is a 95% probability that the constructed limit is less than 95% of the population of interest for the surveillance interval selected"*
- For this distribution of times, the 95/95 one-sided tolerance interval lower bound is 19 months
  - Calculated considering the distribution-free assurance-to-quality (A/Q) criterion described in Chapter 24 of NUREG-1475R1
- The lower tail of the distribution is shown in the lower right figure, depicting the data that would fall outside of the 95/95 one-sided tolerance interval lower bound
- Results shown do not credit LRD or ISI
  - No LBLOCAs are modeled to occur if LRD and ISI are credited

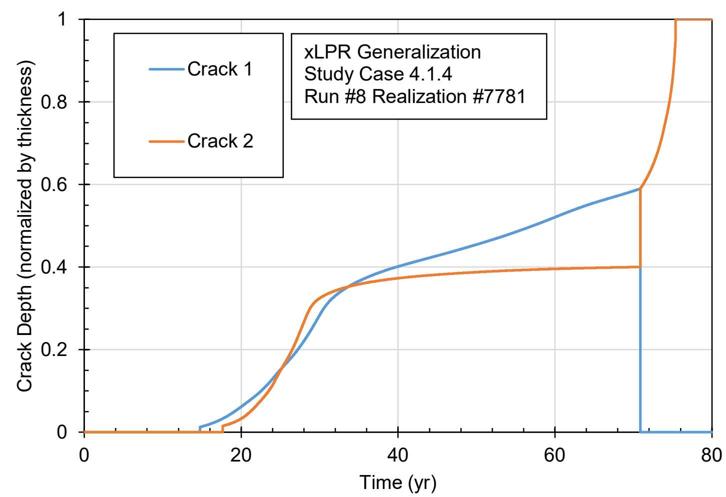




Time from Detectable Leakage to LBLOCA: SGON

- There is one case modeling an unmitigated SGON, xLPR Generalization Study Case 4.1.4
  - This case had 54 realizations out of 100,000 that resulted in LBLOCA
  - Of these, there are two realizations where the leak rate goes from <1 gpm to >5000 gpm in a single time step
    - Time from 1 gpm detectable leakage to LBLOCA is 0 months
- In both realizations, this is caused by multiple large flaws coalescing
  - Leads to extremely high leak rates once the flaw grows through-wall
- These scenarios are highly unlikely when ISI is credited
  - The probability of non-detection is on the order of 1E-5 or less
    - Flaws are present with depths exceeding 10% through-wall for multiple inspection intervals
  - When considering these two realizations among the population of 100,000 realizations and simulation time of 80 years, the annual occurrence of this scenario is on the order of 1E-12 yr^{-1}
- Only one US PWR has an unmitigated SGON





Conclusions

Conclusions

- When crediting ISI and LRD, occurrence of rupture results are on a similar order of magnitude as NUREG-1829 LOCA frequency estimates
  - The only nonzero results were for cases including modeling not representative of plant conditions and operations
  - For cases with zero ruptures w/ LRD, a 95% upper bound based on a one-sided confidence interval is considered for comparison
- For components relevant to the ALS, LBLOCA:
  - Occurs when not crediting ISI or LRD for RVONs
    - Distribution of times between detectable leakage and LBLOCA is characterized by a 95/95 one-sided tolerance interval lower bound of 19 months
    - Does not occur when crediting ISI and LRD
  - Is highly unlikely for unmitigated SGONs when crediting ISI
  - Does not occur for the RVIN, RCP, and mitigated SGINs
- These results demonstrate that there is sufficient time between detectable leakage and LBLOCA to shutdown the reactor and prevent LBLOCA
- The results further demonstrate the significant benefits of ISI and LRD
- MRP-480 includes applicability criteria for these conclusions

Traditional Deterministic LBB Process

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ACRS Meeting of the Fuels Materials, & Structures Subcommittee
June 25, 2024

Traditional Deterministic LBB Process

01 Postulated Through-Wall Crack

02 Leakage Crack Size Calculation

03 Critical Crack Size Calculation

04 Crack Size Comparison

Traditional Deterministic LBB Process

01 **Postulated Through-Wall Crack**

02 **Leakage Crack Size Calculation**

03 **Critical Crack Size Calculation**

04 **Crack Size Comparison**

Conservatism:

