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NUCLEAR REGULATORY COMMISSION

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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

(ACRS)

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SUBCOMMITTEE ON MATERIALS, METALLURGY

AND REACTOR FUELS

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WEDNESDAY, SEPTEMBER 21, 2011

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ROCKVILLE, MARYLAND

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

SUBCOMMITTEE MEMBERS PRESENT:

J. SAM ARMIJO, Chairman

SAID ABDEL-KHALIK

DENNIS C. BLEY

WILLIAM J. SHACK

JOHN D. SIEBER

GORDON R. SKILLMAN

JOHN W. STETKAR

NRC STAFF PRESENT:

CHRISTOPHER BROWN, Designated Federal Official

DAVID RUDLAND

JAY COLLINS

ALSO PRESENT:

MARGORIE ERICKSON

CRAIG HARRINGTON

C-O-N-T-E-N-T-S

P R O C E E D I N G S

8:30 a.m.

CHAIR ARMIJO: Good Morning. The meeting will now come to order. This is a meeting of the Materials, Metallurgy and Reactor Fuels Subcommittee. I am Sam Armijo, chairman of the Subcommittee. ACRS members in attendance are Dennis Bley, John Stetkar, Jack Sieber, Said Abdul-Khalik, Dick Skillman, and Bill Shack. Christopher Brown of the ACRS staff is the designated federal official for this meeting.

The purpose of this subcommittee meeting is to receive a briefing on the Extremely Low Probability of Rupture, xLPR, program. We will hear presentations from representatives of the Office of Nuclear Regulatory Research, and Nuclear Regulatory Regulation. In addition, the Electric Power Research Institute, ERPI, has requested time to make comments on the staff's work. The subcommittee will gather information, analyze relevant issues and facts, and formulate proposed positions and actions as appropriate for deliberation by the whole committee.

The rules for participation in today's meeting were announced as part of the notice of this meeting, previously published in the Federal Register on September 8, 2011. A transcript of the meeting is being kept and will be made available as stated in the Federal Register notice; therefore, we request that participants in this meeting use the microphones located throughout the meeting room when addressing the subcommittee. Participants should first identify themselves and speak with sufficient clarity and volume so that they can be readily heard. We also ask that you silence all iPhones and other electronic devices. The full committee meeting for this topic is scheduled for November 3 or 4, I don't think it's nailed down yet Chris, we're still working on that. We will now proceed with the meeting; I call on David Rudland with the Office of Research to make opening remarks and begin the--

MR. RUDLAND: Good morning everyone, as I was introduced my name is Dave Rudland and I am from the Office of Research, Division of Engineering and Component Integrity Branch, and I'm a senior materials engineer there and the engineer in charge of this xLPR project. I'd like to introduce, sitting next to me is Jay Collins from NRR DCI, who will be making some remarks on the regulatory portions of this project. Also, sitting over on that side is Craig Harrington from EPRI, who will make some statements towards the end of the meeting on the objectives that EPRI may have. And also on this side over here I have Mike Case, who is my division director.

As Sam put it out, the purpose of this meeting is to provide a briefing to the subcommittee on materials on this ongoing program, this xLPR program, and our objectives for today is to come to a common understanding of what we're doing in xLPR, why we're doing it, what the priorities are, what we plan to--how we plan to move forward, to receive your review and your advice, and hopefully after the main committee meeting, receive a letter talking about the efficacy of the project with respect to the safety goals. One of the other things that I request and the project team requests is, because this program is a very ongoing, complex program, it'd be nice if we could have ACRS review and advice on an annual basis once a year or so as we move forward to make sure that we're all aligned with the direction that we're heading.

What I'm going to be talking about today with myself and Jay, we'll start off first talking about the regulatory need for xLPR. I'm going to go into, which lead to a development of a user need request, I'm going to talk about RAS' response to that user need, and that developed into the xLPR project plan. I'll then go into to some details about the technical stuff that's in Version 1 of xLPR. We'll go into the individual deterministic modules and how we tied that together in a probabilistic sense. What lead from Version 1 was a pile of study, I'm going to talk about its goals and results also, and then we'll close the morning presentations with our plans as we move forward to the Version 2 of the code.

CHAIR ARMIJO: Dave, before you go, I just got to get this off my chest.

MR. RUDLAND: Okay.

CHAIR ARMIJO: Why did you pick the term, the label, Extremely Low Probability of Rupture as opposed to Probability of Rupture? It comes across to me that you've predetermined the answer, and you're just going to do a lot of work, then demonstrate the --

MR. RUDLAND: We've had this--

CHAIR ARMIJO: It can't be the first time that you've heard that; it just seems like it's-- doesn't come across very well.

MR. RUDLAND: We had this discussion with several folks in the determination of the name for this project, and it was one of those things that we were trying to come up with a catchy name and one of the objectives was to meet--was try to assess some stuff that's going on in GDC-4 which asked for a extremely low probability of rupture. And so it just kind of flowed into that as the name of the code, but it's not meant to predetermine anything, it's meant to be more of a tool that can calculate it than it is to--

CHAIR ARMIJO: Yes, it seems this may be the out result of your work--

MR. RUDLAND: That's right.

CHAIR ARMIJO: --but it's not predetermined and when the label just kind of sets wrong.

MR. RUDLAND: Yes, and as you'll see from the title space, some of the calculations we did aren't extremely low.

CHAIR ARMIJO: And that's my second question. In this, what is order of magnitude? What do you consider as an extremely low probability of rupture?

MR. RUDLAND: One of the topics that we're tackling as a group is what is an allowable or acceptable value from the regulatory point of view of extremely low probability of rupture and you know, we juggle around with what that value is, and at this point, it's really not determined. If you look at some of the work that was done in the transition break size, we're talking orders of magnitude of times ten to the minus six kind of numbers. So we're shooting for values where we have the ability to calculate things at least a couple of orders magnitude lower than that.

CHAIR ARMIJO: Okay.

MR. RUDLAND: Within a reasonable amount of run time.

CHAIR ARMIJO: All right. thank you. I feel better now.

MEMBER SHACK: Just to correct and defend you a little bit, one of the things is of course you have to set the code up is so that you can calculate probabilities that low, which does sort of govern the way that you approach problems.

MR. RUDLAND: And so as we put this thing together, we always kept that in mind, and the fact that you know, we don't want a code that's going to run for 17 months to give us a number, right? We want a reasonable amount of run time to give us those kinds of relatively low values. I mean 10 to the minus 25 is not something that's seem right. You know, the point that we're trying to make in this thing.

CHAIR ARMIJO: Right. But even one more on that side as you said, you're linked to GDC-4 so it's really--the goal of this it would seem is to show that we're meeting GDC-4 drive toward meeting.

MR. RUDLAND: Right, and the problem that we have with GDC-4 is that it's not very specific; it just uses those general terms. And so there needs to be discussions from the regulator's side to determine what's allowable for that kind of thing. And I think Jay will touch on that during his presentation.

MR. COLLINS: Greetings, I'm Jay Collins, I'm a senior materials engineer in the Piping and NDE branch in the Division of Component Integrity, which actually is going to be put back into the Division of Engineering here not too shortly, we're recombining back from whence we came; a little bit of rearrangement within the Office of NRR. What I'm going to talk about--okay so what we're going to do for this particular presentation is provide basic information on the need we felt for xLPR from the regulatory side, and kind of a framework for what our thoughts were as far as what this was going forward to the user need which we generated and provided to research and asked them to address certain issues. We'll go well back into the background of this issue and things that we've worked on as we've gone forward as the double ended guillotine break postulated and all high industry systems or piping and design, ECS containment, required pipe whip restraints and jet impingement shields to be installed, and leak before break, the terminology was developed to formalize an SRP of 3.6.3 to give a qualitative screening to review to establish candidate systems in a quantitative evaluation for flaw tolerance. And it was weighed to allow for flaw tolerance rather than a flawed calculation that addressed an active degradation mechanism which we later developed through PWSCC, or primary water stress corrosion cracking.

GDC-4 was modified to allow dynamic effects and to be excluded from the design basis when analysis was proved by the NRC staff to demonstrate once again, that extremely low probability of rupture. I guess kind of our take on the names, probability of rupture was putting that extremely low as far as the project name at least in the naming, seemed to give us a little bit more comfort as to the goal of what we wanted to get to, rather than saying what is the end product for this end of the line. So all PWRs, pressurized water reactors, have leak before break approvals in the reactor coolant loop piping. Some

PWRs have leak before break in reactor coolant loop branch piping, and which brings us back through primary water stress corrosion cracking as an active degradation mechanism. An actual leakage starting in 1993 and then in 2000.

CHAIR ARMIJO: Jay, before you go too far, why not IGSCC and BWRs as part of this research?

MR. COLLINS: Through the development of leak before break that was identified, it comes to a point of timeliness and where we are now with the approvals of the leak before breaks and the removement of those--can I go back? The removements of those pipe what percentage of those impingement shields that were installed for the PWRs, and where we are as far as identification of PWSCC as an active degradation mechanism now. And in addressing these issues currently and looking at how we can address PWSCC as an active degradation mechanism now, it has taken a different approach than what was taking a look at IGSCC in the past for BWRs, and that's about the best answer I can give you.

CHAIR ARMIJO: But isn't the methodology that you're going to develop equally applicable if you have the data on crack nucleation growth?

MR. COLLINS: Yes.

CHAIR ARMIJO: Okay, I get you.

MR. RUDLAND: To support what Jay said, there were no PWRs approved for LBBs because--

MEMBER SHACK: No BWRs.

MR. RUDLAND: I'm sorry, BWRs. I'm sorry. BWRs, because of IGSCC, so there are no systems out there now that are in conflict, but you're absolutely right that the mechanisms are the same, the growth laws are similar--

CHAIR ARMIJO: Just very different.

MR. RUDLAND: Yes. So you see as we talk about this, and we go into Version 2, it's a natural progression of how we're going to move forward with this scope.

CHAIR ARMIJO: But your focus right now initially is entirely on PWSCC?

MR. RUDLAND: Because that's the regulatory--the need.

CHAIR ARMIJO: Need, right.

MR. COLLINS: Right, and it's PWSC--primary water stress corrosion cracking as an active degradation mechanism for these plants which have already removed these items, and now the consideration for how to address that problem or make the determination that we need to reverse path on this and go back to those installations.

MEMBER SIEBER: I suspect that some of the logic is that you can detect pretty low levels of leakage in PWRs that I would imagine is more difficult in BWRs?

CHAIR ARMIJO: I don't know.

MEMBER SHACK: It was one in five, but I think the thing is you had an active degradation mechanism which in many BWRs, affects every weld in the plant; at least here, we're talking about a limited number of welds among other things.

MEMBER SIEBER: Okay, let's move on.

MR. COLLINS: So, going to the third bullet here, operating experience with PWSCC was contrary to the assumptions of the original leak before break in that an active degradation mechanism wasn't allowed to be used with the SRP methodology. So we had to come up with what we were looking at as far as a methodology to address PWSCC on its own separate of the SRP, and as we looked at the active degradation mechanism, we had inspection requirements which were upgraded and that was initially through an industry program, MRP-139, which was a long term reinspection program for dissimilar metal butt welds and nickel alloy welds within these systems, which included the leak before break lines, and recently we've completed rule making to mandate the use of ASME Code Case N-770-1, which is--that was done in June 21, 2011, and this is a regulatory--now a regulatory program within 10 CFR 50.55(a) to require the use of an ASME Code Case agreed long term inspection program to address these needs more based on a basis of ensuring meeting code allowables rather than getting to the point of unnecessary point of rupture.

As well, we've had to address ideas of PWSCC different types of mitigation which have come along through this process, through the use of mechanical stress improvement, weld overlays, weld inlays and onlays being on the inside of the pipe. Each of these items trying to address PWSCC as an active degradation mechanism when it no longer--the question of when it no longer becomes active, how it needs to be addressed, our inspection programs capture each one of these elements, and still give us that reliable confidence at this point that we are still adequate for justification for leak before break. When we looked back at the operating experience to be able to justify our position, We're still looking at the amount of circumferential cracking, it's the one that we had the Wolf Creek incident, which our--I'll not call it an incident, that's a poor choice of language--but the identification of indications at Wolf Creek, which did adjust our schedule. But since then, significant circumferential cracking hasn't been identified, and our inspection basis has seemed to be effective. We're identifying these items before they're going to a point of leakage; we do have significant baseline inspections that were performed under MRP-139 and are going to be re-performed under Code Case N-770, and we're following our latest inspection qualification guidelines to ensure effective inspections are being performed.

So once, again getting back to the point of leak before break and what we need to address QDC-4, 3.6.3 does not allow or account for active degradation, and those certain mitigation techniques as we've identified as they've come along, MSIP, full structure weld overlay, the classification of when is it an active degradation mechanism, those as well were giving us difficulties in how to assess under this current program. 3.6.3 is deterministic, yet GDC-4 is looking for a probabilistic answer; we are looking that extremely low probability of leakage, and using that flawed stability approach, while an effective tool to be able to demonstrate it for one set of circumstances, wasn't meeting what we needed for all sets of circumstances and we needed something that was more flexible. We could see the problems in the past of developing probabilistic codes that focused only on one issue, and what we were finding was we needed something that would be more adaptable, more capable of handling various problems, not only in--for this leak before break application but to look into reactor vessel heads, upper heads, lower heads, instrument loop piping that was coming off as well. These were all items which we could foresee in the future which we would need regulatory assistance with and some type of effective probabilistic tool.

So, we wanted to develop this probabilistic assessment tool that can be used to directly demonstrate compliance with 10 CFR 50.55(a) and GDC-4. What we were looking for--and that's I guess where we are at the start, and I'm going to talk in my presentation about necessarily my desires for the future, but we do have a starting point which Dave is going to explain where we are in the process. So all of the little pieces that I'm going to talk about as far as our desires for the future for what this code can do are not necessarily being worked on at this particular point, but the way he's creating this particular probabilistic code will allow us to put in these additional modules, will allow us the flexibility to have--to address these other problems.

So it's comprehensive with respect to known challenges, it's going to be vetted. The problem that we continuously have with some codes that come in for case specific items that are short, quick turnaround projects to address an issue is we begin to get into the QA process. What was done to assess the uncertainties? How are we ensuring that each part of that is being addressed properly? Through this program that is developed through xLPR, that vetting process is developed from stage one; the NRC is a participant from stage one, we have that confidence level from the very beginning. Flexible, once again I'm going to want this to do a number of things as we continue on and as it gets developed. I'm going to see it as a very useful tool on the regulatory side to provide me that number, to provide me that answer, and I'll go into a few examples of what I'm talking about. And then adapatable to, if I have a new degradation mechanism, is there a way to install that new program within there and through this modularization it's going to have those options available.

MEMBER BLEY: Since you mentioned

uncertainly, quite a few years ago, when the work was just beginning on looking at PTS again, Nathan Siu and some other researchers put together a way to look broadly at sources of uncertainly and characterize them; is that work that was done then being factored into the way you guys are thinking about uncertainty?

MR. RUDLAND: Yes, a lot of the way that we deal with uncertainty is driven by the lessons that we learned through the PTS effort.

MEMBER BLEY: Okay.

MR. RUDLAND: And so we're using all of that knowledge base to help guide us, yes. So we'll talk about some of that when we get into some of the details.

MR. COLLINS: So in talking about the modular process and how these items are going to be input into the code, and the--some of the uncertainties identified for all the different items as far as crack behavior, material properties, loads, inspection and leak rate for once we determine long term inspection frequencies and how we're going to address what we're--what is necessary to actually maintain that extreme--or to achieve that goal of extremely low probability of rupture, all get fed into the Monte Carlo stochastic test, and then goes to a leak--time to leak or time to rupture. And our uncertainties, of course, with all of these items being equal at this point, or having certain greater uncertainties, we still have a large uncertainty at that point. But what we'll be able to do is look back at each particular module and try to focus on what is our--through sensitivity studies, look in each particular item and find what is the problem that we need to focus our research on, and give us a better opportunity to help improve our knowledge in that certain area, and that will hopefully give us a better leak per rupture annum, rather than being worried about all of the items and trying to spend our research dollars on each of them. We can focus better on crack growth rates rather than say, be as concerned about crack initiation. Or perhaps it's the other way around; we need to be more worried about crack initiation or the time to develop cracks rather than worrying about crack growth rates.

MEMBER BLEY: Jay, there was something I didn't see in your goals, and I'm reflecting on--this could turn into a fairly large code by the time you're done trying to look at all these things. Things we've seen with other large codes, and in particular when the PTS work was going on, a code down at Oak Ridge they were looking at. Two aspects of that I wonder if you're trying to build in, and one is to be able to understand how results change and what inside the code is driving them as you go from case to case, and the other is how you can gain some confidence that the whole package is actually doing what you think it's trying to do.

MR. RUDLAND: Well, to answer the first part of your question, the struggle between what's driving the problem can be flushed out by doing sensitivity studies, and especially the type of sensitivity studies that are run where in essence, you hold one parameter--hold all the parameters constant and vary one parameter, and then look at how the uncertainty is relative to holding another--holding all the other parameters constant--

MEMBER BLEY: And theoretically, that makes sense if I'm doing hand calcs. Sometimes within a large code--

MR. RUDLAND: That's right.

MEMBER BLEY: --things pop out that aren't quite the way, you know, the theory would have expected them.

MR. RUDLAND: Right, and so what we do is we have a multitude of different types of sensitivity types of packages that we can use to analyze the results to see whether or not what's driving it really is what's driving the problem. I mean, for the studies that we've done so far, we've done very limited types of those kinds of studies, because right now we're only passing through the feasibility stage. But that definitely needs to be investigated further, and that's the step--

MEMBER BLEY: Yes, that's an engineer's approach, and that's the way I'd look at it. I know in the last 10 to 15 years, there's been a lot of research and how codes are put together and how you can test them and testing them with automated tools and that sort of thing. Are you looking at those? Is some of that going to be built in so that you pull into the code ways to have confidence that it's doing what you--

MR. RUDLAND: Yes, you know the tools that are used for sensitivity studies may or may not. I don't think right now there are plans to build those in directly to the code, because they're more of a post-processing kind of a choice that needs to be made at the time. As we move forward--

MEMBER BLEY: I'm not an expert in this area, but I'm suggesting you think about something more than sensitivity cases to look at the results. I'm talking about ways you build into the design of the code--

MR. RUDLAND: Of course.

MEMBER BLEY: Confidence in its capability, and there's some world class experts around on that--

MR. RUDLAND: Yes, definitely. I think that's something that--

MEMBER BLEY: Otherwise, we'll have the same questions we always have, is how do we know this thing is doing the right thing?

MR. RUDLAND: Right. And that brings another--to another point, your second comment about how do we know it's doing the right thing. I mean, we have to go through detailed V&V efforts, right, validation and verification efforts, to determine it's actually doing what I think that it's doing, for one thing, and that the numbers that I'm getting are reasonable. And so that can be a couple-tiered approach where we haven't gotten to the details yet, but these different modules can be V&V'd themselves to determine that they're giving off what they should be giving off, they're coded correctly, and the methodologies and technologies are properly incorporated, but that still doesn't allow you to be able to validate an extremely low probability when there's no operating experience for that kind of thing, right?