- Ignores the role of crack initiation
- Ignores surface crack growth
- Only utilizes idealized through-wall cracks (ignores transitioning through-wall cracks)

Conservatism:

- Ignores role of through-wall crack growth or progression
- Does not account for time
- Margin of 2 on the crack length or 1.4 on the stresses

Traditional Deterministic LBB Process

01 Postulated Through-Wall Crack

02 Leakage Crack Size Calculation

03 Critical Crack Size Calculation

04 Crack Size Comparison

Conservatism:

- Safety factor of 10 on leak rate to account for uncertainty
- Uses plant leakage detection system threshold (typically 1 gpm) when plants can detect changes in leak rate trends at far lower levels

Traditional Deterministic LBB Process

01
Postulated Through-Wall Crack

02
Leakage Crack Size Calculation

03
Critical Crack Size Calculation

04
Crack Size Comparison

Conservatism:

- Includes safety factors in limit load and elastic-plastic fracture mechanics analysis
- Conservatism in input selection
- Design basis versus operating basis calculations
- Ignores pipe-end restraint effects (which can reduce applied moments)

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Loss-of-Coolant-Accident-Induced FFRD with Leak-Before-Break Credit

Storm Kaufman, MPR

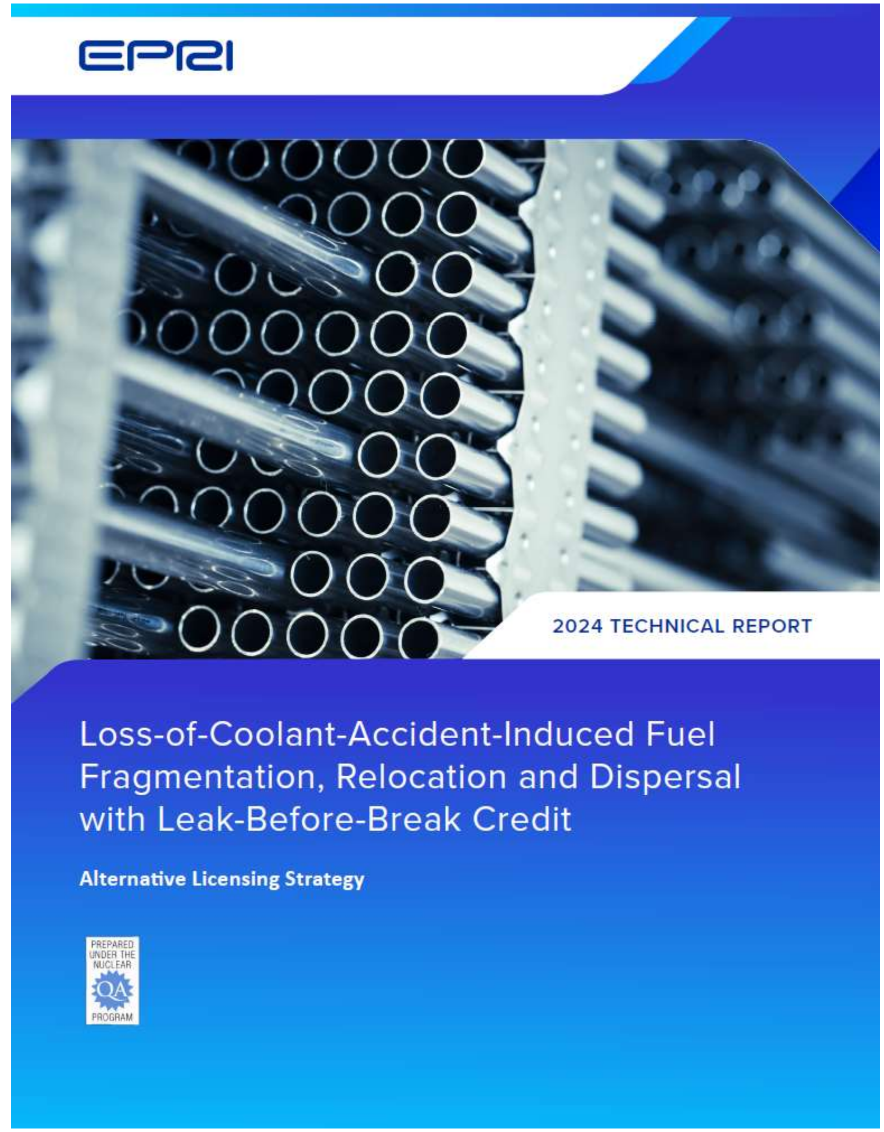
ACRS Meeting of the Fuels Materials, & Structures Subcommittee
June 25, 2024