So you have to go with engineering judgment on how these results and the deterministic steps are giving you these kinds of probabilities, and does that make that kind of sense, does it make sense that you're doing. But you can't really validate times 10 to the minus seven probability of ruptures when there's no operating experience in numbers like that to be able to validate against.

MEMBER BLEY: Okay.

CHAIR ARMIJO: I have a question. This is a good chart, but what's missing on that chart that worries me is the environmental variability. The presumption I get from reading your material is that all PWR environments are equally aggressive, and maybe I missed a point, but I think there's an enormous amount of variability, whether it's start up, shut down, dead legs, all sorts of things. Is that covered for the other models and inputs where you're going to address those variabilities?

MR RUDLAND: Well you know, the variability and the water chemistry and things like that affect, you know, things like the cracking behavior, right? So the way the crack progresses is directly related to how the environment is reacting against the material, so--

CHAIR ARMIJO: But that's a result of cracking occurring, but your extremely low probability wouldn't change, or it would be the same for all PWRs, and my guess is there's certain environments and certain PWRs that are more aggressive than others.

MR. RUDLAND: That's right. I mean, that's right--

CHAIR ARMIJO: And how can you do that up front? How can you assess that up front?

MR. RUDLAND: We have to pool in the variability on those particular parameters, either by the in-reactor, or within the fleet types of uncertainties, depending on how you're using the code, right?

CHAIR ARMIJO: I guess what I'm looking for, is there going to be a water chemistry module that addresses variability in the water chemistries, which then triggers crack nucleation and crack growth?

MR. RUDLAND: No, there's nothing--right now, there's not a plan for an individual water chemistry module. The effects of the water chemistry are built into crack initiation and the crack growth modules and leak rate modules and things like that. It's picked up in the individual mechanistic models within the code right now.

MR. COLLINS: But there may become certain mitigation techniques which are looked at as far as hydrogen water chemistry or use of zinc, and as--if necessary, if we can't include it within another module as identified, then we would have the ability to add a module then, that could address that mitigation technique. As he'll talk about when he goes into the user need, certain material testing that we do have going on right now is looking at certain aspects of some of those items, not so much the zinc, more the hydrogen at this point. But as far as developing those modules and what we're doing, I'm definitely going to leave that to Dave to give you an explanation as far as what those are. But as far as the concept or the idea, I think the versatility of this tool will still allow us to address those as needed, and if they're identified as a concern.

I also believe that in any one of these processes, and if the uncertainty is still large, we still get to transfer that along, and we still, once we determine what's a bounding number for a high confidence value in our final product, we'll still be able to address that and still have good confidence in what we're looking at, even if we do have certain uncertainties. But it will still allow us to go back and look at those particular items that we feel through the sensitivities phase that we can. We--I mean, it may give us that higher number, which may cause us to have a problem, but at least we've identified that with the QA process as we go forward.

CHAIR ARMIJO: I'll wait and listen some more. Thank you.

MR. COLLINS: Thank you.

MEMBER SIEBER: I presume that built into all of this is a fact that all the welds, all the alloys compositions and everything are--meets the standard criteria as opposed to individual differences that may occur in one plant and not other plants? For example, the fact that weld geometry or wrong materials, how do you deal with that, other than try to convince the licensee to make sure all these welds were made the way they were supposed to be made?

MR. RUDLAND: Right now, the way that we structure the codes, it allows the user to input either within weld or weld-to-weld variabilities of geoproperties, of the crack growth parameters and things like that. So you can account for those kinds of things within that--in that framework of uncertainty.

MEMBER SIEBER: Okay, so there will be an individual number for each plant, and for each weld, right?

MR. RUDLAND: That's right. There will be a variability within each weld, and there will be a variability amongst the welds that are being considered in the analysis.

MEMBER SIEBER: Yes, if I scratch around in my memory, it seems to me that all the instances of pipe weld defects came from some kind of fabrication error, and if you don't account for that explicitly in this model, to me the model doesn't mean as much as it could.

MR. RUDLAND: Well, it's not only that, it's also the stress fields that are going on within the weld--

MEMBER SIEBER: That's right.

MR. RUDLAND: --you know, and there's certain repair issues, and those things can be accounted for.

MEMBER SIEBER: You're going to into that a little--

MR. RUDLAND: Yes, we'll go into that in a little more detail.

MEMBER SIEBER: --more detail a little later? Thank you. Appreciate it.

CHAIR ARMIJO: Someone here is a member of the staff?

MS. ERICKSON: Marjorie Erickson, I'm a member of the public.

MEMBER STETKAR: You have to speak at the microphone, please.

CHAIR ARMIJO: Well, normally Marjorie, we'd like to have the presentation, and then there'll be opportunities for the--

MS. ERICKSON: That's what I'm suggesting, is I think a lot of these questions will be answered if you--if we could get into the details, because Dave's got a great program that he's put together.

CHAIR ARMIJO: Well thank you. This is our normal practice, but we appreciate your comment. But let's just go on. This is a briefing for the Subcommittee; we want to get into details. We often interrupt, but we manage to get through. So don't worry.

MEMBER ABDEL-KHALIK: Can we go back to the previous slide, please? I can understand conceptually this process where you have many inputs, and what the outputs are supposed to do. Some of the linkage is empirical, some of it is mechanistic, and some of it is probabilistic. Could you highlight for me which of these is empirical?

MR. RUDLAND: Can you hold that, and as I go on to talk about the details, I'll talk about each of these things in specifics of each of the modules, and how we develop those modules, if that's okay. I mean, we can go through it now, or I can just wait--

MEMBER ABDEL-KHALIK: No, no, no. We'll wait.

MR. RUDLAND: Okay.

MEMBER ABDEL-KHALIK: We'll wait.

MR. RUDLAND: Greatly appreciate that.

MR. COLLINS: And I have to apologize, I guess. These were just general overview slides as far as--

MEMBER ABDEL-KHALIK: Understood.

MR. COLLINS: --to show you what--kind of the idea of what NRR was looking for out of a code and try to--

MEMBER ABDEL-KHALIK: You know, ultimately, we're interested in a robust methodology, and the robustness of the methodology depends on the degree of empiricism that goes into the development of that methodology, and that's why I wanted to know what empiricism goes into this picture?

MR. RUDLAND: It was our goal to stay away from that as much as we possibly could, and get the best estimate mechanistic models that we could.

MEMBER ABDEL-KHALIK: Okay.

MR. RUDLAND: And we tried to meet that in every case where it was not impossible, and there are certain cases that in my mind are kind of impossible to stay away from empiricism, so--and we'll talk about those here in a little bit.

MEMBER ABDEL-KHALIK: Okay.

MR. COLLINS: Any other questions on this slide before I go on? Okay. So as far as, once again, NRR's use of what is going to be this code, in this case we're looking at dissimilar metal weld and the effects of--trying to look at the effectiveness of a mitigation technique, in this case, a full structural weld overlay, and looking at the failure frequency versus the probability density, and once again that uncertainty, and the weld overlay being a number of weld beads over that weld that is identified there. And then being able to say what that affect is, or what that change in risk is as to the effectiveness of putting on that weld overlay, and being able to still look at what is the value of an extremely low probability of risk when we determine that. And being able to qualify those numbers I think is going to be a very effective tool for us.

Going the other way, seeing what the change in risk might be for a relief request type like situation when they come into the NRC, as far as for those inspection programs which we've developed, and being able to use the tool in the opposite direction is a longer term goal that we be able to use this for, to be able to say for a leak before break-qualified weld, a change in inspection frequency is requested due to pulling the core barrel in order to do the inspection. And the request is to go in an extra outage, go to the next outage in order to line that up, due to the hardship of pulling the information beforehand. We'd be able to use a tool such as this to provide us that extra confidence that whatever we've determined through a flaw analysis type technique is also good in a probabilistic methodology.

So that gets me to my final slide, and I guess the items which NRR is really looking for out of this, and that's the modular code to address the issues for which we're going to have for the risk of pressure boundary integrity failure, initially focusing on xLPR to solve NRR's current need, which is really leak before break, and that's what is going to be the main focus of it; piping, dissimilar metal welds and these actual items. I know I've talked about a lot of other things, but once again, our long-term goals and the flexibility that we want built initially within the program, so we don't have reinvent the wheel every time we need a new--have a new tweaker to the process, which he's looking forward to get to do for me.

Thus, the effectiveness of each mitigation technique that we're going to have, and coming along an interesting one is peening, which is going to be an interesting development for us as far as just a surface affect. Hopefully in the longer term, we'll be able to use this for that as well. Assist in the validation of long-term inspection frequencies for all practical and pressure boundary components. So this gets to really where I'm from. I've developed or worked in developing the long-term inspection programs for the upper heads, the dissimilar metal welds; where we are within those programs and looking at the probability of failure rather than just going for more of a deterministic method, and which we've been generally doing with some probabilistic to support, but usually that probabilistic is narrower focused to a certain area.

This tool we hope to be able to give us a more vetted, a more QAed approach to help that validation of those programs as we go forward, still using everything else that we are using currently, the operating experience and looking at the various items. And then the final bullet there is just assisting in assessing relief requests that we have from industry, which we still currently have. I mean, the requirements are built usually on generically for the fleet, have conservative basis, when it gets to a plant-specific response, sometimes there's an opportunity to give some leeway, depending on hardship or identification of issues. Having this tool as an available back up is going to be a very effective use of begin able to clearly say what is that change in risk.

And that is my presentation as far as what we're looking for in NRR to be able to use this tool as we go forward. And I kind of echo the item of Dave's request of interaction from the ACRS to help insure that we are getting to those goals, and we are going to be able to use an effective tool that's going to be effective throughout--over the next 20 years as far as still being able to plug in and plug out.

CHAIR ARMIJO: What do you do to assess relief requests today?

MR. COLLINS: For relief requests today, typically we do do a more deterministic analysis as far as we're looking at as far as a change in our risk assessment. So as far as a relief request that came in for a certain plant requested, because their dissimilar metal weld was in a sandbox, hard to get to, we have visual inspections, which are only looking for the possibility of leakage in a really a defense in depth mechanism for volumetric inspections, looking for cracks on the pipe. But they had a difficulty in doing this visual inspection. For plants, we give them the option of doing the volumetric instead, but this plant chose to submit in a flaw analysis, which would identify--which would allow them to run a certain period without having to perform either the visual or the volumetric inspection technique.

So we looked at one, the hardship for what is necessary to do the visual inspection technique versus the change in safety as far as allowing that additional frequency, and mainly through that we're doing a deterministic flaw analysis to say okay, so you're going to go this long without performing an inspection. We did do it heavily conservative in this particular thing; we said you're getting no value at all for a few items, so we do get into conservatisms in that nature. But in this particular case, we had a difficulty through the flaw analysis, and we identified a problem which required us to shorten the amount of time in which they can have that relief request for.

Through the use of this tool, we could more assess the risk by looking at the overall risk change, but it's still--I think it's not going to reduce that deterministic affect as well that's going to be in there to show that the no flaw would grow to a 75% through-wall and meet ASME code limits. And that's I guess what I'm trying to get to as far as the flaw analysis technique.

MR. RUDLAND: And I've helped Jay on several of these relief requests, and what we do is we do basis sensitivity studies, which is a mini-probabilistic analysis where we change the variables that we think are the most important, just based on our past knowledge, and run through a gamut of different cases. And he looks at all the results and says okay, we're not good, but we're doing basically this on a small scale, doing what this thing is going to do.

CHAIR ARMIJO: Okay, with less structure?

MR. RUDLAND: With less structure and us guessing on what's driving it, instead of really knowing what's driving it.

MR. COLLINS: And effectively, it's going to provide us defense in depth, if you will, to our relief requests in the future as far as the tool which we're going to be able to use. Plus effectively, since there is cooperation with industry in looking at these particular items, industry will have the opportunity to run this as well, to get some understanding of what they would be looking at as far as a change in relief, and be able to have that to inform the staff as far as what they're looking for, or to more focus what they can possibly do.

MEMBER SIEBER: As you go through all of this, are you going to make the distinction between what's treated epistemically and what is treated aleatorially?

MR. RUDLAND: Oh yes.

MEMBER SIEBER: So we can make judgments as to what the breadth of the resulting probability curves really is, and how valid they are?

MR. RUDLAND: Yes. Yes, definitely. And I think Bill's already commented, given you his opinion a couple of things already just from looking through the slides, so yes, we'll touch on all that here in a few minutes.

MEMBER SIEBER: If you will point that out as you go through, that would help me.

MR. RUDLAND: Okay. I definitely will.

MEMBER SHACK: We'll be discussing that, Jack.

MR. RUDLAND: This next--

MEMBER BLEY: Dave? Sorry. Before you get into the meat of this, I sneaked ahead and looked at your last package on scheduling. A couple of questions. It looks like this project started first of the year, but within a month, you got out a pretty thorough report. It's a joint report with EPRI, and you had papers over the last couple of years. So this is the culmination of a lot of past work. Is this a joint project with EPRI?

MR. RUDLAND: Yes.

MEMBER BLEY: I think you mentioned that--

MR. RUDLAND: Yes, and when I talk about Research's project plan based on this need, I'll go through all those details on how we're structured--

MEMBER BLEY: Okay.

MR. RUDLAND: --and how we work cooperatively, and how that works from both a technical side, as well as an administrative side.

MEMBER BLEY: Okay, great. Thanks.

MEMBER SIEBER: Now did you do a lot of independent testing of samples for this project, or did you use data and materials from all these past studies over the last 50 years?

MR. RUDLAND: Both. Both. I mean, we did a lot of independent testing of the coding work that we've done, but a lot of the data to support it was old, older experiments that were done. Some of these were done at Argonne, some that were done at Battelle, some that's done by the industry; they've shared a lot of data that they've developed in our development of these models.

MEMBER SIEBER: Is there data from European plants involved?

MR. RUDLAND: There are some models from the Europeans; a lot of the data--I'm not sure if any of the data from EPRI includes international data or not. I'm not sure. I know some of the piping databases that we have include European as well as Japanese experimental data, and we are trying to get more international involvement through a separate program that is running parallel to this also.

MEMBER SIEBER: Okay. Thanks.

CHAIR ARMIJO: Do you plan to do any more experimental work for laboratory stress corrosion, crack nucleation, crack growth?

MR. RUDLAND: Yes. It's a continuing effort.

CHAIR ARMIJO: Okay.

MR. RUDLAND: Yes, it's a continuing effort both on the subcritical cracking, stress corrosion cracking and things like that. We're also doing a bunch of stability work also for these unusual complex cracks that's continually ongoing right now. I won't get into much of those details right now, because it's kind of a parallel effort to the xLPR in support of. I won't get into details; I'll talk about them in a little bit in this project plan, but yes, that's continually ongoing.

Okay so again, I want to talk about the RES' response to this user need. The user need itself is shown here, and the main objective was to develop this flexible, modular, probabilistic code, and it specifically asked for to include things like active degradation, and inspection mitigation repair as Jay mentioned, but also to correctly quantify, characterize, and propagate the uncertainties, which is a very important aspect. The final deliverable from this, besides the code, was a technical basis and reg guide for LBB, and we'll talk about that schedule here in a little bit. So we developed a complete program plan, that's to be updated bi-annually as we move through this project, that will detail our work plan, as well as our budgets and the work flow and all that kind of important support things that being developed through the course of the program.

I'm not going to go over this; Jay did this, so I will skip that slide. But again, RES' thought was really the ideal would be to develop a code that's non-application specific. We want to have a flexible, modular code that doesn't apply to a single application, that we can use it for a variety of different applications. And focusing on xLPR, because it's the current regulatory need, but we don't want to pigeonhole ourselves into a structure that will only be applicable to dissimilar metal weld pipe--butt wells, right? We don't want to do that. And so in doing that, we wanted to make sure we had a wide variety of different people working on the program, and so we cooperatively joined into an agreement with

EPRI through our ongoing Memorandum of Understanding to develop this thing cooperatively, both in staff, in funds, as it's best suited both parties. So we have detailed documents that say how we are going to do that, how we're going to share that load. And one of the ways is that we have relatively equal participation from both the NRC and the industry side on the development of this code. So the teams that we've developed, which I'll talk about in a second, are all staffed with both either NRC staff, NRC contractors, EPRI staff, EPRI contractors, in developing the code, and we all work together in a very good, cooperative environment.

But we realize that our overall vision of developing this non-application specific code is a big job, and it's a difficult job, and so we wanted to do a pilot study to begin with, and the pilot study was basically a feasibility study to demonstrate A) that we could do it; B) that we could work together cooperatively without running into roadblocks, both personally and professionally, and we didn't know exactly what kind of computational platform to use, so we wanted to determine that in a feasibility study also. So we proposed to do a pilot study, and the pilot study is basically what I'm going to talk about today; this is Version 1 of the code. And that again, its main objective was to determine the feasibility of doing this kind of project.

Well, before I do that, so we developed a structure that looks kind of like this figure right here, where we have different groups that all work together, they're overseen by an advisory board, and that advisory board allows us to go to them with questions and problems, it helps us--guides us both technically and administratively to move in the right direction. We also have external and internal review boards, and of course as you can see, we wanted to have the interaction with ACRS included in that loop also.

I'm going to talk a little bit about these different groups and what they're comprised of. The Computational group, their job was basically to take all of the computational elements and integrate them into a fully robust, tested, developed, verified tool. And their job was again, to determine what was the best way to propagate uncertainty, what sampling methods we needed to use or that we needed to include in the code, and to provide documentation and training as the code--

MEMBER BLEY: This group's a joint effort too?

MR. RUDLAND: All of these groups are joint efforts.

MEMBER BLEY: I assume our labs, various labs are--

MR. RUDLAND: Yes. Yes.

MEMBER BLEY: --participating?

MR. RUDLAND: This particular group has got folks from Sandia National Labs, Oakridge National Labs, and PNNL, as well as from the industry, there's Structural Integrity Associates, and Westinghouse on this particular group. And all of the groups are very similar like that.

CHAIR ARMIJO: Now all of this was done for the PTS work to some extent, maybe to a great extent; what are you going to do differently that wouldn't--couldn't you just pick that up and say hey, that was a very effective approach, and--

MR. RUDLAND: The issue with the--personally, the issue with the PTS code that that came out is that it's a very ad hoc kind of code, and ad hoc is difficult to create a modular, flexible arena to work in. And so our goal was to have this thing coded by a multitude of individuals and have a framework where these different modules could be plugged in so that A) it's not ad hoc; and B) there's not one entity or lab that's in control of everything, so that if something happens, we're not having to take 10 steps back in order to move forward again. So we learned that from the PTS effort. We also learned that we need to start from day one looking at QA and procedures so that we do these things correctly, where in PTS, it kind of was done on the back end, instead of actually done during the development. We learned those main things.

The Models group is a larger, more diverse group, and their objectives again is to select and document the individual mechanistic or empirical models based on their expertise. So we have--the different topics within the code have different selections of experts; those experts include again, staff or contractors as well as the industry, and they have a procedure for choosing which modules they want to include into the code. And they're responsible for developing this ranking system to help us pick which modules are appropriate for xLPR. And of course, everybody's--and their responsibility also is to aid in the quantifying of uncertainties.