Outline of Presentation

EPRI 3002028673 [ML24121A207]: *Loss-of-Coolant-Accident-Induced Fuel Fragmentation, Relocation and Dispersal with Leak-Before-Break Credit – Alternative Licensing Strategy*

Presentation outline:

- Overview: the Alternative Licensing Strategy (ALS)
  - Purpose
  - Advantages
  - Basis
  - Coverage of the reactor coolant system (RCS)
  - Regulations and guidance
- ALS Precedents
- Leak detection and response
- Non-piping assessment
- Summary



Overview:
Alternative Licensing Strategy (ALS)

Alternative Licensing Strategy Purpose

Purpose:

Provide technical justification to exclude consideration of fuel fragmentation, relocation, and dispersal (FFRD) from the core cooling evaluation for a loss of coolant accident (LOCA) in a pressurized water reactor (PWR) to allow increasing the fuel burnup limit.

Problem Statement

FFRD involves multiple phenomena potentially induced in high burnup (HBU) fuel by large-break (LB) LOCAs. The usual approach of validating methodology against empirical data does not support desired schedule.

Proposed Approach

Based on precedents and on existing regulations and guidance define a methodology that shows that:

1) Burst of clad of high burnup fuel is not credible for LB-LOCAs
2) Smaller LOCAs do not cause clad burst

Advantages of the ALS as Basis for Burnup Extension

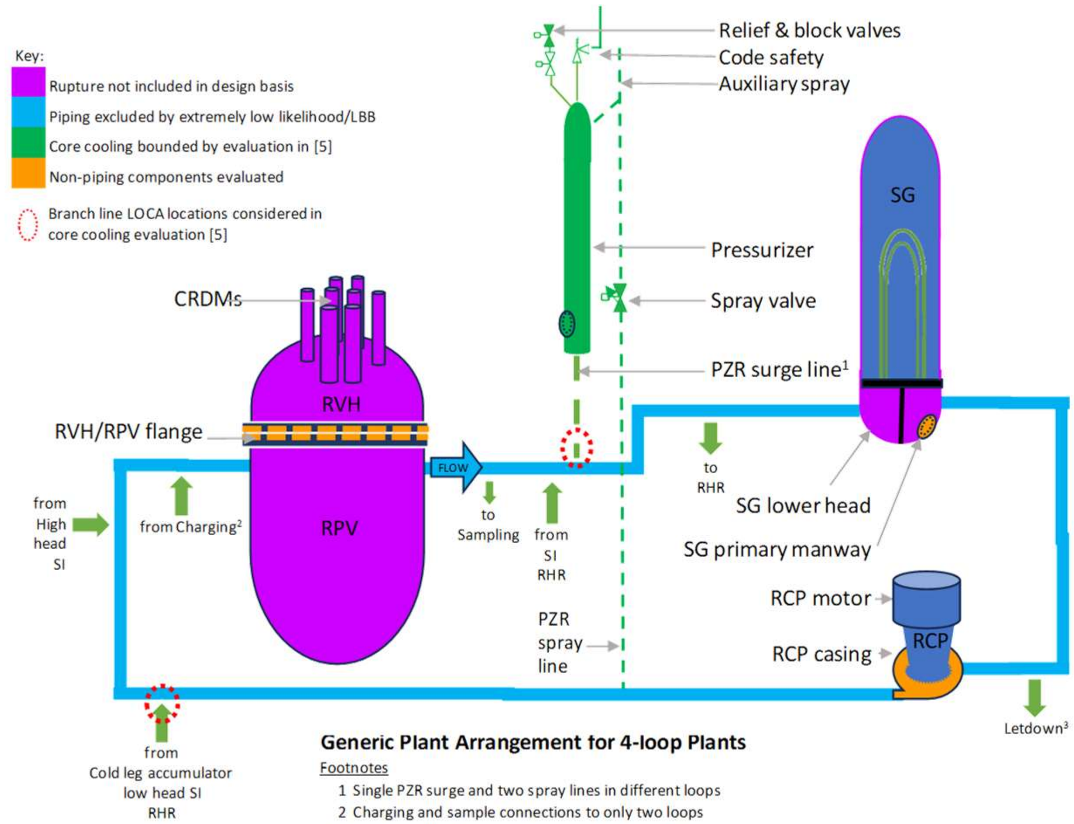
- Considers risk insights
- Minimizes licensee and NRC effort
  - Standard, generally applicable approach
  - Consistent with NRC Alternative 5 of regulatory basis document [ML23032A504] for increased enrichment rulemaking, but more limited
- Allows NRC to establish criteria now by avoiding need for
  - Additional experimental data
  - Qualification of analytical models of consequences (i.e., fuel dispersal)