Inputs group, it's just as the name implies, is to develop and collect the associated input data for the code and for the models that are in there, and to quantify the parameters and the uncertainty also that may go with that. And finally, the Acceptance group is tasked with a tough job in determining what the limits are. What is extremely low probability of rupture, how do we get to that, and what are the guidelines for using xLPR to obtain that application-specific result. And again, they also needed to help determine what form we need to use the results in to help as a basis for the regulation or inclusion into the code at a later state.

In the pilot study, we grouped all these together under one big umbrella. As I talk about it as we move forward, it fleshed out this didn't work as well as we had wanted. Keeping Acceptance in with the Model Development was a little incestuous, and so we took Acceptance out of this round kind of structure, to allow them to do their job independent of any of the code development effort, and we'll talk about that in a little bit.

MEMBER ABDEL-KHALIK: When you talk about Acceptance, are you talking about V&V?

MR. RUDLAND: No, no; I'm talking about--

MEMBER ABDEL-KHALIK: So where does V&V fit within this picture?

MR. RUDLAND: V&V falls in with every single one of these groups. We all do our own independent V&V, and Computational group ends up doing the V&V of the entire code at the end. So the modules themselves are, as I'll get into in a second, are all self-contained modules. So if I have a module for crack growth, it's self-contained, and that can be V&Vd in itself, okay. And all of these different things are V&Vd separately, and then the code is V&Vd to make sure that things are plopped in in the right place, put together in the right pieces, and that the results are giving us what we think that they should be giving us. So it's a continuous process, and not something that's going to be done at the beginning or the end; it's something that we do throughout the development of the code.

MEMBER SIEBER: Boy, then everybody's structure must really be complex.

MR. RUDLAND: It can be. It can be.

MEMBER SIEBER: Having done some of this work years ago, I can attest to that. Because everybody's got their different way of doing it.

MEMBER SHACK: Considering how much computation you have to do in this thing, does the modularity, the structural modularity that you're putting in, do you pay a big price for that in terms of computational efficiency? Because I mean I have no idea how these runs are going.

MR. RUDLAND: Big is subjective.

MEMBER SHACK: Subjective.

MR. RUDLAND: I think of course, because you have--what we do is we actually compile the modules as DLLs, so they're like executables, and--

MEMBER SHACK: But when you have Python scripts that are running to pace things together, and I don't know what the commercial program does.

MR. RUDLAND: It does the same kind of thing. Yes, so there is some loss of efficiency, and we've looked at that as compared to a fully self-compiled code, and of course you've got I/O issues that you're not going to get into, and so you have to--it's a trade off between what you want in terms of efficiency, what is something that you can live with, versus the modularity and the ease of being able to plug and play basically. It's a tough call, and it's something that--

MEMBER SHACK: But do you see any difference between the two codes in terms of run time?

MR. RUDLAND: You mean between the two codes that we developed?

MEMBER SHACK: Yes.

MR. RUDLAND: Yes, there's still some differences.

MEMBER SHACK: There's still--

MR. RUDLAND: Some slight differences, yes. Yes, the commercial software that we use for the framework runs a little bit slower than an open source developed--fully developed code, and it's an optimization thing, you know, and it's something that we are, you know, as we move forward are working with the commercial software developers to help with that optimization. They're becoming part of the team now to help us to streamline a lot of that stuff.

MEMBER SHACK: Well I guess that's another question, is why proceed with two? I mean, I can--

MR. RUDLAND: And we'll get into that.

MEMBER SHACK: You'll get into that. Okay.

MEMBER ABDEL-KHALIK: Back to the big picture of V&V, you indicated that the Models group, they will have V&V for individual models, and then ultimately, V&V for the entire code will be done by the Computational group?

MR. RUDLAND: Yes.

MEMBER ABDEL-KHALIK: Okay. Let's say

that the validation part of the big integrated code doesn't quite match the data.

MR. RUDLAND: Okay.

MEMBER ABDEL-KHALIK: How do you go back hunting for the cause if pieces have already been individually validated?

MR. RUDLAND: Well if you know that particular modules are producing the results that they should, so they're fully verified, right, so they should be producing the results, and they have been validated themselves through experiments, then those modules' outputs are giving you what they think they should give you, right, what you should get. And it's got to be in the implementation of how that module is plugged into the framework, or its use. So it becomes a validation effort of the mail flow of the code to make sure things are in the right order. It's done in any way a V&V effort would do. Once that module has been fully verified and validated, there's no reason to go back into it again, as long as you know you're putting in what you're putting in and you're getting out the right results. Then you have to look at the flow downstream to figure out where the problem is. And it becomes a computational issue more than it does the actual modular issue.

CHAIR ARMIJO: Well some things are more difficult to V&V than others, you know, and so there must be some weak models that you would, I would guess you'd go back to--

MR. RUDLAND: And there's some models--

CHAIR ARMIJO: --the weakest ones and take another look, but--

MEMBER SIEBER: And then they would be able to pick up weak models and do the weakest data. V&V to me, once you verify that you have enough data to draw some kind of conclusion and can produce some result, the rest of it is sort of mechanical, the way you go through it. You know, you've got all these test cases that try out all the loops and see if you get the right answer.

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

MEMBER SIEBER: But that's just the mechanics of it. The more concern is, is there a phenomenon out there that we're missing someplace?

MR. RUDLAND: That's different than I think the question that he was asking, right? I mean, you're talking about a mechanistic issue that we've missed, rather that the fact that it's not producing the results that you would expect.

MEMBER SIEBER: Right, or you didn't model it right.

MR. RUDLAND: Right, so there's two things; you could have a validation problem, or you could have a fact data that a mechanistic model has actually missed because some mechanism was not captured correctly.

MEMBER SIEBER: Right. I would not -- you know, this is going to take eight years to do, right? This whole project?

MR. RUDLAND: I don't know exactly how long it's going to take, because I don't know what the final outcome will be. The LBB effort is going to be done in a couple of years, but--

MEMBER SIEBER: In any event, you may end up with an issue in the plant that the model didn't predict, and then you know there's going to be a lot of head scratching going on to figure out why didn't we test for that; why didn't we evaluate it; was it a mistake in the code; was it efficiencies in data?

MR. RUDLAND: There's no reason why you can't go back to the individual module after they've been V&Vd, right--

MEMBER SIEBER: That happens on every model.

MR. RUDLAND: --that happens everywhere,

that's right.

MEMBER SIEBER: Yes, but I can't of one that didn't get some kind of reworking or updating.

MR. RUDLAND: I think I kind of alluded to this, but I'll just go through it quickly again. The first version of the code we developed so far is based only on the pilot study that we developed to demonstrate feasibility. And to do that, we focused only on a particular weld type at a particular location, so a surge nozzle, pressurizer to surge line dissimilar metal weld. And we did that for a reason that we had a lot of available data through this Wolf Creek effort that Jay had talked about a little bit earlier. So we wanted to use that, because we had material properties, we had loads, we had geometries, we had residual stresses, we had all kinds of good stuff from that effort. We wanted to use that, so we focused on that for the pilot study. And again, we wanted just to demonstrate that the process can be done, that it's feasible to do within the organizational structure, and that we could pick the appropriate framework to do the code, to program the code in. And it's also to help us develop a plan for how we're going to move forward in the future.

Version 2, then, is going to be focused on primary piping to support the LBB issues, but not necessarily be only for the LBB issues. It could be also looking at any other piping issues. It will also help us prioritize the future research efforts in piping. And then Version 3, which is a lot farther down the road, which is why I didn't answer your question, because I don't know exactly where that's going to go at this point.

MEMBER SIEBER: Right.

MR. RUDLAND: Is to cover the entire reactor coolant pressure boundary, some things like taking the FAVOR code from the PTS effort, and incorporating it, the modularity into this framework. That's one option. Steam generator issues, upper head issues, where we're going to go beyond the LBB, we just have to see how it is as we move forward. But the plan is for Version 3 to include a lot more than just piping.

MEMBER SIEBER: One of the nice things is that the more you try to expand it beyond the reactor coolant system piping, the less impact it has on the dynamics of an accident.

MR. RUDLAND: You're right. You're absolutely right. That's right.

MEMBER SIEBER: So you end up getting the priorities set for you by the nature of the problem.

MR. RUDLAND: Very good point.

MEMBER SIEBER: And that fortunately corresponds to what the real risk is, in my view anyway.

MEMBER ABDEL-KHALIK: Can the selection of this particular pilot study be misleading in a sense? That you indicated that it was selected because you have so much data.

MR. RUDLAND: Yes.

MEMBER ADBEL-KHALIK: And you go through it, and sure enough you can do it, but does that mean you can do it for anything else?

MR. RUDLAND: I think that it may not be. I think that--the thing is that the data is there, it's just that we had to gather that particular geometry, because of this effort. So the amount of data that is out there I think is out there for a lot of these other--for all of these different types of welds that are in the LBB systems, at least for the uppers that EPRI has, that it has done, and it's just that they happen to be available because that particular problem had just occurred. And so they had spent the time to gather all that information at the time that we had started this pilot study. I think so; I don't think it's going to be misleading. I don't think that it's--we're trying to keep in mind what's available in terms of data, and how difficult or expensive it is to develop the data that is needed, right. So one of the things that we're looking at right now is for Version 2 do we use actual loads or designed loads? Well, actual loads, nobody has actual loads, right? So it would be unrealistic for us to say you've got to use actual loads in order to do these calculations, because they just don't exist, and it would be impossible, or very costly to be able to develop those for each individual application. So we're trying to keep that in mind as we develop the code.

MR. HARRINGTON: Do the range of piping geometries and materials, when we expand from the surge nozzle to the rest of the reactor coolant loop, they're not that different, so it's not a dramatically different problem, it's a more complex problem because you've got more variables to deal with, but you haven't dramatically expanded it. Once we start talking about vessels, steam generator, other kinds of geometries and situations, that's a big step change. But this should not be.

MEMBER SIEBER: And the other challenge is that depending on where you are in the system, the dynamics of the transients will have different time constants, and that makes a difference, too, because the stresses are different.

CHAIR ARMIJO: Now, in your study, you--I may have misread it, but it looked like it was focused on--using steady state loads. You're not going to have--include cyclic fatigue?

MR. RUDLAND: Oh, yes.

CHAIR ARMIJO: You are going to include--

MR. RUDLAND: Yes. The pilot study look at SSC loading, it did look at some thermal stratification loads, but again, the pilot study is focused just on PWSCC, so there wasn't a lot of affect of that in terms of fatigue type--

CHAIR ARMIJO: Okay, and you do include some way of treating weld residual stresses?

MR. RUDLAND: We'll talk about that when I get to the details of Version 1, of how we did it for Version 1. I need to point out again that from the very beginning, we made it clear that the absolute results that come out of the pilot study may not be truly representative of the probabilities for that particular application, because it was mainly used just as a feasibility study, and so a lot of things like that were not necessarily included because those are things that aren't necessarily needed for the direct determination of feasibility. But we know they need to be included, so as we move forward in Version 2, those extra things will be included. You know, whether or not you have PWSCC or whether you have fatigue, the structure of--the development is not all that different. You still have to have a crack, you still have to grow the crack, you still have to determine whether the crack is stable or not, and so it doesn't change the overall structure all that much.

MEMBER ABDEL-KHALIK: So the pilot's just aimed at answering the question whether the structure is appropriate?

MR. RUDLAND: That's exactly right. Whether or not we can do this program--

MEMBER ABDEL-KHALIK: And whether or not you can actually get good results from this.

MR. RUDLAND: Right. We wanted to determine is it feasible to do it; how easily can we do it; can we calculate these low probabilities of rupture with run times that don't take three months, four months to do, within a modular framework. Is the overall mechanistic structure something that we can develop and get it into the code in this modular fashion; those are the kinds of things we were struggling with to begin with. Instead of diving in and trying to do this all at once, you know, we would have been spinning our wheels an awful lot if we hadn't done the pilot study to learn the things that we learned before we actually go and create the all appropriate modules. A lot of stuff that we did in pilot study we'll be able to use.

MEMBER ABDEL-KHALIK: But you don't know whether these modules will be appropriate if you don't know whether or not you're getting good answers.

MR. RUDLAND: Well I think you can--if you know a particular module, let's say, crack stability, you know whether or not that module's good, whether or not--whatever the probability calculations are, because you have experiments that you've either calibrated or verified to, and that module is good for doing the job that it needs to do. Just to demonstrate some of the amount of people that we have working on this, this is a listing of those involved in the pilot study, and a illustration of their logos from the different companies. And so we had a pretty good combination of folks that were working on this initial study.

User Need has a lot of tasks that are

beyond just the development of the code; there's a lot of supporting tasks. Some of them are this crack growth testing, stability testing, things like that. So this is just an overall schedule from the response to demonstrate that right now our user need deliverable goes out to 2015, and that at this point is when the user--I'm sorry, the reg guide will be delivered to NRR. Version 2, which is going to be meet that need, will be done at the end of 2013. But we have issues of testing, one that says new reg Alloy 52/152 issue, testing feeds into that. You'll there's a bottom--task at the bottom called Alloy Crack Growth Testing. Some chemical mitigation work that we're doing as part of the user need, so there's a lot of support tasks that I didn't have time to go into today, that are supporting this work, as well as helping Jay with his relief requests.

CHAIR ARMIJO: Just what are you looking at under chemical mitigation?

MR. RUDLAND: What we're going to do--well right now, our job is to do nothing more than try to confirm what the industry's done. And I think ongoing right now we have some hydrogen tests going, so we're changing the level of hydrogen and looking at the crack growth rates to confirm with the industry--

CHAIR ARMIJO: Lowering or raising or?

MR. RUDLAND: Both. Mostly increasing the hydrogen, yes. And the same kind of work may be done with zinc, we know; we have to kind of follow the industry's lead on that, and their technical basis hasn't quite been delivered at this point, but they claim factors of improvement on initiation with the addition of zinc into the coolant system. So we will need to confirm those kinds of things.

MEMBER SHACK: Your already sparse data will get sparser.

MEMBER SIEBER: Actually, there's still some testing going on, and will be for the next five years or so, right?

MR. RUDLAND: Yes, we have continually testing going on right now, because right now, we're focusing a lot more on the--

MEMBER SIEBER: Like for example.

MR. RUDLAND: --looking at the higher-chrome alloys actually right now, and we're focusing a lot on, and their added resistance for PWSCC.

MEMBER SIEBER: Do you expect any surprises?

MR. RUDLAND: We haven't seen any so far. In some cases, the data's been higher growths than we thought originally.

MEMBER SIEBER: That's a surprise.

MR. RUDLAND: I always--in my mind, I knew it wasn't going to be resistant as they claimed.

MEMBER SIEBER: You knew.

MR. RUDLAND: I knew.

MEMBER SIEBER: But no new phenomenon have shown up?

MR RUDLAND: I don't think so. Jay, are you familiar?

MR. COLLINS: We could go into this quite a bit, but I don't want to this talk, for his presentation. But there was some items with significant code work, but those applications don't appear to be as realistic for actual plant applications at this time. We're looking into the mechanisms which might be driving that. As well, we're looking at weld dilution because of the chromium content; we're trying to break that down. So there's a number of things which we're still looking in as we're going forward. Plus we still have field materials. As components get replaced, we have the opportunity to do some testing on those. Recently the Davis-Besse Alloy 600, we're looking at that and testing it at Argonne National Lab, as well as PNNL.

So I mean, there's these opportunities still to look at those items, as well as look at chemical affects as we go forward, so. That program, the residual stress validation program, is going to filter in here as well, as we develop additional programs as we're going along. So a lot is actually going to filter in to help this program as it moves along.

MEMBER SIEBER: Yes, the residual stress is, I think a significant factor.

MR. RUDLAND: No doubt.

MEMBER SIEBER: I don't know how you determine how much residual stress you already have in an existing piping setup.

MR. RUDLAND: Yes, and we've been spending a lot of time--

MEMBER SIEBER: Does it say where you are on the curve?

MR. RUDLAND: --we have a very similar program right now, it's ongoing cooperatively with EPRI, to validate all of our residual stress analyses, to help understand what parameters are driving some of these stresses and things like that.

MEMBER SIEBER: Yes, are there any publicly available papers out there that talk about that? They're really interesting.

MR. RUDLAND: There are actually. We've just begun to publish a lot of the results from the validation efforts.

MEMBER SIEBER: Yes, I wouldn't mind having a list of those so that I can keep myself busy.

MEMBER SKILLMAN: I'd like to ask a question, please?

CHAIR ARMIJO: Go ahead, Dick.

MEMBER SKILLMAN: I'm Dick Skillman, a new member here. On your list of current team members, the question is which of these team members is going to help bring in international OE? The French have 60 P; the Germans have a dozen, 15, the Japanese have a bunch. I've been impressed over the years at how much extraordinarily good work the French have on materials, chemistry, degradation. They were the ones who predicted the head degradation. So it seems to me, kind of getting back to Said's question, on your Version 1, you chose one surge line, because you wanted to test the capability of the code to predict that. It would have seemed to me you might have wished to have two or three, just to have the sampling so you're not stuck in the--bound to one instrument band kind of thing. It gets me to--are there some items of foreign experience that could enhance the strength of your argument and the strength of your program? Those, EDF and others, have had experiences we have had, and some bad experience that is meaningful to us. Is there a way to draw that in as a way of making your product, if you will, internationally robust?

MR. RUDLAND: Yes; what we're trying to do is that, if you notice on that list, there's several folks from Battelle Memorial Institute, and as I mentioned a little earlier, there is a parallel effort that's going on there right now for an international group program called PARTRIDGE, which is looking at a risk-based applications to pipe rupture, and they are involved--part of that program is involved in support for xLPR. And currently right now they have the Swedish authorities, Canadians, the Koreans, Taiwan, EPRI and the NRC are members right now; I think there's five or six. And they've got--they're in conversations with the French to also try to join that program. And that's a program to help us to do knowledge management between all the different companies to help us guide this effort. And it's their way--it's our way of also being able to tap into that resource. So that's one way that we're doing it.

The other way is that we are--have an external review panel that we're putting together of experts in different categories, and those experts will be filled with some international folks that we know are heavily involved in this kind of work. There's some folks from Sweden we know that have done a lot of work in probability calculations and pipe rupture calculations and things like that, so they'll fill the board, and we have several options to do that. So we're trying to get the international participation through those two different mechanisms.

CHAIR ARMIJO: Dave, we probably--I need to move along; you've got a lot of slides, and I've let it slip.

MR. RUDLAND: And I'll kind of just mention this, that's exactly what I was just saying, is that--so we've got an extra review board that will help us along in terms of guiding us in the direction and providing information; we hope to have a major review with them per year, as well as these briefings I mentioned earlier with ACRS.

I don't think there's any reason to go through this; I've said all this already. We've got this user need, we're going to develop xLPR and working cooperatively with EPRI to do that. I think the next presentation then is going to go into some of the more technical details of what we put into Version 1, and I think will hopefully address a lot of the questions that have been coming up. If it's okay, I'll move forward.

CHAIR ARMIJO: Yes, please.