Basis for the ALS

- LB-LOCA-induced FFRD not credible
  - Rupture of piping of RCS main loop extremely unlikely
    - Main loop piping already approved for LBB
    - NUREG-1829 frequency less than 10^{-6}/year threshold for screening
    - Supported by xLPR probabilistic fracture mechanics evaluation of piping
      - Extremely unlikely to 80-year plant life
      - Ample time (months) to detect precursor leakage and respond
    - Reactor coolant leakage is a focus area
      - Multiple means of detection by plant operating staff and others
      - Per Tech Specs (TS): shut down, cool down, and depressurization removes driving force needed to cause either LB-LOCA or fuel dispersal
- Smaller LOCAs, though more likely, shown to not cause clad burst
  - Fuel vendor LOCA analysis methodology and results in separate documents

ALS Methodology Coverage of RCS

- Piping:
  - Small/intermediate breaks: no HBU fuel clad burst based on vendor-specific LOCA analysis
  - Large piping (RCS main loop):
    - Extremely low probability of failure (NUREG-1829), as confirmed by xLPR evaluation
    - Ample time for operator recognition and response
- Non-piping – existing evaluations (e.g., license renewal/life extension) reviewed
  - ALS consistent with existing design basis
    - Screened
    - Bolted
    - Component bodies
    - Active component failures
  - No need for changes or further analyses



Generic Plant Arrangement for 4-loop Plants

Footnotes
1 Single PZR surge and two spray lines in different loops
2 Charging and sample connections to only two loops
3 Letdown from only one loop

Other notes
a RCIVs not shown, as they are not present in most plants
b Small lines not shown (e.g., ≤1-in. instrumentation)

Regulations & Guidance: Large-break (LB) LOCAs

- Reactor coolant pressure boundary (RCPB) integrity is priority
  - Ductile materials
  - Structural analysis per ASME Code Section III
  - Procedural constraints to avoid adverse conditions
  - Inservice inspection (ISI) to detect unexpected degradation in advance
  - Plant performance indicator
- Piping LB-LOCA
  - Set of conservative assumptions: single active failure, worst initial conditions, etc.
  - Defined in 10 CFR 50.46

ALS Methodology Precedents

LBB – Refined Guidance

53 FR 11311, April 6, 1988

> "Until recently, severe failure for piping has been defined as the instantaneous double-ended guillotine leak regardless of the standards applied to piping. Under leak-before break technology, it has become possible to exclude the double-ended guillotine break from the dynamic structural design basis because it is unrealistic and overly conservative in certain situations. Piping which meets NRC's acceptance criteria now need only postulate stipulated 'leakage cracks' as severe failure."

- SECY-88-325, 4/13/1989, 54 FR 18149, Published 5/2/89

Policy Statement on Additional Applications of Leak-Before-Break Technology

> "Additionally, other breaches in the fluid system boundary, such as failed manways or valve bonnets, must be examined to determine whether they control EQ profiles."