MR. RUDLAND: Okay, so I'm going to talk about some of the technical details, and I've got a lot--I think there's like 27 slides or something here on this that goes through each of the different modules, and what we put into that, and our decisions and how we made them. And so I'll be talking about the Version 1; in some cases, though, since we've always got our mind moving forward, some of these slides will have the options that we're going to be including in Version 2 also on the same slides. We have a particular through our two-way process. We have a very detailed methodology for adopting changes in the code and things that we do in terms of voting procedures. And so some of the stuff for Version 2 that I have on these slides are proposed and not approved yet by the group, but they're under consideration.

Okay, as I mentioned, the Version 1 scope was a feasibility study. We focused on this one particular, dissimilar metal weld that I mentioned, and we did that because of the availability--

MEMBER SHACK: We've got half an hour to catch up on, Dave.

MR. RUDLAND: I'm catching up. Okay, so let me talk quickly about the technical flow, and this is in more of graphic representation of the flow, just to get you familiar with it. Again, on the left, we have inputs, loads, material properties, mechanisms that are all stochastically based, and those are inputs to the code. We have initiation module that tells us at what time and with what frequency cracks may occur. I'll go into each of the details of this at the end, so if we could hold the questions, then we can talk about the details of how those modules do that. We then grow those cracks, be it one crack, be it two cracks, however many cracks may initiate, we grow those according to the mechanisms that are inherent for that particular problem.

Cracks may or may not coalesce, depending on the criteria, making a much longer crack. There's inspections that are included; the inspection intervals aren't input, we can modify that. It either removes cracks, modifies cracks; mitigations allow us to take the cracks that are there and stop them from growing if mitigations are applied. If they do go through wall, we calculate how much leakage occurs from that, and also be able to compare that to the leak detection limits that are input. if they are not detected in time, they may become unstable, and we can check for stability, and then if that's the case, a rupture occurs, and the code is exited. If not, it continues on through that loop until there's some exit mechanism that occurs.

So this is a draft of a kind of representation; in more of a flow chart representation, we have this kind of structure, where the purple boxes that are shown here are the individual modules that I talked about earlier. So for instance, there's a loaded module, it's a self-contained, verified checked module, a crack growth module. And they're linked in this kind of manner. The process is done basically in a deterministic style loop, that's imbedded within a double looped--a double- nested loop where we sample the aleatory uncertainty on the inside, and the epistemic uncertainty on the outside to be able to take a look at the differences between how much knowledge we had, and how much irreducible uncertainty that there is.

MEMBER STETKAR: Dave, are you going to

talk later about that sampling process in your presentation?

MR. RUDLAND: I don't go into too much detail, but we can.

MEMBER STETKAR: Okay; let's talk about it now.

MR. RUDLAND: Okay.

MEMBER STETKAR: When you run the inner loop, the aleatory loop, is the result of that sampling process a probability distribution, and is it saved, or do you only save the mean value?

MR. RUDLAND: No, we save the entire distribution.

MEMBER STETKAR: You do?

MR. RUDLAND: yes, and it's actually--

MEMBER STETKAR: Good, because that wasn't--that's fine; that's all I need to know. Thank you. Go on.

MR. RUDLAND: And you can see that in the results--

MEMBER STETKAR: No, that's okay. Thanks. Go on.

MR. RUDLAND: So let's delve into some of these models. Crack initiation. Now here's one of these models where it's entirely empirically driven.

The mechanistic understanding of crack initiation, especially stress corrosion crack initiation, is still relatively limited, and the models that are there don't capture the results very well. And not only do they not capture the lab results very well, the transferability between lab results and operating experience isn't there, either. And so we decided in the pilot study at least, to adopt several different types of empirically-driven models to calculate the time to crack initiation. And the differences between these are relatively trivial; some have stress thresholds, some have constant stress thresholds, some have variable stress thresholds, but they're all driven basically by the stress and the temperature, and it's stress to some power, and temperature through this exponential relationship.

CHAIR ARMIJO: But there's no water chemistry variable in any of those relationships.

MR. RUDLAND: No. No, because it need to be--

CHAIR ARMIJO: That all water chemistries are equally aggressive--

MEMBER SHACK: No, it's buried in A, you know, if you run the test in a certain environment, you get an A for that environment; if you run it in a different environment, you'll get a different A.

MR. RUDLAND: Right. so it's through the calibration, and we'll show how we did that for a particular case, and I'll talk about that in the next slide. But there is also placeholders right now for handling zinc and hydrogen, but the data is not quite there enough to be able to incorporate it, so we didn't, but we're able to make corrections for the zinc and hydrogen also on these.

CHAIR ARMIJO: For what it's worth, I think this is probably the weakest part of the whole process, this nucleation, and it's been in BWRs as well as here, and the effort in the lab work could really be, I think--

MR. RUDLAND: Right, and I wanted to mention that--

CHAIR ARMIJO: The only way you can address this thing is in the lab.

MR. RUDLAND: There's a lot of lab work that's done, and the problem comes in the transferability to the operating experience.

CHAIR ARMIJO: I understand.

MR. RUDLAND: It's not transferring appropriately to the operating experience.

MEMBER SHACK: And as much as we like to

absorb money at national labs, we can't really run tests for 20 years, so we're always accelerating the tests and we have no good mechanism for taking that accelerated test and translating it to the real world conditions, and that's--

CHAIR ARMIJO: Yes, you can't--

MEMBER SHACK: --that's why we do crack growth. We can do that pretty well.

MR. COLLINS: There are some industry programs that are looking at still initiation, so there is testing that is going on.

MR. RUDLAND: Yes, and really the plan for moving forward, or what we're doing is we're developing, to the best we can, an expert panel on this to say okay, at this state of knowledge that we have now, what's the best that we can do? And that's all that we can do right now, is the best that we can do. So this expert panel is going to help guide us, if we can do any better than this. I don't think we can personally, but we have to figure out if that's really the best path forward.

MEMBER ABDEL-KHALIK: I mean conceptually, this should be in some way related to the pedigree of the material on the QA program that was initially used to accept, you know, they're all Appendix B, but there's Appendix B and there's Appendix B. And I'm not sure doing it empirically in this manner you would be able to capture the wide range of variability that might exist.

MR. RUDLAND: And I don't disagree, and if there is a methodology and a phenomenological way of doing this, I'm more than happy to listen and understand, but we have not been able to find it at this point, and Bill and I worked on this many, many years ago--

MEMBER SHACK: Right. I mean I think we-- we actually can capture the range and behavior for crack growth. That's an easier problem, and we do know all alloy 600s are not equal, and it's basically uncontrollable variables at this moment. I mean, we know that there's a factor of 20 difference in crack growth rates; why that's there, what metallurgical structure gives that to, you really don't know. And I'm sure that the range in initiation is at least that much, only it's harder to do tests on initiation that translates well to the field condition. We can run realistic crack growth rate tests; it's much harder to run realistic initiation tests because you can't wait.

MEMBER ABDEL-KHALIK: The time constants are different.

MEMBER SIEBER: And licensees really don't know exactly what it is they have, either.

MR. RUDLAND: That's exactly right.

MEMBER SIEBER: And that's why you take this approach, because it gives you a range, a reasonable range for some probabilities associated with it, and you can make a decision. But there--I don't think there's been big surprises if you've been around long enough; the height of the surprise goes down.

MR. RUDLAND: Right. But it's definitely--even when we calibrate, your point is really well taken, because when we calibrate to whatever operating experience data we have, we really don't know what's going on there. We know that there was some indication, we can back-calculate what maybe some of the initiation is, but I don't even know if that's a crack.

MEMBER SIEBER: Right.

MR. RUDLAND: You know, I know it's an indication is all I know, and in a lot of cases, they don't find out if those things are cracks--

MEMBER SIEBER: I think there's a couple of issues there. If you know the phenomenon occurs, and you know that it is likely to lead to a leak before break, then I think from a public safety standpoint, you're probably okay as long as the licensees are doing what they need to do to be able to make leak before break work. The thing that I worry about is phenomenon that cascade and escalate and cascade, that we have not perhaps yet imagined, and could be caused by a structure error that hasn't been analyzed. You know, it seems to me there was a plant not too long ago where they found a weld repair in the reactor coolant system that did not match what the design--

MR. RUDLAND: I think that happens often, actually with weld repairs.

MEMBER SIEBER: Yes. Yes.

MR. RUDLAND: And I mean--and we've talked a lot internally--

MEMBER SIEBER: But that's the surprise, and this stuff won't work for that.

MR. RUDLAND: Well--

CHAIR ARMIJO: Maybe in the future--in future Subcommittee meetings, we could focus on some of these particular models, whether it's new initiation and growth, and obviously we're not going to be able to do that today, although we'd like to, but--

MR. RUDLAND: I think that's a great idea. Yes, I think that's a great idea. And to your point, we spent time talking about how to account for unknown unknowns.

MEMBER SIEBER: Right.

MR. RUDLAND: You know, and that's another point where I--you scratch your head and say you guys take a best stab at it.

MEMBER SIEBER: Even though they're probably going to use it.

MR. RUDLAND: That's right.

MEMBER SHACK: Well, I always come back to the weld--and I'm a weld residual stress guy myself. Because if the weld residual stresses are right, it doesn't matter what the crack growth rates are or the initiation; the cracks won't go anywhere.

MR. RUDLAND: That's exactly right.

MEMBER SHACK: Okay, so in some ways to me, the key variable here for leak before break and rupture is the weld residual stress, and a lot of the other stuff sort of comes out in the wash. Now I don't know that weld residual stress is any better than early initiation.

MEMBER SIEBER: Well, the other problem is I'm not sure we know the actual physical loads, and those are combined with weld residual stress, you know, jet impingements and all kinds of stuff that can go on. On the other hand, I can't think of anything to do any of this better than what you're doing.

CHAIR ARMIJO: Okay, I think we better--

MEMBER SIEBER: And I looked at that conservatively.

CHAIR ARMIJO: --I think we better get going.

MR. RUDLAND: So yes, it's always if we posited -- is we calibrated these models to some data that was in the MRP-216 for cracks that were found in pressurized or surge nozzles. And how we handled that is we also allow the crack, based on the stress around the circumference, to initiate at different locations, could possibly initiate at different locations or in multiple locations around the circumference, based on the arrival rate and the stress at the particular location around the circumference. So to give the opportunity for multiple cracks to grow and coalesce and create long, not so deep surface cracks that could possibly violate the leak before break criteria.

For the pilot study, again, we only focused on circumferential cracks, and we'll be handling axial cracks, which affect mainly just the leak probabilities in Version 2. Growth, as Bill pointed out, has been much more studied a lot closely in a lot more detail in its development; developed by a multitude of different types of experiments, different types of labs doing the experiments, calculating stress corrosion cracking as a function of the stress intensity and temperature and stress and all those kinds of things, are all captured in MRP-263, which also includes the affects of hydrogen level on the crack growth rate. So this model is included in right now in the Version 1 code, and it allows us to change the hydrogen content to affect the crack growth rate. The variability again is captured not only within weld, but weld to weld also.

Stress intensity, we have several different solutions that are in there right now. We are using idealized solutions, semi-elliptical surface cracks, and radial through-wall cracks. For the pilot study, we chose a fourth order fit through the wall thickness for stress, and we'll get into the stress definitions here in a few minutes. We controlled the growth at the deepest and surface points of the crack, and for through wall crack we did something very similar; we used similar kinds of solutions and we averaged the K through the thickness for the growth.

MEMBER SHACK: Now, you did more sophisticated things for Wolf Creek.

MR. RUDLAND: We did. We did--

MEMBER SHACK: And that's just too computationally intensive for this purpose?

MR. RUDLAND: Well what we try to do is, we try to do sensitivity studies to help guide the development of these kinds of models with that technology, but to run one solution for that takes a day, and so it's much too computationally intensive to include in probabilistic code. But what we're doing is we're creating non-idealized solutions for transitioning from surface crack to through-wall crack and other things, and we're taking the lessons learned from those types of analyses to help us guide what kind of flaws we need to look at.

And speaking of crack transition, because of the solutions that are available, we chose a very idealized transition from a surface breaking defect to a through-wall crack, and we did that just to allow equal areas between a leaking surface crack and the resulting through wall crack, because solutions aren't available. But in Version 2, we're planning to come up with these non-idealized solutions as we transition from a semi-elliptical type of surface crack to a more idealized type of through-wall crack.

MEMBER STETKAR: Dave, it would seem--I'm not a pipe guy; I know nothing about this stuff, but it--trying to step back from this whole thing, it seems that this particular model would affect the overall results pretty strongly, wouldn't it? Once you apply the back end leak detection--

MR. RUDLAND: This assumption affects the leak rates, it does affect the leak rates.

MEMBER STETKAR: Which affects--which certainly affects the effectiveness of your leak detection methodology--

MR. RUDLAND: And that's one of the reasons why we're focusing in Version 2 right away--

MEMBER STETKAR: I just wanted to make sure I understood--

MR. RUDLAND: Oh yes, yes definitely.

MEMBER STETKAR: --where that sensitivity was coming--

MR. RUDLAND: We end up with a lot bigger crack openings--

MEMBER STETKAR: --yes, that's right, because your overall results don't show a lot of sensitivity whatever leak detection schemes you have, and that's probably driven by this, right?

MR. RUDLAND: Yes.

MEMBER STETKAR: Okay.

MR. RUDLAND: Weld residual stress. Okay, so what we did for residual stress was since we were tied in Version 1 to a polynomial, we decided to use a polynomial representation to--for residual stress in Version 1, and to incorporate the uncertainty of residual stress, we allowed both the ID residual stress, which is over on the left side of that particular axis of the illustration, and this distance where X crosses through zero as variables. And so we can input the variation residual stress through that, and keep the third-order form through a series of constraints, and sample those things either independently or dependently, and develop the residual stress distributions through that methodology. Works great, as long as the residual stress take a third-order form, which they don't. I'll show in a few slides, they don't really always take that form, so in Version 2, we're looking at more of a piecewise, linear type representation of the residual stresses--

MEMBER ABDEL-KHALIK: It's not just how they fit, but whether or not you know them at all.

MR. RUDLAND: That's right. Well, there's a couple of different uncertainties that fall in there, and unfortunately I don't have the time to go into residual stress validation here, but there's a lot of work, like I said before, that's being done to try to understand how well our predictions match the actual stresses, through measurements of residual stress.

CHAIR ARMIJO: David, I think you should look at it broader than just the weld's residual stress. It's a fabrication residual stress, and that can also be affected, at least it was in BWR pipe cracking, by post weld grinding, which was a most effective way to nucleate cracks we could ever develop in our laboratory work, and you don't know how somebody actually built some of the stuff that's out there, or whether there was a lot of what we call abusive post weld grinding, but it really has a huge affect on nucleation cracks for IGSCC. I don't know if it makes any difference for PWSCC, but I think you should look at it broader from a residual stress at the surface, it's affected by the coolant.

MR. RUDLAND: No doubt, and as Jay alluded to earlier, one of the things that we have to look at is peening. And peening really can't be captured by this; the peening effect, as well as the grinding effect, are shallow effects; they don't create a step change, and they really won't have a big effect on the growth, it'll basically be at initiation. So they need to be factored into the initiation model, and I think this be kept separate to help drive the growth.

MR. COLLINS: There's other conservatisms that we can put in with a 50% weld repair initially upon--I don't know exactly what's been--

MR. RUDLAND: I don't like to use any conservatism when we talk about probabilistic codes. So the way that we handle that is that if you are able to put in a weld repair, if you know you have one, you can put it in along with its distribution residual stress; if you don't know you have one, you can put in the weld repair distribution with a probability of occurrence, and look after your sensitivity studies.

MEMBER ABDEL-KHALIK: Would you have enough data to capture field changes?

MR. RUDLAND: In residual stress?

MEMBER ABDEL-KHALIK: In whatever field changes were done at the time this weld was done, or anything else.

MR. RUDLAND: Now if you talk the guys from the industry, oh yes, they've got great records of everything that's happened. But just like you pointed out earlier, is that there's welds out there that I'm sure were repaired that we don't know about. So we've got to be able to account for that, and the only way to really do that is to take some distribution and say I have a probability of occurrence, you know, if that probability of occurrence is one in 1,000, how does that affect my rupture results? I mean, because there's no way really, it's an unknown unknown again on how to deal with that.

MR. HARRINGTON: Even those of us in industry realize that the upper--if the weld repair was recorded, it was recorded; and if the weld repair wasn't recorded, you just don't know.

MR. RUDLAND: But we're still working on how best to model the uncertainty in a piecewise linear type of representation of the stress field, and that's ongoing work that's going right now as we move forward in Version 2.

MEMBER SIEBER: Now does it make any difference at all what the operating parameters are for the actual physical specimen, like temperatures, pressures, rate of transients or--

MR. RUDLAND: Oh yes, of course.

MEMBER SIEBER: Okay, and how--where does that fit in?

MR. RUDLAND: All of the operating loads, transient loads are input and then added basically to these residual stresses for the--

MEMBER SIEBER: But put in as max values, right? As opposed to--

MEMBER SHACK: Design values.

MR. RUDLAND: Design values. Everything's design values right now because of this--

MEMBER SIEBER: So there's margin built in there?

MR. RUDLAND: There's some margin built in there, and we have to be able to quantify that as we look at the results.

MEMBER SIEBER: Okay. So something that goes beyond the design value and unanticipated transient may be covered by the--

MR. RUDLAND: It depends on the distribution of the inputted transient, and if it's captured by the distribution--

MEMBER SIEBER: And what that goes to as far as loads are concerned, the physical parameters of the transient translate themselves into loads, which is what the cause is--okay. Okay. Thanks.

MR. RUDLAND: I mean, you're allowed to put in distributions on those loads, and if you're able to as a user incorporate those into the distribution, then you're good to go. Again, if it's an unknown unknown, then it's difficult to--

MEMBER SIEBER: But for a pressurizer surge line, 2500 pounds is the assumed--

MR. RUDLAND: Yes, that's right. That's right. And that's, again, you're allowed to put a distribution on that if you feel that that's important to the problems you're handling.

MEMBER SIEBER: On the other hand, it's sort of hard to, unless you do a transient analysis, it's sort of hard to predict what the temperature range is. Okay.

MR. RUDLAND: We see crack coalescence very simply; it's a--we follow the ASME rules; I don't think there's any reason to go into that into very much detail, but we allow the two cracks to coalesce if they do, if they get close enough to each other. Crack stability is handled right now; surface crack stability is in essence a collapse analysis. We will be including EPFM in Version 2. A through-wall crack is a J-tearing analysis, as well as a net section collapse, depending on what controls, and the codes--I would push the failure based on the lowest value between the critical size and the margin. And these analysis methodologies, this LBB.ENG2, has been verified through a series of experiments that were done as the best methodology for predicting the maximum load rate capacity for through-wall cracked pipes.

Crack opening displacement is calculated using a GE/EPRI solution, and again it was chosen because through the validation efforts, it was found to be the best scheme to predict crack opening displacement. It considers elastic and plastic behaviors, and there is a separate tension and bending solutions, and a blending solution that we came up to blend the two solutions together for combined tension and bending. Leak rate, in the 80's, a version of a code called SQUIRT was developed to calculate leak rate through tight cracks, that allows two-phase flow to occur. That code was extracted and sent through the QA process and incorporated into Version 1. It has the Fausky two-phase laws, as well as orifice flow models and all steam models. And it's COD-dependent, so the crack opening, as well as the morphology parameters are all input into this code for the calculation of leak rate, and it allows for an elliptical crack opening area.

Inspection, we use--in Version 1,

inspection is dictated by the probability of the detection curve; MRP-262 focused on the PODs for dissimilar metal welds in surge lines, and so we used that data, and how we incorporate that into the code is for Version 1, we tracked the PND, which is basically the one minus the POD; and then in the post-processing phase, we're able to modify the probabilities based on the inspection intervals and whether or not a crack is found. If a crack is found in Version 1, it is completely removed and repaired. There is no option in Version 1 for any kind of in-service repair or remediation, or any other kind of distribution, crack distribution that may occur due to a repair process. Those are right now as proposed for Version 2. We also don't have a sizing model in Version 1 where a decision needs to be made on a particular size of that found indication; it will be incorporated into Version 2.

MEMBER STETKAR: Dave, I looked at this a little bit, and I--again, for kindergarten sort of mentality like myself, the uncertainty in whatever parameter beta 2 is, is very large, and the estimated value for holding all the other parameters constant of the probability of non-detection is quite large. For example, if I look at a one sigma, plus or minus one sigma variability in beta 2, I can get non-detection probabilities that run from about two times 10 to the minus four, to about .2. So that's a pretty large variation. What physically affects Beta 2, what is that?

MR. RUDLAND: Beta 2--beta 1--this whole model is a fit to a series of inspector qualification tests that were done through EPRI. They had a series of welds, and they did a whole bunch of inspector qualification tests, and they took that data and fit this functional form to. So I think that--I don't think that beta 1 and beta 2 are independently fit parameters, so I don't think that there's independently affects one that doesn't affect the other. They're fit at the same time, I think, through this functional form, and Craig may be able to speak better to this, because this is an EPRI initiative.

MR. HARRINGTON: Probably not much better, but yes, it's many, many data points from inspector qualifications, and there was some discussion to even include those that failed the exam or not; those that failed are not out in the field doing exams, but we did it both way and produced curves.

MEMBER STETKAR: I'm asking for some sort of just--again, assuming I'm a kindergarten guy--a physical meaning for what those are.

MEMBER SHACK: Let me try. X is the depth, and so the question--

MEMBER STETKAR: I understand that.

MEMBER SHACK: The question is does--what kind of signal does a crack of a certain depth generate? Because they're not simple, plain, flat slats; it really depends on how tight the crack is, whether it's filled with junk, and how branched the crack actually is. So how good a reflector that crack really is for a given estimate of depth shows up in this model as an uncertainty in beta 2.

MEMBER STETKAR: Okay. So it's a physical process, it's not because--is there anything, because what I thought I was hearing was it also has to do with the capabilities of people performing the test.

MR. RUDLAND: I think it's also an interpretation kind of thing. It's more of an interpretation where as you get to the shallower defects, it becomes much harder to be able to identify those--

MEMBER SHACK: It's hard to sort the two out, because if the signal is big enough, the guy sees it. If the reflection is weak, then it is an interpretation and you know so--but if the physical basis for it is the variability in reflection of a given depth. If every 10% through-wall crack gave out the same signal--

MEMBER STETKAR: Then the variability would be in the--

MEMBER SHACK: Would be in the pursers, right.

MR. HARRINGTON: There's a lot of effort in the inspection procedures to drive forward a structured process that doesn't rely so much on inspector interpretation and, you know, what Joe sees and Sally doesn't, but--

MEMBER STETKAR: You know, I understand that, I'm just trying to look at ultimately, regardless of what your predictive models on crack rate--what you fit on the back end of this stuff in terms of leak detection and inspection is going to drive your overall probabilities, which--

MEMBER SHACK: No, no; your weld residual stress, if the crack never gets--

MEMBER STETKAR: Okay, you're a weld residual stress guy, but I look at the results of their simulations, and I can get--

MEMBER SHACK: Well that's because he's got weld residual stress--that's okay.

MEMBER STETKAR: I just want to understand this. This is a very large uncertainty, and a driver, and I wanted to understand what it was.

CHAIR ARMIJO: It's also dependent on the inspection technique. There are new, better inspection methods, and they'll have different PODs once they're qualified and developed, and so it's the best you can do for now.

MEMBER BLEY: And this incorporates all of the randomness we see.

MEMBER STETKAR: I just wanted to understand which--there's two elements of randomness here, and I wanted to understand.

MR. RUDLAND: Yes, and it's location specific, and if you're talking about a surge nozzle, it's much easier than something that's in the sandbox, that's much more difficult to do the inspection on.

MEMBER STETKAR: Thanks.

CHAIR ARMIJO: Okay, mitigation.

MR. RUDLAND: Mitigation, how we handled it in Version 1 is we chose the MSIP methodology, so we basically changed the residual stress distribution at a particular pre-defined time at which the mitigation effect was implemented. There's also placeholders for other mitigation models, but they're not currently incorporated in Version 1, but they will be incorporated in Version 2, and we'll be talking about incorporating not only stress-based mitigation and material replacement based mitigations, but also chemical mitigation techniques also, which is the change in environment that we talked about earlier.

Now to demonstrate feasibility, we developed a series of pilot study problems, so that re ran through to demonstrate all the different affects that we have incorporated in the code, just to understand whether or not what we're doing makes sense, and that it is feasible to do. so we chose a base case; that base case has a higher residual stress field, with a certain set amount of uncertainty, no inspections, mitigations, or leak detections. So there's nothing on there to stop the crack from growing. We then did our series of sensitivity studies on that base case, looking a different residual stresses, looking at different mitigations, looking at different crack initiation, looking at different hydrogen levels, as well as looking at inspections and leak detection, and a combination of those all together.

I'm not--I'm going to go through this quickly because these are just the inputs that came directly out of 216, to give you a feel for what the level of loads are. In this particular case, the applied loads for the pilot study are all constants, they're not distributions. Material properties, same kind of thing, we did have a series of database--

MEMBER SHACK: Dave, just dropping back for just a second. So you grow it under the normal load, and then you check for rupture under the earthquake?

MR. RUDLAND: We do both.

MEMBER SHACK: You do?

MR. RUDLAND: We do both. We put--we check for rupture under operating conditions and under the earthquake conditions, and then there's a probability of the currents of the earthquake. Whether or not we include seismic hazard curve and that kind of stuff into Version 2 is under discussion. Fuel properties database, and those are all variable, which are properties, correlated properties, and these came all out of material property experiments that were run through the 80's, 70's and 80's and 90's on these materials.

Residual stresses. So what we did for the base case is we chose, again, a Westinghouse service nozzle without a safe end weld, and the datapoint are all analysis results in this particular case. And again, we talked about validation; we have a separate validation effort that's ongoing to help us validate that these particular residual stresses are properly capturing the residual stress that was actually in the weld itself. From that set of distributions, then, we can develop the ID residual stress, the distribution as well as the exceed distribution, where this thing crosses the X axis, and this distribution crosses the X axis. We can develop those distributions, and then run a couple of cases to demonstrate how the curve fits match the finite element results. And in most cases it's not so bad; we don't capture a lot of the high points, we don't capture a lot of low points, that's more a byproduct of the third-order fit.

CHAIR ARMIJO: Dave, just to make sure I understood. So where you have data points, those were experimentally dealt with?

MR. RUDLAND: Finite element analyses.

CHAIR ARMIJO: Okay, and then the other ones where there are no data points, what are those?

MR. RUDLAND: The model that we use to describe the finite element results.

CHAIR ARMIJO: Okay.

MR. RUDLAND: And you can do the same

thing with experimental results instead of finite element results, if those are available. It's all the same kind of distribution.

CHAIR ARMIJO: Okay.

MR. RUDLAND: We do the same kind of thing for mitigation. The mitigation data we had was a lot limited, so the distribution is a lot tighter, but it shows a much larger compressive stress on the ID surface. But again, it doesn't really fit the third-order polynomial very well, especially when we talk about a particular case for a safe end, when the dissimilar metal weld has a safe end that's very close to it; the safe end interacts with the stresses in the dissimilar metal weld, and causes much lower stresses on the ID surface. And the third-order approximation is not appropriate, is what we learned through the pilot study. You can see we're missing very extreme low points, we're missing all of the tension on the OD surface, so the model does not do a great job in this case of capturing the behavior that's predicted through the finite element results.

CHAIR ARMIJO: So on the ID surface in this situation, you could have either compressive or tensile stresses of the same magnitude?

MR. RUDLAND: Yes. It all depends on how

that particular weld was modeled, in this case. Yes.

CHAIR ARMIJO: Okay.

MEMBER SHACK: Are these strictly modeling variabilities, or are these different weld procedures that are being modeled?

MR. RUDLAND: In this particular case, it's all the same weld procedures.

MEMBER SHACK: So this is pure model--

MR. RUDLAND: Model--when I forward the papers on the residual stress, that's the overwhelming uncertainty is the model uncertainty, the weld variability uncertainty is a lot smaller, which is opposite of what we expected when we started the validation problem. Because we had very defined mock ups made, very defined procedures, gave it to an international group of people, and they all came back with really different numbers. It was very discouraging. So--

MEMBER SHACK: But we're working on that.

MR. RUDLAND: It's ongoing, and hopefully we can make sense out of it, but right now it seems the model of uncertainty is much larger than the weld variability--

MEMBER SHACK: It didn't vary the safe handling on this?

MR. RUDLAND: In this particular case, no, we had it on safe handling. Okay, so uncertainty, so how we do that is we allowed the models and inputs group to classify the uncertainty. And my second vote, it's very clear that we need to do something better probably as we move forward, and increase that discussion based on how we make those decisions, but for the pilot study it was satisfactory I think. And this is how the Models group and Inputs group had classified the uncertainties. On how we propagated those uncertainties, I mentioned earlier, is that we had epistemic and aleatory loops. We sampled those kind of differently, whether or not they were epistemic or aleatory. We had several different types of sampling methods, Latin hypercube as well as discrete probability distributions as also, and those are very similar, it's just a different way of how the sampling is handled. And we also focused a lot on important sampling in order to get to the low probabilities of rupture. And I'll talk--

MEMBER STETKAR: I'll let you finish your sentence.

MR. RUDLAND: --and I'll talk about the actual results from these in the next set of slides.

MEMBER STETKAR: Now, epistemic

uncertainties, are there--is there anything in this process that would correlate the uncertainties in any of those phenomena? If you're familiar with this kind of state of knowledge correlation; in other words, if the state of knowledge for crack initiation is such that you would be somewhere in the uncertainty distribution, then you would be in the same point of the corresponding uncertainty distribution for crack growth?

MR. RUDLAND: There's no doubt that there is correlation. I mean, crack growth initiation need to be correlated; they can't be treated uncorrelated, right? So there is a need to have that.

MEMBER STETKAR: Does this model do that?

MR. RUDLAND: The model will do that; it doesn't do it as fast.

MEMBER STETKAR: Okay. Thanks.

MR. RUDLAND: It needs to consider that.

MEMBER STETKAR: Okay.

MR. RUDLAND: I mean, it's the same with material--

MEMBER STETKAR: Right now, they're treated as all independent variables?

MR. RUDLAND: Right, in material properties, what we did for the demonstration was we have correlated material properties, so strength--I'm sorry, yield strength and ultimate strength need to be correlated.

MEMBER STETKAR: Yes, but I mean that you did by putting constraints on--

MR. RUDLAND: That's right, and where we have--we have correlations with the data which allow us to develop the correlations. Developing the correlations in this case simply don't hold that much value in initiation; it's difficult to correlate--to develop the correlation parameters that are needed, so we're going to have to work on that in a little bit more detail.

MEMBER STETKAR: Thanks.

MEMBER SHACK: Well, I'll make the comment here. Again, crack initiation is always aleatory. There are crack initiation parameters that are epistemic, but you can't have the crack being initiated as an epistemic uncertainty.

MR. RUDLAND: I totally agree.

MEMBER SHACK: And you'll get very funny results when you do it.

MEMBER STETKAR: Which is why--which we'll see later.

MR. RUDLAND: Which is why we did what we did. To talk a little bit about the framework, again, we wanted to pick the best framework, so we looked at commercial and fully open source software, and these modules that were developed were developed independently, and used consistently between these two frameworks. So we wanted to see which one worked the best, we had a series of metrics that we developed for choosing which framework, and they considered both technical and cost considerations. The first is this commercial software called GoldSim, and it's an object-orientated language that allows you to plug and play different aspects, whether it be DLLs, Excel spreadsheets, Access databases, and control how the data flows between these. It has a very self-contained probability distribution selection techniques and things like that. It allows you to also develop dash fours so that you can monitor and run the problem on the fly and look at how things are changing and developing and things like that. It also has a series of post-processing tools built in to calculate the probabilities and any kind of distribution that you may be interested in of any kind of variable that's running throughout the course of the code.

For the pilot study, we used Excel as our input for the framework. It's not limited to Excel, again, we can use Access databases, which is what we're probably going to for Version 2. The code itself is only--the licensing fees are only applicable for the developmental version; for the player run version, there is no licensing fee, so it doesn't come into effect if you just want to run the code, only if you want to develop it. Oh, I'm sorry. This was developed at Sandia National Labs.

SIAM is a open source code that's written in Python, developed by Oakridge; it uses more of a typical tab-based types of input, but again uses the same modules that we used in the GoldSim version, and it allows you to do the same kind of flexibility that occurred in the GoldSim model, but it was all programmed from open source software.

CHAIR ARMIJO: So neither of these things are proprietary software, right?

MR. RUDLAND: The source code for GoldSim of course is proprietary.

CHAIR ARMIJO: If it was developed by Sandia, who could it be--

MR. RUDLAND: Well no, the xLPR model within the GoldSim framework was developed at Sandia, but the GoldSim software itself is distributed commercially through a company called GoldSim International or something like that.

CHAIR ARMIJO: So if you settled on the use of this code, you'd always be--

MR. RUDLAND: Yes, and we have--I'll talk about that here in second, as I get into the pilot study.

MEMBER BLEY: It's the big simulation code that was used for Yucca Mountain, for that analysis. You can build a scary amount of stuff at--

MR. RUDLAND: I'm going to dive right into the results, because this is just a continuation of the prior problem.

CHAIR ARMIJO: Well, before you go on, I think it's a good time to take a break. We'll take a 15 minute break--Jack had one question.

MEMBER SIEBER: Yes, just a quick one. You bound the operational loads on the piping system that you're studying by using design values. When you have a seismic event, to what extent do you accommodate actual seismic events that exceed the design--seismic design capacity of the plant itself? For example, there's a probability associated with the loads and the frequencies transmitted by seismic event to a piping system, and--

MR. RUDLAND: Right, so those are developed in seismic hazard curves, right, so it gives you the probability of a certain g that occurs for that particular plant.

MEMBER SIEBER: And one of the things that can happen is the pipe may not rupture, but the support may fail.

MR. RUDLAND: That's right.

MEMBER SIEBER: And do you make any attempt to model support failures and its effect on increasing loads on the piping system, which would then cause a failure of the piping system?

MR. RUDLAND: Now this code's not meant to be a structural, full-blown analysis. We're focusing just on the piping ruptures. It could be that as we move forward in future versions, we can include those kinds of things, but then there's a lot of complexities that go into that. You've got to get the actual plant design into this kind of code, right, and --

MEMBER SIEBER: I can think of two units that sit side by side, that basically have the same seismic profile, but if you walk through one and look at the hangers and supports, and then go to the other unit, it's different codes that are developed to design the supports, there's a factor of two or three difference in the strength of the supports.

MR. RUDLAND: But going from the seismic hazard curve to the actual stresses at this location takes a very detailed analysis, right? So right now the code only allows the inputs of the stresses at that location. How you get to that is up to the user. If we want to go down the path of putting in the actual seismic hazard curves, then the design of the plant has to follow behind it.

MEMBER SIEBER: Yes, you actually can't get to the ultimate solution without both parts.

MR. RUDLAND: That's right.

MEMBER SIEBER: This part, plus the--

MR. RUDLAND: That's right.

CHAIR ARMIJO: Okay, we're going to take--

MEMBER SIEBER: --analysis and the loads.

CHAIR ARMIJO: Jack, you're finished? We're going to take about 15 minutes, but let's not--let's be back at quarter of 11, okay?

(Whereupon, a recess was taken from 10:29 a.m. to 10:43 a.m.)

CHAIR ARMIJO: Hey David? We're going to need you to get started again. Thank you.

MR. RUDLAND: All right, so in this

portion of the presentation, I'm going to talk about the results of the pilot study problems and sensitivity studies that we did, and this is just a listing of those again, and in some cases we did with and without inspection and leak detection; in other cases, we included mitigation with that study also. All right, so this first set of results, it'll take me a little bit of time to go through this, but what we're looking at here is, on the left hand side is the probability of crack occurrence. And you'll see there's some gray lines, there's some green lines, there's some red lines. The gray lines represent individual epistemic realizations. So each one of those is the distribution according to the aleatory uncertainty. So this is the answer to your question. We keep each of those curves that represents the aleatory uncertainty.

MEMBER STETKAR: But in this particular case, those curves are represented by either a zero or a one, right?

MR. RUDLAND: In this particular case. In the next case, not, but in this case they are. And the reason--you're jumping my gun here--but the reason they are--

MEMBER STETKAR: Okay, go ahead.

MR. RUDLAND: It's because of the classification of the uncertainty in the initiation.

MEMBER STETKAR: Go ahead.

MR. RUDLAND: The red line is the mean value, and the green line is the 95th percentile, and as it was pointed out, it's either zero or one, and that's because of the way that the initiation was--initiation uncertainty was characterized.

MEMBER STETKAR: And David, if I plotted this on a log linear scale rather than the linear-linear scale, the median and the fifth percentile in this are precisely zero, or are they just smaller than--

MR. RUDLAND: These are precisely zero.

MEMBER STETKAR: They are--just because of the--

MR. RUDLAND: You had zero--you had more than 50% where there was actually no cracks.

MEMBER STETKAR: Precisely zero? Okay.

MR. RUDLAND: Yes; precisely zero. And again, these have no inspection, leak detection or mitigation through the course of the analysis. If I look at it and categorize the initiation as aleatory, you get a big difference in the response. The mean value, of course, is the same, but you see now that the gray lines, which again represent the epistemic realizations, aren't zero anymore.

MEMBER STETKAR: Okay, now why? if you're actually carrying through all of the distributions, and you have a full sampling of all of the distributions, why this dramatic change just because you throw one parameter into one bin versus another?

MR. RUDLAND: Because the gray lines represent the aleatory uncertainty, right? And the different lines--so if you have no variables as aleatory, you're not going to get any lines. If you have them all as aleatory, all of that randomness will fall into the gray lines.

MEMBER STETKAR: I guess maybe I'm not phrasing my question--

MEMBER SHACK: Well, how about this way. If it was truly epistemic, that means I could do enough study to tell me when the thing would initiate, and that's not true. I--no matter how many tests I run--

MEMBER STETKAR: It's a different--yes.