ALS

- Is consistent with modified LBB applicability established in 1988-89
  - Containment, ECCS, and EQ functional and performance requirements are unchanged
  - Non-piping LOCAs (e.g., bolted closures, pump casings) are assessed

LBB Applied to Exclude LOCA Effects

WCAP-16498-NP, March 2008

17x17 Next Generation Fuel (17x17 NGF) Reference Core Report

- "Currently, all Westinghouse designed US PWR primary coolant main loop piping has been excluded from consideration for dynamic effects associated with postulated pipe rupture…. all current fuel qualification analyses are performed on the basis of postulated rupture of branch lines connected to the primary coolant loop.
- "The primary success criteria for the baffle bolting program are the same as those documented in SRP Section 4.2 discussed above: i.e., no fuel fragmentation, 10 CFR 50.46 criteria continue to be met, and control rod insertability is maintained. These analyses were also based on LBB exclusion of the main coolant loop piping.
- "…only the branch line breaks not covered by LBB are considered in the licensing basis."

ALS

- Is consistent in use of LBB for NGF fuel in excluding effects of LB-LOCA from the design basis
  - No fuel fragmentation caused by blowdown hydraulic loads for all fuel vs. no fuel dispersal for HBU rods
  - 10 CFR 50.46 limits must be met after exclusion applied

LBB – Summary of Extended Applicability

Application Approved	Year	Action	Description	Timing of Effect	Technical Area	SSCs Affected
USI A-2	1986	Approved	DEGB loads could alter plant geometry	Blow down	Mechanical	RPV
Pipe Whip / Jet Impingement	1986	Approved	Remove of pipe whip restraints	Blow down	Mechanical	Piping supports
Control rod insertion	2008	Approved	Exclude LB-LOCA blowdown forces	Blow down	Mechanical Nuclear	Control rods
NGF structural	2008	Approved	No fuel fragmentation Meet 50.46 Control rod insertability	Blow down	Fuels Thermal Mechanical	Fuel
GSI-191 sump blockage	2010	Rejected	Eliminate debris generated by LB-LOCA	Post blow down	Many	ECCS: recirculation
Baffle-former-bolt breakage	1998	Approved	No fuel fragmentation Meet 50.46 Control rod insertability	Blow down	Fuels Thermal Mechanical	Core
ECCS cross-connect valve	2003-2007	Approved	Eliminate pipe whip that could fail both trains of ECCS	Post blow down	Mechanical	ECCS: low pressure injection
FFRD dispersal	2024	TBD	Not consider FFRD for excluded breaks	Prior to reflood	Fuels Thermal Mechanical	Fuel

ALS

- Considers past precedents for application of LBB
  - Exclusion of fuel dispersal from HBU fuel does not affect the requirement for ECCS to mitigate the full spectrum of break sizes and locations. It does eliminate the need to posit fuel fragment dispersal of the highest burnup rods during LOCAs.
  - The EPRI ALS explicitly considers other possible failures such as valve bonnets, flanges, manways that could be large enough to possibly cause FFRD.

Leak Detection and Response

Leakage Technical Specifications

- TS 3.4.13 Limiting Condition for Operation (LCO)
  - No more than 1 gpm unidentified RCS leakage
  - Operators would act *before* reaching 1 gpm
    - If not addressed, continued leakage will lead to annunciated alarm and implementing abnormal or emergency procedures

3.4 REACTOR COOLANT SYSTEM (RCS)

3.4.13 RCS Operational LEAKAGE

LCO 3.4.13 RCS operational LEAKAGE shall be limited to:

a. No pressure boundary LEAKAGE,

b. 1 gpm unidentified LEAKAGE,

c. 10 gpm identified LEAKAGE, and

d. 150 gallons per day primary to secondary LEAKAGE through any one steam generator (SG).