MEMBER SHACK: --I will never get an epistemic--so it's a physically unrealizable situation. This is one case where you can't say one is epistemic and aleatory; this is--the initiation is aleatory. Now there's an epistemic component to that, you know, what he has here, I don't know how he got the data, but what he shows here, in this case, the distribution of parameters that he's using for aleatory should be the distribution of initiation times he sees on a given heat of material, and that gives him this aleatory distribution. He could then have a different one of those distributions for different heats, which he would then pick in his epistemic loop and come through. And then when you switch them around, you would not see this--

MEMBER STETKAR: In principle, that's right.

MEMBER STACK: --this bizarro behavior.

MR. RUDLAND: What we did in the first case though, we just forced everything to be epistemic. So it's saying that for an epistemic realization on crack initiation, there's no variability, is basically what's it's saying. That's why you get either zero or one; it either happens or it doesn't; there's no variability. Where when it's aleatory, now there is variability per epistemic realization, so you see that now there's curves on the gray lines for each of those different realizations. And again, it doesn't change the mean value because when you sum them all up, you're still summing them all up, whether they're in one bin or the other. But the 95^{th} percentile changes because of how you characterize that particular type of uncertainty.

MEMBER STETKAR: Well, and your understanding of the uncertainty, especially around the 10 to 20 year time frame changes substantially, of course.

MR. RUDLAND: But what this tells us is that the problem, no matter how you characterize it, is driven by initiation, because--

MEMBER STETKAR: This particular set of weld residual stresses.

MR. RUDLAND: You're absolutely right. This problem is driven by crack initiation. So the left side shows the occurrence of a crack, but the right side shows the probability of rupture, and the differences are relatively trivial. the crack growth rates are very fast, so as soon as they initiate, they rupture in a very short amount of time. So there's not a big effect of anything other than the crack initiation. And when we did the sensitivity studies we'll talk about in a second, residual stress falls out of that as being one of the major drivers. So since I just said that, I guess I'll talk about it.

CHAIR ARMIJO: Stop initiation.

MR. RUDLAND: So we did a series of sensitivity studies to determine the driving variables, and what fell out of it was that residual stress for this set of problems is controlling 43% of the uncertainty. So it's a huge portion of the results is being driven by sigma-nought WRS, which is the ID residual stress. B-1 is one of the initiation parameters that fell out it; it also has a pretty large driver to the uncertainty of the problem. However, no matter how you analyze it, both the GoldSim and SIAM results were very, very close to each other; there were some slight differences in how the initiation model was incorporated into the framework caused those slight differences that you can see between the two results.

MEMBER STETKAR: On a log scale factors--those are factors of two to five down in the 10, so that's--depending on what you think is slight.

CHAIR ARMIJO: In this business, that's very subjective.

MEMBER STETKAR: Do you understand why those differences are occurring between the two--

MR. RUDLAND: Yes, it was how they incorporated the initiation models into the framework.

MEMBER STETKAR: Okay.

MR. RUDLAND: It was what we factored down. Looking at some of the other results--

MEMBER BLEY: And that's a bit of--due to the fact we have this--each of the groups are working separately, so they're doing these things on their own, and then after they've finished, you're comparing notes?

MR. RUDLAND: Yes. So there's a set of documents that have to be developed through the QA process that allows the Models group to talk to the Computational group of how the model is developed with the--what's in the model, and how it should be incorporated into the framework. And so there's talk that goes on, nothing's done in vacuum, right? So the groups talk to each other during the development of the modules, but--

MEMBER SHACK: No, but I mean do they then go back and decide which is the right way to incorporate the initiation module into the framework?

MR. RUDLAND: Yes; there's discussions as it's being incorporated and how to do that.

MEMBER SHACK: And presumably that would reduce those differences, then?

MR. RUDLAND: It would. And that's how we actually found those differences. As we're talking within the Computational group, and we saw those differences, we talked about between the Sandia group and the Oak Ridge group, how are these things incorporated, through flow charts and through that, we found how they populate those--

CHAIR ARMIJO: Dave, in these curves, the mitigation is then assumed to be 100% successful? Once you mitigate something, the probability is--

MR. RUDLAND: Yes, that's right. The distributions that were chosen for the mitigation stresses were enough to stop the crack from growing, and that was all the cases. If you notice though--and I'll jump the gun a little bit--if you notice here in the mitigation case, the purple line is slightly above the orange line in this particular case. And what happens is there's a certain select group where the cracks are deeper than the compressive residual stress field, and in those cases, it actually increased the probability, even though it was slight, it increased the probability when you--

CHAIR ARMIJO: So it was too late.

MR. RUDLAND: It was too late.

CHAIR ARMIJO: Okay. And this is strictly for the weld overlay mitigation, or any other kind of mitigation?

MR. RUDLAND: This one is just a mechanical stress improvement, so this is the one where they actually squeeze the white--

CHAIR ARMIJO: Squeeze it, okay.

MR. RUDLAND: Yes, the other mitigations aren't incorporated in Version 1 yet, but the results would be expected to be similar.

CHAIR ARMIJO: All right.

MR. RUDLAND: The problem with overlay--or the difference between overlay and MSIP is that you also have the replacement materials in light of additional material for the wall to grow through before you leak or rupture, right? So it's going from an Alloy 82 material to now an Alloy 52 material, adding thickness, changing the wall thickness, so it has a lot more material to grow through.

CHAIR ARMIJO: Does the probability go down after you do--

MR. RUDLAND: It would seem so. I would think so, yes, because you're mitigating not only from a stress base, but also from a material base.

CHAIR ARMIJO: Yes, and material.

MR. RUDLAND: For some of the other results, the upper left hand corner is the effect of inspection only on the base case results, because the PWSCC model, crack growth models, are relatively aggressive at these temperatures, the inspection interval is not as sensitive as you would expect. A two-year inspection--a 10-year inspection level did not reduce the probabilities more than a factor of two. Down to a two-year ISI was you know, on a order of magnitude or a little bit more than an order of magnitude. So they weren't very sensitive to the inspection because of the high growth rates that are experienced at these temperatures. Looking at the two-year ISI plus a 1 gpm leak detection, now we're seeing more like four orders of magnitude, four orders of magnitude decrease in the probabilities.

MEMBER STETKAR: You know, I read through these results, and I looked at--I tried to understand them, and I understand why the inspection, you know, in principle gives you what those results show on the upper left hand corner. I also understand why the leak detection doesn't give you an awful lot, because of the size of the leak. In fact, the inspection if I look at a two-year inspection interval, it's roughly a factor of 25, let's say, and the leak detection at a 1 gpm leak detection gives you a factor of, I'm going to say 10; it's a little less than 10. If I combine those two now, suddenly I get 25 from one, 10 from another, and somehow they combine to 10,000. That to me--and it's explained--there's explanatory text in your report about leak detection individually, about inspection individually; the sole explanation for the upper right hand corner is "the effective combination of leak detection and inspection and the base case mean probability of rupture is shown figure 28. These results illustrate almost a full order of magnitude decrease in the probability of rupture." Why? You know, what's going on in the model that results in such an extensive compound effect from those two things that are not individually--

MR. RUDLAND: Yes, it's a combination--

MEMBER STETKAR: --you know, very, very effective?

MR. RUDLAND: Yes, it's a combination of the flaws that are being missed by inspection may be larger flaws that would produce very large leak rates, right? So there's certain cases where what drives the lower probabilities are the very long flaws that don't have much margin between when they first leak and when they rupture. Those are the ones that really drive anything that's on the lower probability side. Because if you allow the crack that may only have a tenth of a--a margin of 1.1 to go through, you don't have as much time to remove it as you do one that has a margin of 10 on crack size or something like that. So I think it's a combination of those--it's finding those particular cases where you have a very long crack--

MEMBER STETKAR: Let me just--because I know nothing about cracking. Have you really dissected that particular set of results so that you understand why, when you combine two things that individually have rather modest effect on the results, they produce a really dramatic effect on the results?

MR. RUDLAND: Yes. You know, I think to the extent that we did in the pilot study, we looked at--we record that--what we received was not an error in the code.

MEMBER STETKAR: Could you, in future versions of the report, or somewhere try to explain that behavior?

MR. RUDLAND: Of course.

MEMBER STETKAR: Because it's certainly not--was rather surprising to me. Because I thought I understood the mechanics of it individually pretty well, and suddenly they get super good together, and we're talking about low probability, so we--this tells me that an effective leakage detection and inspection program is what I can rely on a mean value estimator to get me down to those really, really little numbers that you really, really want to get to, and I would then really, really like to have confidence that I understand how that model's working.

MR. RUDLAND: Yes, and from our investigations, the ones that cause--when you have mitigation, leak detection and ISI, the ones that get through are the ones that are again, longer, much longer cracks, okay. Much longer surface cracks that when they leak, are right near the rupture properties of that particular pipe. So they don't have any time to be caught by detection, because as soon as they penetrate the wall, they rupture. And those are the ones that drive the low probability events.

CHAIR ARMIJO: I'd like to ask a question about the hydrogen mitigation effect.

MR. RUDLAND: Okay.

CHAIR ARMIJO: That's your lower left hand corner chart. Now, is there data that supports this higher--the effect of higher hydrogen on crack nucleation and growth for PWSCC?

MR. RUDLAND: Yes.

CHAIR ARMIJO: So you have data there.

Then the question I have is, let's say, why don't those curves parallel each other? Why--it looks like it, for 20 years, you have almost an order of magnitude of reduction in probability of rupture, but even holding the hydrogen at the maximum level, doesn't make much difference at 50 years or 60 years. What's going on there? Is it losing its effectiveness? I'm just trying to understand what's--how this--

MR. RUDLAND: Oh, you mean why is delta bigger at 20 years than at 60 years?

CHAIR ARMIJO: No; why aren't the deltas the same as it comes through time?

MR. RUDLAND: I'm not positive. The effects of hydrogen is not a linear effect, right, so if you look at the equations or how hydrogen works into the crack growth rate, it's not a linear relationship with the change in the amount of hydrogen concentration.

CHAIR ARMIJO: But in the BWR case, where hydrogen was added, it was terminated, that's crack growth, and if it's true, if you waited longer, maybe it would lose its effectiveness for a deeper crack. I don't know, but it just seems like this is--over time, the hydrogen loses its effectiveness as far as reducing the probability of rupture. And I don't understand that.

MR. RUDLAND: Yes, I think someone else will go into a little bit more detail. Again, I'm not an expert right now on what was done in this MRP-263 when these models were developed, but--

CHAIR ARMIJO: Okay. Well, just a point to think about.

MEMBER ABDEL-KHALIK: Back to John's question. What happens when you actually mitigate? What does mitigation effectively mean in terms of the modeling? Do you essentially restart the problem?

MR. RUDLAND: No. No. We change the--

MEMBER ABEL-KHALIK: What does it--

MR. RUDLAND: --we change the environment that's affecting the crack growth somehow or another, be it by a material, be it by the geometry, or be it by the stress.

MEMBER STETKAR: He's using the term mitigation differently--use the word repair, and ask the same question.

MEMBER ABDEL-KHALIK: Okay. Once you discover one of these things, you repair it. You essentially throw that sample out of--

MR. RUDLAND: During the inspection you're talking about?

MEMBER STETKAR: That's exactly right.

MR. RUDLAND: Yes, during the inspection, if a flaw is found, that's the end of that particular simulation for that flaw.

MEMBER STETKAR: That never becomes a rupture?

MR. RUDLAND: That flaw never causes a rupture in this version. Now--

MEMBER STETKAR: In a sense, that simulation is removed from the results?

MR. RUDLAND: Right. In the future versions, it's going to be repair, remediation techniques that are incorporated, such that something else will be put in its place that may initiate a flaw down the road.

MEMBER ABDEL-KHALIK: I'm just trying to get to his question, whether that's just a matter of how we define mitigation.

MEMBER STETKAR: It's--well, the repair model is applied equally for the--whether it's a leak detection or whether it's an inspection that discovers the crack, so that individually, however they apply that, throwing out a simulation is the way I think of it, but that's the way it's done for the upper left hand curve, and for the curve that's not shown on here that shows the effect of leak detection.

MR. RUDLAND: Yes, they're all done post processing, so you've got all these numbers, and you basically take out the ones that go above a certain--

MEMBER STETKAR: Yes, you say okay, I found this one, so it's thrown out of my results, so it never contributes to the break, and what's left over is this.

MR. RUDLAND: That's right.

MEMBER STETKAR: So how they apply it doesn't make any--you can argue with how they apply it, but how they apply it doesn't affect my question about why the compound effects--

MEMBER ABDEL-KHALIK: Right, that's what I'm trying to get to.

MEMBER STETKAR: --over time, both detection and inspection give you such a dramatic change, that everything else being held equal, I would have estimated a factor of maybe a few hundred, maybe a thousand, because I understand there's compound effects. But 10,000 is a pretty large number, or small number, depending on which way you're going.

MR. RUDLAND: Did that answer your question? I mean, I'm not sure--

MEMBER ABDEL-KHALIK: No, not really, but that's okay. I--then your question is imminently valid. I don't know how you would--

MEMBER STETKAR: Well, they seem to--I'd just like a better explanation in laymen's terms, because as I said, I sort of understood individually why. It was a bit surprising, but when I thought about it, I understood individually why they were not as effective as I would have expected them to be, but then I was surprised that the composite effect was so much more effective than I would have expected to be, given the individual contributors. So if there's a reasonably--a reasonable explanation for that, it would be appreciated, because--

MR. RUDLAND: And there is, and maybe I'm not expressing it very well. But for the cases, again, that create the low probability, you have a situation where you have a flaw that is very long, such that when it leaks, it ruptures right away. So the cases that are removed by leak detection are something other than that. Now whatever numbers there are, those numbers that are removed by the leak detection aren't those cases where a low flaw gets very close to rupture.

MEMBER STETKAR: But why then the leak

detection by itself? Your 2 gpm leak detection by itself doesn't give you any more than a factor of--

MR. RUDLAND: Because there's other flaws that may be--because there's other flaws that may not be in that particular category that are very long surface flaws that rupture right away, that get by the leak detection.

MEMBER STETKAR: I understand that. That's driving--it can't get any lower than that because of the frequency of those flaws.

MR. RUDLAND: Right.

MEMBER STETKAR: I understand that. The question is why does the leak detection alone not discover all the other population of flaws that are growing to through wall leaks that are between your dashed orange line and your blue line?

MR. RUDLAND: All right, so the ones that the leak detection missed are those that I'm just talking about--

MEMBER STETKAR: I understand that, the leak detection and the inspection both missed that because they're big enough, and they happen fast enough that the pipe breaks.

MR. RUDLAND: Right, I was trying to demonstrate that there's certain ones that the leak detection missed, and there's certain ones that the inspection missed--

MEMBER STETKAR: I understand both of those individually; I'm trying to understand why--

MR. RUDLAND: When you combine those together, there's only one set of results that are left, right? So there's certain flaws that the inspection can miss that the leak detection will pick up, and there's certain flaws that the leak detection will miss that the detection could pick up. For instance, these long--

CHAIR ARMIJO: High probability.

MR. RUDLAND: --these long flaws that as soon as they leak rupture, could be caught by the inspection. Won't be caught by the leak detection, but could be caught by the inspection, but may not be caught by the inspection.

CHAIR ARMIJO: But should be highly--

MR. RUDLAND: Should be what?

CHAIR ARMIJO: You have a very high probability of catching these super long, deep cracks that haven't leaked if ISI isn't good enough to catch those.

MR. RUDLAND: But there's always a probability that it won't, right?

CHAIR ARMIJO: If it's that bad, you know there's something wrong with your inspection technique.

MR. RUDLAND: I'm saying that there are--what drives something that's times 10 to the minus nine? It's not very many times that that actually happens, but there's still that probability in a POD curve that you will miss that particular--

CHAIR ARMIJO: Yes, that's getting down to a real low, low number.

MEMBER STETKAR: Some of this stuff is the genesis for my question originally about the uncertainty in that POD curve, because the POD curve itself is a set plus or minus one sigma, and one of the parameters there gives you about a three order of magnitude, three orders of magnitude, and that's just one sigma, in the likelihood of non-detection. So the detection for the inspection part of the problem is very, very broadly uncertain. And you're right--

MR. RUDLAND: Can I make a suggestion? How about we--I'll create a write up for you if you'd like--

MEMBER STETKAR: I'd appreciate that. You know, as I said, I'm not a crack growth sort of guy, so--thanks.

MR. RUDLAND: And then we can discuss it at additional--at further meetings down the road--

MEMBER STETKAR: Just send it to--

MR. RUDLAND: I'll send it through Chris.

MEMBER STETKAR: --through Chris, because I think a number of us might be interested in that.

CHAIR ARMIJO: We'll get it to everybody on the committee.

MEMBER STETKAR: It was just notable, actually it was just notable in the report. You did such a good job of explaining individually both of those things, and there's just sort of a sentence and a curve and say oh, gee, look what we found.

MR. RUDLAND: Yes. We'll have a better explanation of that.

MEMBER SIEBER: I have just a real quick, simple-minded question. If you have a long, thin flaw, is that going to be circumferential?

MR. RUDLAND: Could be.

MEMBER SIEBER: Could be, or will be?

MR. RUDLAND: No. Could be. Could be. It--again--

MEMBER SIEBER: Is it going to be OD or ID?

MR. RUDLAND: OD or ID, because that's

where--

MEMBER SIEBER: It could be either one?

MR. RUDLAND: There's no driving force, there's nothing to drive it on the OD. There's no environment to drive it on the OD.

MEMBER SIEBER: Okay.

MR. RUDLAND: So it would be on the ID.

MEMBER SIEBER: So it's going to be ID?

MR. RUDLAND: Yes. Yes, and what drives the long circ flaws is a high ID residual stress. So if you have a high ID residual stress, the growth in the length direction for a circumferential flaw is a lot higher, and you end up with a long--and that's what we learned through this Wolf Creek effort, was that you can get some cases where you end up with a 360 degree flaw.

CHAIR ARMIJO: And you also have to have a very favorable nucleation environment, because without a--almost simultaneously, and that's a real dangerous situation.

MR. RUDLAND: And in some cases, if the stresses are high enough, it will grow without any other additional nucleation besides the main one.

MEMBER SHACK: What you need is something through wall to slow it from growing through wall too fast, but a high ID so it keeps on going around.

MR. RUDLAND: And that's what this is, the third order type of representation of the curve for certain geometries, that's what happens, is once you start to get to that compressive, the driving force and the crack basis tends towards zero as you go through wall, but on the ID, it's very high and it'll just keep wrapping around the circumference.

CHAIR ARMIJO: So you have two ways to get to that situation. You have multiple nucleation sites, or one nucleation site with a very unfavorable residual stress pattern that just makes it grow.

MR. RUDLAND: For the smaller diameter pipes, it's much more likely to grow around the circumference. For the hot-leg size pipe, the circumference to the thickness is a lot different ratio, so it's going to grow through thickness before, unless it arrests through thickness.

CHAIR ARMIJO: Okay.

MEMBER SHACK: In BWRs, you had lots of large diameter pipes with lots of cracking around the ID, because it just didn't get through the wall very fast.

CHAIR ARMIJO: But I think, you know, I worked on that problem, you know. We were convinced, and it may not be true, but we were convinced that we had set that up by the fabrication process that we allowed, and that was post weld grinding of every ID, and nucleation was the easiest thing you could do, and we confirmed that in the pipe test lab work that we did, and Jerry Gordon did. So if you nucleate--if you have a favorable nucleation environment, you can grow some of these cracks that are never going to leak until it's too late; as far as I know, only one experiment's ever been done that led to something like that, and Bill did it. I actually got a rupture because of very uniform--

MEMBER SHACK: Well, I did it at PNL, but I was sponsoring the experiment. Yes, thank goodness it was at PNL, not my lab.

CHAIR ARMIJO: Well, I didn't say your lab, Bill; I said in the lab, so.

MR. RUDLAND: There was some PC results that I remember seeing on the recirc line that had been grounded on the ID surface, and it was just littered with flaws all the way around the circumference.

MEMBER SHACK: Well at Duane Arnold of course in the field was the biggest.

MR. RUDLAND: Yes, right.

CHAIR ARMIJO: You know, that was generally accepted practice to make a nice ID surface so you could get a great x-ray and in fact, you created nucleation site, and that's bad news, and somewhere in there, that's got to be discouraged in future plans.

MR. RUDLAND: We also did the safe-end case, and again here is the--this is a case where the residual stresses were slightly different than the base case, but we looked at no inspection, leak detection or mitigation, with mitigation, with inspection and leak detection, and then with all three put together, and looked at how those probabilities changed. We then can take a look--and these again are all mean probability of results, they're not any of the quantiles, just the mean value. But we can look at how confident we are in the mean value by doing bootstrap methods that allow us to come up with distributions based on that particular analysis to help us have confidence that we have a converged solution. So in this particular case, the case with the ISI and leak detection and mitigation, we're not so confident that the results are good, and so we would have to do additional realizations to boost that confidence.

MEMBER STETKAR: When you did your realizations, did you have any sort of convergence criteria on the mean? I mean, that's one way of--did you apply those, and did you look at those?

MR. RUDLAND: No, we do all that in the post processing. So after we run the results, we have to do something like this here to give us the confidence--

MEMBER STETKAR: Yes, okay; but actually, when you--you just had a--I don't want to use the term arbitrarily, but you had a selected set of number of samples for both the aleatory and--

MR. RUDLAND: And basically what--the numbers that we ended up using in the pilot study, it's kind of a circular study, right, so the numbers that we used were based on results that gave us this kind of--

MEMBER STETKAR: Okay. Okay. So you sort of did that--

MR. RUDLAND: We figured it out, yes, and it's not automated. In addition to all this work that we've done with this team that I showed you, we also have--we contracted independent review and V&V with the guys down at Southwest Research and the Center for Nuclear Waste Regulatory Analysis. And they were mainly tasked with the comparison between--independent comparison between the GoldSim and the SIAM versions of Version 1. And we gave them a set of metrics, and they went in and they tried to install dummy modules and tried to crash the code and to characterize them by these particular metrics. And they did a very thorough and complete evaluation of both frameworks, as well ass the modules within the frameworks. And we did that, again, to get an independent view of how the codes were going, and to help us in the decision-making process between the open source software and the commercial software. And there's no time to go into their results, but from that effort, as well as from our independent effort, there was a series of lessons learned and gaps that we came up with.

There was some organization issues, we had some communication issues, we set up this--originally, this advisory board as an oversight board, but it was too many people to be able to make a good decision with; we had too many cooks basically. So we had a team of 12 guys trying to make a decision; it just didn't work. It was just too many.

MEMBER STETKAR: Now you have a SAR?

MR. RUDLAND: So we had to do that. We had to come up with a clear leadership, and we had to reduce the membership to make it more workable. We had some intergroup communication difficulties; as we're talking about the Models group talking to the Computational group; sometimes it worked, sometimes it didn't. So we needed to be able to smooth that out a little bit more. There was a bunch of framework issues; we had some input-output issues with it being user-friendly, just because we didn't focus on a lot of the goodness of how things look and how things run in feasibility studies. The purpose was not to demonstrate the feasibility of running this code fast; it was basically just as the process. So there were some issues there.

Again, there's uncertainty classification, how we do that, and we need to look at that a little better. We wanted to come up with some improved sampling techniques. Important sampling works really well, as long as you know what's the important samples. If you don't know the important sample, it's useless. So we're developing adaptive techniques that will actually go in and be able to important sample based on the results of what it's calculating instead of actually ahead of time picking variables.

MEMBER STETKAR: When you do that, though, be careful that you look at the shapes and the breadths of the distributions, because it's not just sampling from distributions that are fairly narrow that just happen to show up as important contributors--

MR. RUDLAND: In some cases, in certain variables, it's not the tables either that you need to concentrate on.

MEMBER STETKAR: Well yes, I mean, you know. Sure, sure.

MR. RUDLAND: So it's--and hopefully those adaptive methods will be able to do that, and those are still being developed. Storage, handling, post processing are all things that can be modified as we move forward. For the models issues, having the right people for the right jobs is really important. Sometimes you can get those people, but then you have to deal with their time commitments. So we had to figure out ways of being able to access the experts that we needed and use their time efficiently. And again, we need to expand scope beyond LBB, and what we did in Version 1 was a relatively complex, but not CM system, configuration management system, but it wasn't really tied to any formal QA program. So we needed to develop the full QA program.

MEMBER BLEY: Dave? We slipped off at the last slide so quickly, I didn't get to ask a question. On that review of GoldSim versus SIAM, would you speak just a little bit to the, if you found differences in the flexibility and adaptability issue?

MR. RUDLAND: Yes sir. I can go through each of those metrics real quick and tell you what they found out. I'll start with the easiest one, which is run time. The precompiled open source software ran faster, there was no doubt. It didn't run extremely fast--extremely fast, that's kind of subjective also--it didn't run any faster than what we had expected, basically. and the I/O in the open source stuff did slow it down somewhat.

MEMBER BLEY: Enough to matter?

MR. RUDLAND: No. Well, it depends on your perspective. Not enough for me to matter, you know. The typical run here in this case took three or four hours, and whether it's three or four hours or three and a half hours, or four and half hours--

MEMBER BLEY: I see. No big deal.

MR. RUDLAND: --it's not a huge deal. Now there's certain folks in our groups that want these things to run in a half an hour, which I don't know if that's going to actually happen. I know I don't want it to run three weeks, but four hours, five hours a day to me is not that big of a deal.

MEMBER SIEBER: And what are you running it on?

MR. RUDLAND: We're running it on everything we can. I've run it on my laptop, actually. It takes a lot longer--

MEMBER SIEBER: How long does that take?

MR. RUDLAND: It takes a day, probably to run one of these problems. A day.

MEMBER SIEBER: A day?

MR. RUDLAND: But Sandia is using an x-number of processor machine, and they can run it in an hour, so it depends on the machine, of course, that's running it also. Ease of use, they both are relatively easy to use and easy to adapt. The problem becomes in how well or proficient of a covert you are if you're doing the development. If you're working on the GoldSim model, and you're able to understand the GoldSim stuff, you're great. If you're working on SIAM, and you're a Python programmer, you're great. If you're not, then of course the ease of use is not as good in terms of modifying the code. Both of them were about equally flexible and adaptable; there wasn't anything large that stuck out that said that one is more adaptable than the other, it's just that sometimes the ease of adaptability is different depending on the code and the coder's experience.

The friendliness was an issue. What we did for the commercial software was we used Excel as the input deck, and Southwest found that there was some issues with that, because you couldn't manually change the distribution type on a lot of the input parameters with Excel through the player file. It was a simple thing that could be easily changed within the GoldSim software, and not something that was a major driver towards--away or towards GoldSim. So overall, those were the main differences. Southwest themselves, in terms of technical stuff, said at the end it's a coin flip. That's basically what they said.

MEMBER BLEY: Okay. No significant differences in the ability to evaluate the dependability of the system?

MR. RUDLAND: No, not really. Not really. So they were easily navigated through, and easily changed. Like I said, they incorporated the dummy module to see how long it would take them, what the difficulty was, and in the end it was about the same.

MEMBER BLEY: Okay.

MR. RUDLAND: Where the big difference

came in was in supportability and maintenance. You know, you have a software company that is driven to support and maintain through not only your contract, but their contract, versus an open source software where a national lab is maintaining it; the cost differences become large. And that's kind of what drove the final decision. And all this is located in the Center's report, all this discussion is located in the Center's report.

MEMBER SHACK: So the National Lab was more expensive than the commercial lab?

MEMBER SIEBER: I'm sure of it.

MR. RUDLAND: For maintenance, it's got to be. There's just no way--this can't be--I can--not to talk numbers, but I can hire a guy from GoldSim for a year, dedicated for $100k. If you come for Argonne--

(LAUGHTER)

MR. RUDLAND: So the main results was that we demonstrated that it is feasible to do this in this fashion, with this kind of management structure, working within the cooperative agreement. We have a ways to go, but it's definitely feasible to do. The management structure itself was promising, but needs to be--some slight reorganization needs to occur to be able to make it more efficient, and make the communications better. We found that we decided at the end of the day to go with GoldSim, mainly because of the cost issues, but you know the technical issues there, too. There's some issues with--somebody made a comment about it--oh now you've got a commercial entity that you've got to deal with, and it's not completely open, and what could be done about that. Well, there's issues that we can deal with that. GoldSim has agreed to allow us to put the source code of GoldSim in escrow, so if something happen--

CHAIR ARMIJO: If they go belly up--

MR. RUDLAND: Yes, if they go belly up, we can get our hands on the source codes if we agree not to distribute it commercially ourselves. There's things like that that can be developed to get away from that kind of problem.

MEMBER STETKAR: Dave, will that cause problems down the--take the situation where they do go belly up. Will that cause problems because of the EPRI memorandum of understanding to make it available to EPRI users?

MR. RUDLAND: It shouldn't, I wouldn't think. I don't think it should be a problem. I mean, where the problem comes, my bigger concern than them going belly up, is that they could pull it out.

MEMBER STETKAR: Yes, well, and it disappears in entity.

MR. RUDLAND: If they get bought out, and the new people that buy them out decide to go a different route or do something different, that would be the largest impact I would think. But again, you know, the Yucca Mountain work has been--GoldSim was built around the Yucca Mountain effort basically, and they have--we have a very large client base now, and GoldSim is used for a wide variety of things. One of the things that they look at is they have a whiskey distillery that actually uses GoldSim in making predictions of how their casks are evolving. So they have a wide variety, and the fear I have is not so much of them going belly up as of them getting bought out.

MEMBER STETKAR: Well, I mean belly up is-- if it's less reliable as its current form.

MR. RUDLAND: So as we get into further contract dealings with them, we have to put the appropriate safeguards in place for us, I think. Okay. And the other thing is that--you've got this in your handouts--all of these reports that I talk about are all publicly available. What I sent you guys was just the Version 1 report, which is kind of the red box in the middle, but all of the other reports except for the final report, which is still in NRR review, are publicly available I think.

MR. HARRINGTON: The Models report is about to go to publishing, and the Comparison report we're still talking about.

MR. RUDLAND: Right, and what I'll do is I'll take those reports, once they are finally published, and stick them in ADAMS also, so they'll have independent ML numbers.

MEMBER BLEY: Now you reference this agile programming style, based on the agile manifesto of some years ago, and that clearly, at least to me, has some positive effects in moving toward good software as fast as possible. It also at least feels like it may have some problems with respect to code configuration control, or something like that. And especially after you do some significant calculations and then things change later, and I mean that's happened with the PRA code out at Idaho and other cases, where all of sudden, you can't run an old model. And how are we doing with that?

MR. RUDLAND: We are hoping to capture a lot of that in this--how we're developing Version 2 is using a spiral framework of development, where we go through a series of prototypical releases, both on modular level as well as on a final code level. Hopefully we can capture a lot of that stuff through that, because you know--I don't know if I talk about in this or not--but as you go through the modular--the spiral methodology for development of software, you go through risk management. Each time you go through another loop, you go through a risk management stage. And at that time, you have to assess those kinds of things, so hopefully you can catch them proactively, than try to catch them reactively when something does change or something needs to be changed.

MEMBER BLEY: And for significant--you'll be archiving versions of this as you go somehow, so five years from now if you need to confirm a calculation, you can find what it was run on?

MR. RUDLAND: Yes. Version 2 is being developed under a very strict QA program that includes total tracking of all of the revisions of everything, including not only the code, but all the documentation also. Yes. And it has to be able to meet a very strict program.

MEMBER BLEY: There's one of the tenets of agile programming that I wonder how you're doing with, which is working software is more important than comprehensive documentation. Are we living by that one or not?

MR. RUDLAND: We're trying to, and I think that's the most important thing, because that's what we're trying to develop, right, is the working software.

MEMBER BLEY: That's right.

MR. RUDLAND: We can write--

MEMBER BLEY: But you need to use it five years from now, too.

MR. RUDLAND: That's right. And I hope through this spiral process, after we get beyond Version 2, that we can continue on that, because any changes that we make, and additions, and new modules, have to go through that same risk management and developmental stage, and prototyping and release as we are in the development of this--

MEMBER BLEY: That's good, because you will be making improvements and changes and adding new things.

MR. RUDLAND: How we go beyond Version 2 into maintenance and changes, I'm not sure quite yet. We have to focus on the need that we have at hand, at least from the NRC point of view, we have to focus on the need.

MEMBER BLEY: Some of the discussion this morning brought up something that I'm a little interested in, because we've had some discussions about complex software at times. There was--a couple of years ago, there was a National Academy report called "Software for Dependable Systems - Sufficient Evidence," and a couple of their conclusions were there are many times simplicity in simplifying your models has a great advantage over adding complexity, especially for the aspects of being able to ensure that it's proper and working and that you don't have hidden problems operating--when you get to places in the calculation where certain phenomena are clearly important and others are not, do you have a goal of trying to simplify the models for those?

MR. RUDLAND: Yes. And that's one of the goals of the Computation group, especially if one happens to be a bottleneck or something like that; it definitely has to be addressed. I'll give you an example. I mentioned SQUIRT, which is this leakway code, and it's a very complex code. And it's a bottleneck, and really what's SQUIRT used for? Where is SQUIRT really applicable is through a very limited range, right, from the time of the first leakage to the time of leak detection. Not very much. Why the heck do I need to run it all this time, and do I need to really focus on having this huge code in there which is soaking up all of my run time and my--

MEMBER BLEY: It's somehow interacting--

MR. RUDLAND: --and it's somehow interacting when it doesn't really need it. So we're looking at that in Version 2 to say where are these portions of the code where we've got huge things programmed that maybe we can do something different. Maybe we can run that offline and read in a look up table of results that's much more efficient, but gives us the same values, the same results.

MEMBER BLEY: I hope you're able to do that, because--

MR. RUDLAND: I do, too.

MEMBER BLEY: --that's a really troublesome thing to me, is figuring out when these things get very big and complex and are interacting, it's real hard to know what's actually going on.

MR. RUDLAND: We're looking at it for leakway, we're looking at it for crack stability, because for a set of materials and a set of flaw sizes, you can calculate criticality off-line, and going through those processes which are numerically integrated in the code, it's time-consuming. It's CPU time-consuming.

CHAIR ARMIJO: What are you doing with crack nucleation to simplify that, since there's so much uncertainty in that thing? What are you going to with that?

MR. RUDLAND: Well again, the first thing we've got to do is we've got to attack it from the expert point of view. What can we do? Can we do anything better than this? Craig actually is organizing this expert panel on PWSCC, and we're going to attack it first. Can we do any better? If we can't do any better, how can we attack the uncertainty the way that we have it in the model that exists? I don't really need a way of doing this. And if there are suggestions from the committee, then that would great, but--

CHAIR ARMIJO: We have to think about it.

MR. RUDLAND: Because we'd be fighting initiation forever, and I don't see it--I don't think we're that much closer than we were 10 years ago.

MEMBER BLEY: Or simpler that at least is convincing.

MR. RUDLAND: The thing about empirical models is that they're not very time-consuming to run. Mechanistic models sometimes take a lot more to run than the nice empirical models that are just simple fits to data.

MEMBER SHACK: Garbage in, garbage out.

MR. RUDLAND: Okay, for the last few minutes, I just want to go over our plans for Version 2. I've kind of hit on it a few places in our discussions here, but I want to touch on a couple of other things. Again, because Version 1 was a feasibility study, we really--we needed to take what we've done and what we've learned, and we need to expand it to piping systems within the LBB-approved--piping welds within the LBB-approved systems. We don't want to limit ourselves to that, so in Version 2, if things like IGSCC and BWR piping welds flow easily from it, there's no reason why we shouldn't take that scope on. It would be silly for us not to waste that little bit of additional effort for a large payoff in terms of what the code can do. But we really want to focus on what we've learned in the pilot study to make sure we make the proper improvements.

CHAIR ARMIJO: I'd just like to add that one of the reasons I think you might benefit from including IGSCC and the BWR stuff is there's a wealth of information there to help you validate and test your model that you might not have with the PWSCC database, so.

MR. RUDLAND: Yes, no doubt. Definitely, I think it's important, and our goal is to get buy-in from the industry side, from the BWR VIPP and get them involved in the program. Of course now they're really not; I think if they get involved in the program, that will help us move it along a lot better down the road. The Version 2 business where we sit right now is the scope has been discussed among the leaders of these groups, and we're having a public kick-off meeting, a public meeting kick-off next week, to actually roll out some of the stuff that we're planning to do in Version 2. So we're just starting on Version 2. What we've been doing over the summer is developing this QA plan, which is, you know, I'm not a QA guy, I'm a mechanics guy, and QA scares me. And so I've been kind of thrown into this QA world, and if you're not careful, you can drown in it, but once you get the hang of it, it's really not--it's not all that bad. And it's good because it allows us to keep the traceability, which is I think is the most important thing.

We had a QA workshop, where we brought in regulatory and industry QA experts and said "what level of QA do we need for this application?" We don't want to do too much, we don't want to do too little; we want to do just the right amount. And that was very, very useful because we were able to come out of that with saying we could follow the top level requirements of NQA, and that's sufficient to meet our needs. We learned how far down the rabbit hole we have to go in validation. Do we need to validate not only the models, but the data that was used to develop those models, or the instruments that were used to measure the data that was used to validate those models? How far down that rabbit hole do we have to go? We learned those kind of things from the workshop.

In addition, we're going to have ongoing QA audits to make sure that we are following these procedures and doing everything correctly, because none of us really are experts at this QA business.

MEMBER SKILLMAN: Dave, could I ask a question please?

MR. RUDLAND: Of course.

MEMBER SKILLMAN: On the first bullet there, you make the comment about configuration management; in the second bullet, QA. Those are really different things.

MR. RUDLAND: Oh, they're definitely different things.

MEMBER SKILLMAN: And that's my question; do you see those as different? CM is being able to track where you came from, whereas QA is the ultimate accuracy and quality of your product.

MR. RUDLAND: That's right. Configuration management is only one small part of an overall QA program.

MEMBER SKILLMAN: Okay.

MR. RUDLAND: Okay. And it just allows us to--QA allows us to keep that traceability and to record that traceability through development of whatever it is that we're doing, right. So in the hierarchy that we've developed, we've got two main program basis documents, one is the Quality Assurance Plan, and the other is the Project Management Plan that describes how we're going to do the project, what the flow is, what the costs are, what the goals are and things like that. And then underlying underneath that are software configuration management and the individual work plans which will define the requirements, the design, the implementation and the testing and the release of each of the different phases of the program.