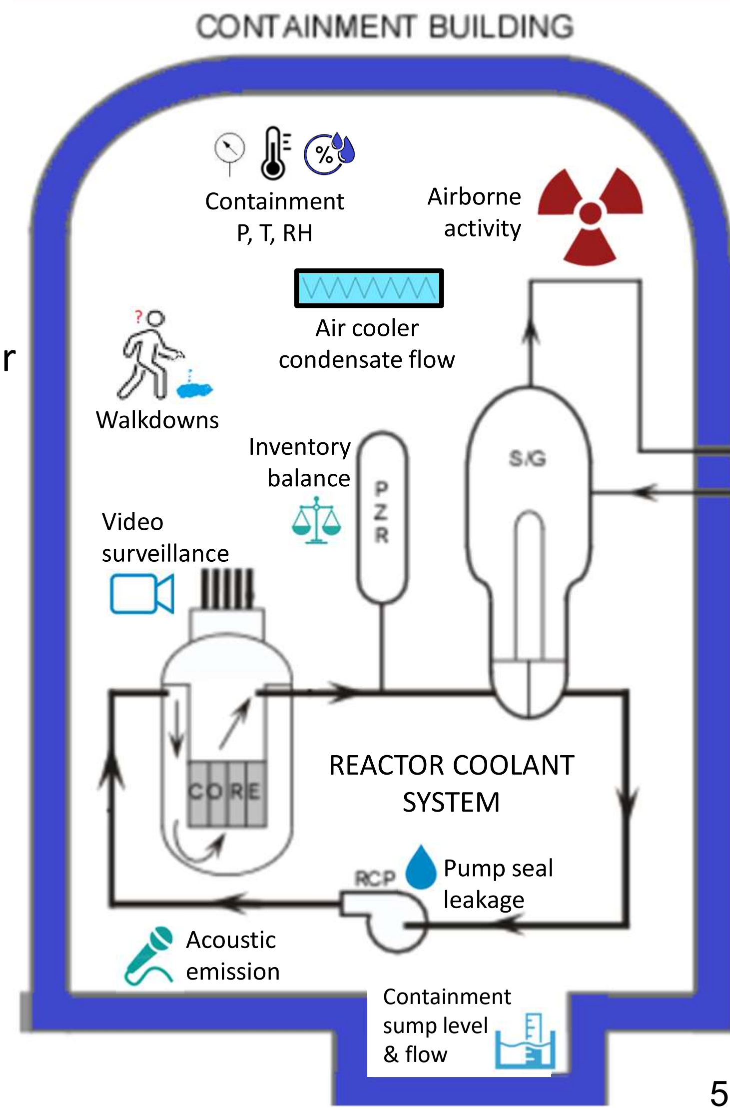
APPLICABILITY: MODES 1, 2, 3, and 4.

ACTIONS

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. RCS operational LEAKAGE not within limits for reasons other than pressure boundary LEAKAGE or primary to secondary LEAKAGE.	A.1 Reduce LEAKAGE to within limits.	4 hours
B. Required Action and associated Completion Time of Condition A not met. <u>OR</u> Pressure boundary LEAKAGE exists. <u>OR</u> Primary to secondary LEAKAGE not within limit.	B.1 Be in MODE 3. <u>AND</u> B.2 Be in MODE 5.	6 hours 36 hours

Leak Detection

- Regulatory Guide 1.45, “Guidance on Monitoring and Responding to Reactor Coolant System Leakage”*
  - Unidentified leak rate > 0.05 gpm detection/quantification
  - Response time (excluding transport time) of no more than 1 hour for leak rate of 1 gpm
  - Leakage Monitoring Parameters
    - Inventory balance
    - Containment sump level or flow
    - Airborne particulate activity
    - Air cooler condensate flow
    - Airborne gaseous activity
    - Containment pressure, temperature, humidity
    - Acoustic emission
    - Video surveillance
    - Pump seal leakage
    - Makeup flow rate
    - Walkdowns



*Most PWRs were licensed to and still apply Revision 0

RCS Unidentified Leakage Action Levels

- WCAP-16465-NP, “Standard RCS Leakage Action Levels and Response Guidelines for PWRs,” 9/06
  - Specifies three action level tiers based on RCS leak rate; lower tier triggers set to focus attention on detection of very small leaks
    - Tier 1:
      - One 7-day rolling average daily unidentified rate > 0.1 gpm
      - Nine consecutive daily unidentified rate > baseline mean
    - Tier 2:
      - Two consecutive daily unidentified rate > 0.15 gpm
      - Two of 3 daily unidentified rates > mean +2σ
      - 30-day total unidentified leakage > 5,000 gal. (0.116 gpm average over 30 days)
    - Tier 3:
      - One daily unidentified rate > 0.3 gpm or > mean +2σ
      - Long term (operating cycle) total unidentified leakage > 50,000 gal.
  - Summarizes operating experience
    - Detected as small as 0.01 gpm while operating
    - Only two RCS piping welds have had leaks
  - If annunciated alarm occurs, plant abnormal/emergency procedures apply

Non-piping Assessment

Assessment of Non-Piping Failures

- 10 CFR 50.46 requires core cooling analysis of range of LOCAs caused by piping failure
- The ALS also considers potential for non-piping failure to cause FFRD
  - Considered as part of life extension/license renewal
  - ALS consistent with existing design basis
  - No need for changes or further analyses identified

Operating Experience – Assess for Relevance

- Licensee Event Reports
  - No events identified that showed gaps in the ALS framework
  - Addressed by industry actions

Summary

Summary: Alternative Licensing Strategy

- Addresses LB-LOCA with potential to cause FFRD:
  - Extremely low likelihood of occurrence based on NUREG-1829
    - Below 10^{-6} per year, considering piping and component failures
    - Consistent with threshold for screening licensing basis events
- LBB for PWR RCS main loop piping already authorized
  - xLPR confirms extremely low likelihood
  - xLPR shows long time for operator detection/response before rupture
- Non-piping components
  - Design features preclude failures potentially leading to clad burst
- Core cooling analyses for LOCAs smaller than RCS main loop
  - No clad burst for HBU rods
- Operating experience
  - ALS considers risk insights
- Criteria for implementation at individual plants

ALS

- Is consistent with NRC precedents & guidance
  - No existing regulations nor guidance specifically for FFRD
  - PWR RCS main loop piping already approved for LBB
  - Exclude events with extremely low probability of failure such as reactor vessel asymmetric loading
  - LBB accepted to exclude fuel fragmentation caused by blowdown hydraulic forces for broken baffle bolts
  - IE rulemaking basis FFRD alternative

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Defense-in-Depth

Fred Smith
Sr. Technical Executive, EPRI

ACRS Meeting of the Fuels Materials, & Structures Subcommittee
June 25, 2024

LB-LOCA induced FFRD

- LB-LOCA induced FFRD has an extremely low likelihood of occurrence as supported by
  - NUREG-1829 expert elicitation
  - Confirmed by xLPR analysis probabilistic fracture mechanics analysis
  - LBB piping qualification process with deterministic fracture mechanics, supports a conclusion that the probability of piping rupture is extremely low
- Layers of Defense that support prevention of LB-LOCA
  - NSSS piping system design (e.g. material selection, geometry…)
  - NSSS piping system fabrication (Q/A, welding procedures, welder qualification, weld inspection…)
  - NSSS normal and abnormal operating procedures that limit piping loads
  - In-service Inspection
  - Leak Rate Detection
- ECCS system actuation mitigates LB-LOCA with conservative equipment performance assumptions

LB-LOCA Induced FFRD Defense Layers Performance Comparison

Barrier	Short Time between detectable leak rate and LOCA	Extended time between detectable leak rate and LOCA (ALS Approach)
NSSS Piping) System Design	Same	Same
NSSS Piping System Fabrication	Same	Same
Inservice Inspection	Same	Same
Leak Rate Detection	Less reliable operator response and LRD equipment response	Highly reliable operator response, indications of leakage increase with time and LRD equipment response accuracy increases
ECCS actuation	Performance impacted by some equipment performance variations	Plant is shutdown and cooled off before LB-LOCA occurs, removing motive force driving LB-LOCA. ECCS not relied upon, so equipment variations have no impact
Fuel Dispersal Consequence	Some dispersal may occur, impacting containment	No cladding rupture so no dispersal.

Defense-in-Depth for LB-LOCA induced FFRD in ALS

- Potential risk of ALS approach:
  - While it is highly unlikely, if an Operator failed to identify a detectable leak during initial surveillance
      - Plants monitors to threshold well below T/S limit
      - Various operator tools employed to highlight change in plan conditions
      - Surveillance must be repeated in 3 days or less
      - With operator shift changes other personnel will eventually perform this surveillance
      - Given the long time between detectable leakage and LB-LOCA the risk of repletely failing to detect the leak is negligible
    - Unit shutdown and cooled off, no motive force to cause pipe rupture
    - Even if LOCA could occur, limited/no impact on cladding integrity
  - Over reliance on xLPR results
    - Current results predict time between detectable leakage and LB-LOCA at 19 months
    - Results include appropriate treatment of uncertainties
    - ALS approach remains valid even if xLPR is off by factor of 10 (i.e. 1.9 months)
- Critical performance risks for LB-LOCA induced FFRD adequately addressed

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