Well, what do I mean by phases? I mean the modules as well as the main code itself. So each of them have to have individual work plans that have to meet these requirements, and we've got a series of documents that describe all this and templates to follow, and the configuration management system set up that allows us to do all of this. The management structure as I mentioned was reorganized, this Project Integration board that encircled the technical tasks groups in the pilot study has been moved down to an advisory-level role, and will be separated, like I mentioned, out of the Acceptance group from the--

MEMBER STETKAR: That's one way to solve the problem.

MR. RUDLAND: -- well we reduced the numbers and we made them into an advisory role, mainly because we had such difficulty with the decision-making process, and we wanted to separate out the Acceptance, again, to allow that to develop independently of the code development, because we didn't want to imply that we were developing a code to give us a certain probability of rupture. We wanted to develop the code separately, develop the acceptance criteria separately, and allow those to evolve however they're going to evolve. But the basics of the technical working groups are the same as they were in the pilot study.

This is not meant to read, this was meant to just show you a graphic of how we have the overall schedule going for Version 2, ending at the end of 2013. We have individual developments of the models and the inputs and the computational, as well as their independent validation and verification. Some of this stuff is still in the development phase; for instance, line 33 is called Code V&V, and our QA guys changed that to just validation because verification is actually done in a different phase, it's done through each of the individual group's work plans, and not as a full code, and the code is basically just validated at the end and not verified. So it was a QA issue, but it shows just the incremental change in how we're moving forward with our milestones being meetings as well as deliverables of tests, of work plans and code and finally, a final product at the end of 2013.

MEMBER STETKAR: Dave? And again, with a caveat that I don't know anything about the actual process, given this two-year schedule, I mean basically two years from now for Version 2, is your scope back on slide 2--it sounds awfully optimistic. In that second bullet, to handle welds within piping systems approved for leak before break, that's a big leap, isn't it?

MR. RUDLAND: I don't think so. I mean, the controlling welds are the dissimilar metal welds, which we began to look at, and we have to look at the other welds.

MEMBER STETKAR: Do you think that part of the problem is actually--

MR. RUDLAND: Yes, dissimilar metal welds, I think we have a pretty good handle on, at least in the LBB systems. I don't think that that's a big deal. But what we've done as part of the QA is that what we've asked the working groups to do, the working groups are developing their work plans based on the scope that we developed now, and one of the questions I have for them is does it match the schedule?

MEMBER STETKAR: Yes; okay.

MR. RUDLAND: And if it doesn't, if we're really off by five years, then we've got to rethink--

MEMBER STETKAR: Okay, so that's still a work in progress?

MR. RUDLAND: We're still in that process, developing those work plans.

MEMBER STETKAR: Thanks.

MR. RUDLAND: This is--this meets Jay's

needs.

MEMBER STETKAR: That's what I understood, that this fits into the user need; it's a question of-

MR. RUDLAND: Right, now whether all the scope that we're going to talk about fits into this--

MEMBER STETKAR: To get apples or apple seeds or applesauce as a result of it is the problem.

MR. RUDLAND: Well what I've asked the working groups to do is when they're developing their work plan, they're also prioritizing. Things that they think are the most important things to solving these problems. Things at the bottom will get cut if the schedule doesn't match.

MR. HARRINGTON: Or the budget.

MR. RUDLAND: That's right; and within budget also, yes.

MR. COLLINS: There really is a lot of information that's been worked on these particular items to where in trying to change out the code to some of these other things like the upper head, the lower head, that's definitely going to take more retooling of the--for the differences between each weld location, they've all been identified, MRP has a number of reports which has identified the differences that they have out there. We've gone through an MRP program of our own through the ACRS site inspection guideline, and more technical basis. There should be a lot of the base information available for them to--

MR. RUDLAND: Yes, and what's in front of you say the other applications, there's codes written for CFDMs, there's codes written for vessels, there's codes written for--and it may be as easy as taking those codes and making modifications so that they fit into this format, but that's for beyond this schedule.

MEMBER STETKAR: Sorry I asked. We need to--

MR. RUDLAND: Yes. Again the scope for Version 2 is under development by the team; there's been recommendations made by the leads and this program integration board; now these groups have to go back and decide, like I just mentioned, whether it's going to fit into the time and scope and schedules that we've set forth in the program. The--this is some of the things that came out of our team lead meeting, things that we want to add or modify in Version 2, and the red represents high-priority items. So if we go through this, there is a bunch of things on increasing the solution accuracy and efficiency through different types of important sampling and other sampling techniques. Revisiting uncertainty propagation; one of the things is do we really need to do this double-nested loop business with the aleatory and uncertainty? Is there a way we can get around that and get the same results? We've got ideas and options that we're investigating that will help the efficiency of the program if we don't have to do that.

Look at the post processing and output and user capabilities; they're on the list but they're of lower priority. Models initiation. We've got to do something about initiation. So we've got this extra panel; it's top of the list, it's highest priority. Residual stress model, we need to be able to do that a little bit better, and we need to include weld repairs a little differently, I think. And then we have to update our case solutions to be consistent with that. I think those three are all very high priority items. There's a lot of other things, we've got these mitigation techniques to look at, update ISI models, crack stability, leak rate, like I talked about, we may come up with something that totally gets rid of SQUIRT and use an input table, lookup table, instead of running SQUIRT. All of these things, though, we plan to update are in the work plan; whether or not they'll be captured in the time and budget that we have is another thing that we have to come up with. But we're going to be focusing on these red ones that are here, so looking at full structural and optimized overlays first before we move into inlays and things like that.

Inputs, again, we have to include all of the transients, or a proper way of inputting generic transients into the code. Not a huge issue. We have some changes to the framework that we're going to do; we definitely know we want to change to a different type of input structure, an Access database. We're going to be adding--these are additions. We're going to be adding environmental fatigue and axial cracks, for sure, because those are the biggest drivers probably to the LBB process. We are considering IGSCC, looking at different through wall crack transitions, manufacturing defects, things like that, that are in proposed additions to Version 2.

CHAIR ARMIJO: Do you mean manufacturing defects or fabrication?

MR. RUDLAND: Fabrication defects.

CHAIR ARMIJO: Yes, right, because--

MR. RUDLAND: Weld defects--pre-existing weld defects is really what we're considering. There's a split on whether or not we really want to include those, or do they give you the wrong impression of the results.

CHAIR ARMIJO: It's a fabrication procedures which may be the cause of some of these problems.

MR. RUDLAND: Right.

CHAIR ARMIJO: The pipe itself is unlikely to have built-in defects, but--

MR. RUDLAND: So I would include that; we're still kind of investigation. So our path forward, the final report for the pilot study, which is new reg EPRI doc, and it is drafted in Jay's group's hands, is undergoing review, and we have, like I said, begin developing Version 2, we've gone through this whole QA program development effort, and are now working on model development efforts. Hopefully, I'd like to be able to talk to this group annually and have a little bit more detailed discussions about some of the things that we discussed today, as well as some of the things we may want to add. We're going to have external review panel that meets annually; this internal review panel, which is the PIB, is meeting bi-annually or on an as-needed basis. Hope to have Version 2 released at the end of 2013, and then we have a couple of years into develop and publish the reg guide for LBB, by the end of 2015. I think that's it.

CHAIR ARMIJO: Okay, any comments or questions on this part by the committee? I think our next presentation, or comments by EPRI.

MR. HARRINGTON: And in the interest of time, this is not going to take long. This has been a cooperative effort, almost from its inception, between Research and EPRI as the industry representative. I think that's resulted in significant technical synergies, both essential to bringing important perspectives and information, knowledge that has been very helpful in working through the issues that we worked through in the pilot study, and should as we move forward. It has the added benefit of producing a shared product in the end that while on the one hand, we don't have competing things to compare, we're both invested in the end point, and understand what's there, involved from its creation, so it's not one group trying to force something on the other and explain it.

As with any kind of an endeavor like this that has regulatory significance to the to the licensees, there are those that are reluctant, there's those that are skeptical, and then others that embrace it--

CHAIR ARMIJO: What's new?

MR. HARRINGTON: And I think overall, the prevailing approach has been the latter; more are embracing it, accepting it, and looking for ways to use this to everybody's benefit down the road. To improve planning of additional work activities within MRPs, some of our research work, other groups in mitigation and other areas are looking forward to how they can incorporate their interests and things that they're working on into future versions of xLRP.

I don't want to give the impression that we're always in 100% lockstep on everything that goes on; that should come as no surprise either, but we do have a very open, professional, collegial organization. We've worked well together, like some of the organizational issues that Dave mentioned, it wasn't that the Models group didn't want to talk to the Computational group, they're meeting at different places at different times; there's a lot discussed with each group. In causing that communication to occur is more the problem than a willingness, so the groups have worked well together, and that's been one positive outcome in the pilot, and one thing that we really needed to know from the pilot. As we work through this QA environment and the documentation will of course have built into that efforts to deal with professional disagreements and such should they arise, but overall, that has not been a huge problem to date.

CHAIR ARMIJO: Questions from the committee? Thank you very much. I think what I'd like to do now is get public comments and anybody on the bridge line; anybody here who wants to make comments, you're welcome to do that now, and then we'll have just a little quick wrap up by the Subcommittee members. I guess there's no one here; is there anyone on the bridge line that would like to make some comments? First of all, let's make sure they can be heard. I guess there's no one on the bridge line.

I would just like to go around the table and see if there's some wrap up comments from the members. Jack?

MEMBER SIEBER: Okay, I actually think that there's a lot of work that's been done; I think that it's technically legitimate, and I think the process is working well, so I don't have any major comments to offer that would alter the direction of what the staff and Research and the Labs and EPRI are doing. And so I'm pretty satisfied that they're heading in the right direction.

CHAIR ARMIJO: Dennis?

MEMBER BLEY: It's been a very informative morning, and I don't have any additional comments to make.

CHAIR ARMIJO: John?

MEMBER STETKAR: Nothing, thanks.

CHAIR ARMIJO: Bill?

MEMBER SHACK: Well, I'd like to say it's a really good piece of work; from my point of view, I think the Subcommittee will be looking forward to meeting with the staff. I'm particularly interested in meeting on topics rather than the entire thing. Maybe a topic related to nucleation, crack nucleation, once your expert panel figures out what direction you're going to take in that area, but the other Subcommittee members may suggest from time to time, and maybe a brief topical type reviews rather than trying to swallow the whole thing in one big annual Subcommittee meeting might be a better use of the expertise here. And with that, if there's nothing else--

MR. BROWN: Full Committee is in November; any guidance on what you want them to present?

CHAIR ARMIJO: I think it's--there's an awful lot here. I think clearly you've got to--you've got to pare it down and I think the results of your pilot study are very interesting, and pointing out where you've got some problems and your plans to address those. They're not really problems, but issues.

MR. RUDLAND: How much time is allotted for the--

CHAIR ARMIJO:Typically, a couple of hours.

MEMBER STETKAR: An hour and a half to two hours typically.

MR. BROWN: About an hour and a half to two, it depends on what you--

CHAIR ARMIJO: But I don't think there's anything that I would say definitely leave out or anything, you're just going to have to slim it down.

MEMBER STETKAR: Or talk really fast.

CHAIR ARMIJO: Or every other chart. That's about it.

MR. RUDLAND: Okay.

MEMBER SIEBER: One thing I noticed is I didn't see in your list of things you're going to produce a User Plan, and I think a User's Manual--

MR. RUDLAND: That's definitely in the plans, yes.

MEMBER SIEBER: How to use it as opposed

to one that's not only says how to use it, but has all this other stuff in it. I would separate the two.

MR. RUDLAND: Yes, if you look on the slides in that one plot that I showed that had all the reports, two of those are User's Manuals for each of the Version 1 Codes.

MEMBER SIEBER: Yes, I'm from a generation that actually had to read those kind of reports, so User Manuals are great.

CHAIR ARMIJO: Okay.

MR. RUDLAND: Do you think annually is good, is okay, or is that too much, or--

CHAIR ARMIJO: Well I think--I don't think--definitely no less than annually, but I think in the course of picking the time, you might say hey look, we're just wrapping up something that we think is significant, definitive. Before maybe that time, you just raise a flag and say would you guys like to meet on this topic, and whether it's--

MR. RUDLAND: Because one of the--I talked to Bill at the break, residual stress validation I think might be an interesting--

CHAIR ARMIJO: That's another major--it's those kinds of things, real problem areas that aren't really resolved that you decided how to take it on, that would be good.

MR. RUDLAND: Okay, great.

MEMBER SHACK: You probably ought to think about some strategies, too. I mean, you know, one of the good things that came out of this first one was, although you used very conservative residual stresses and a very conservative initiation model, by the time you put in the inspection and the leak detection, things didn't look all that bad. I mean--so you know, it may be that you're going to have to learn to live with conservatism and still--because you won't be able to get--or you may not be able to get rid of the uncertainty in the initiation and weld residual--

CHAIR ARMIJO: And it may be so big that it doesn't mean--it doesn't really impact the end result.

MEMBER SHACK: Now of course, we were only looking at mean values, and when we go back and look at 95th percentiles, it's--

MR. RUDLAND: Going to be higher.

CHAIR ARMIJO: Different story. With that, I will now adjourn the meeting. Thank you very much.

MR. RUDLAND: Thank you.

(Whereupon, the meeting was adjourned at 11:53 a.m.)

xLPR Version 2.0 Plans

David Rudland
Senior Materials Engineer
RES/DE/CIB

ACRS Meeting of the Subcommittee on Materials, Metallurgy, & Reactor Fuels
September 21, 2011
Rockville, MD

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

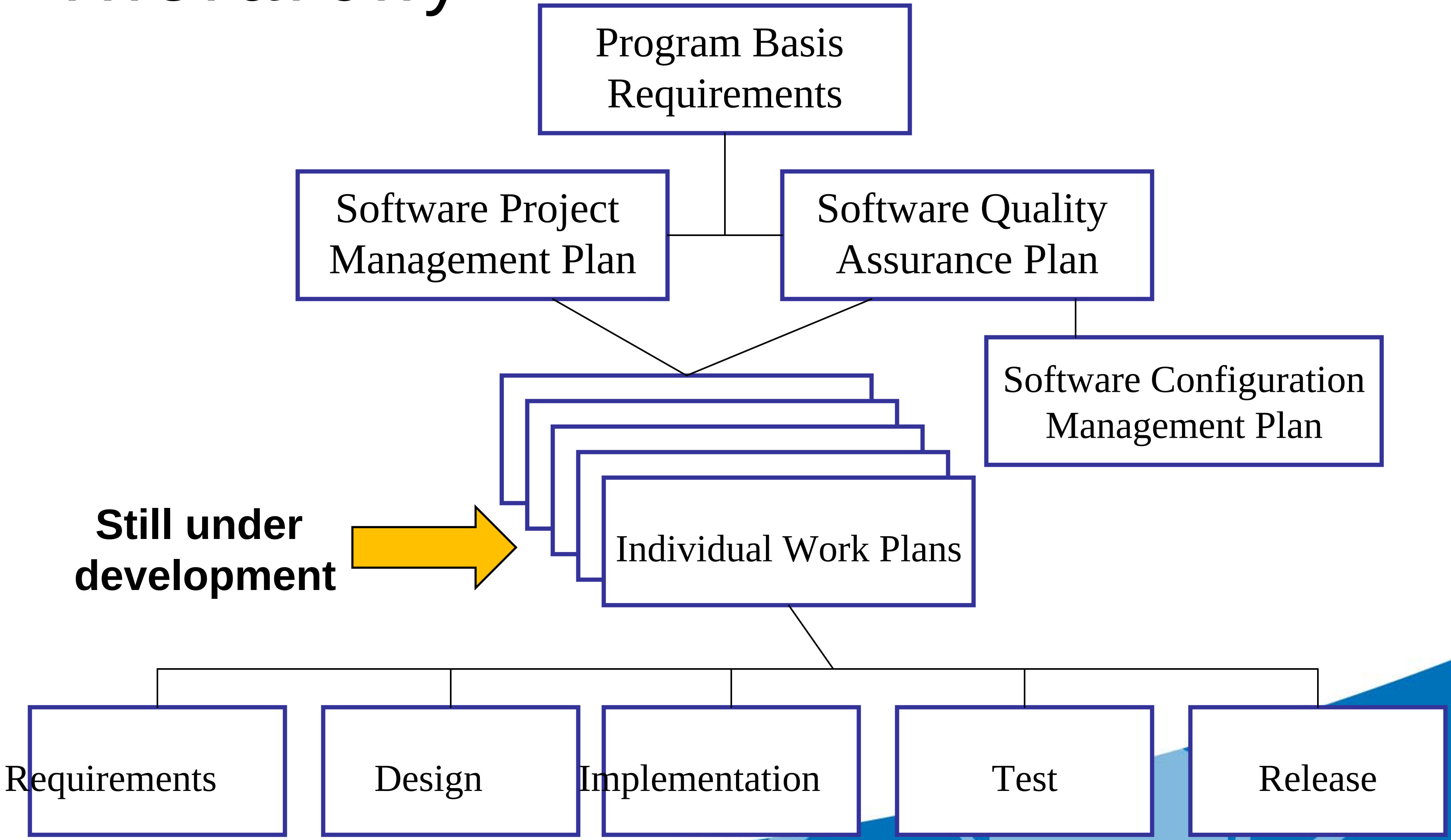
Scope

- xLPR Version 1.0 was developed as part of a feasibility study and focuses on PWSCC in a Westinghouse-style pressurizer surge nozzle DM weld
- Version 2.0 must be expanded to handle welds within piping systems approved for LBB
- In addition, the lesson's learned from the pilot study provided many area where improvement was needed
- Version 2.0 scope discussed/prioritized by team leaders – Kick off meeting to be held Sept 28-29, 2011

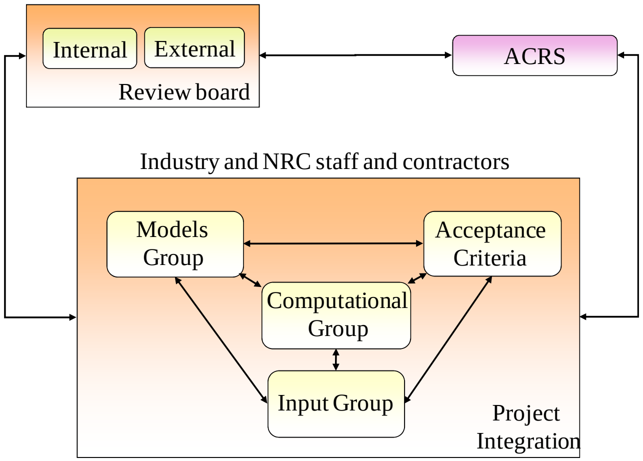
xLPR QA

- Version 1.0 was controlled by a Configuration Management plan but not associated with a detailed QA structure
- Conducted QA workshop with appropriate Regulatory/Industry QA experts
- Consensus agreement that the top level requirements in ASME NQA-1 are sufficient to meet xLPR program, NRC, Industry, and DOE requirements for software development
- QA audits will occur and be aligned with key milestones

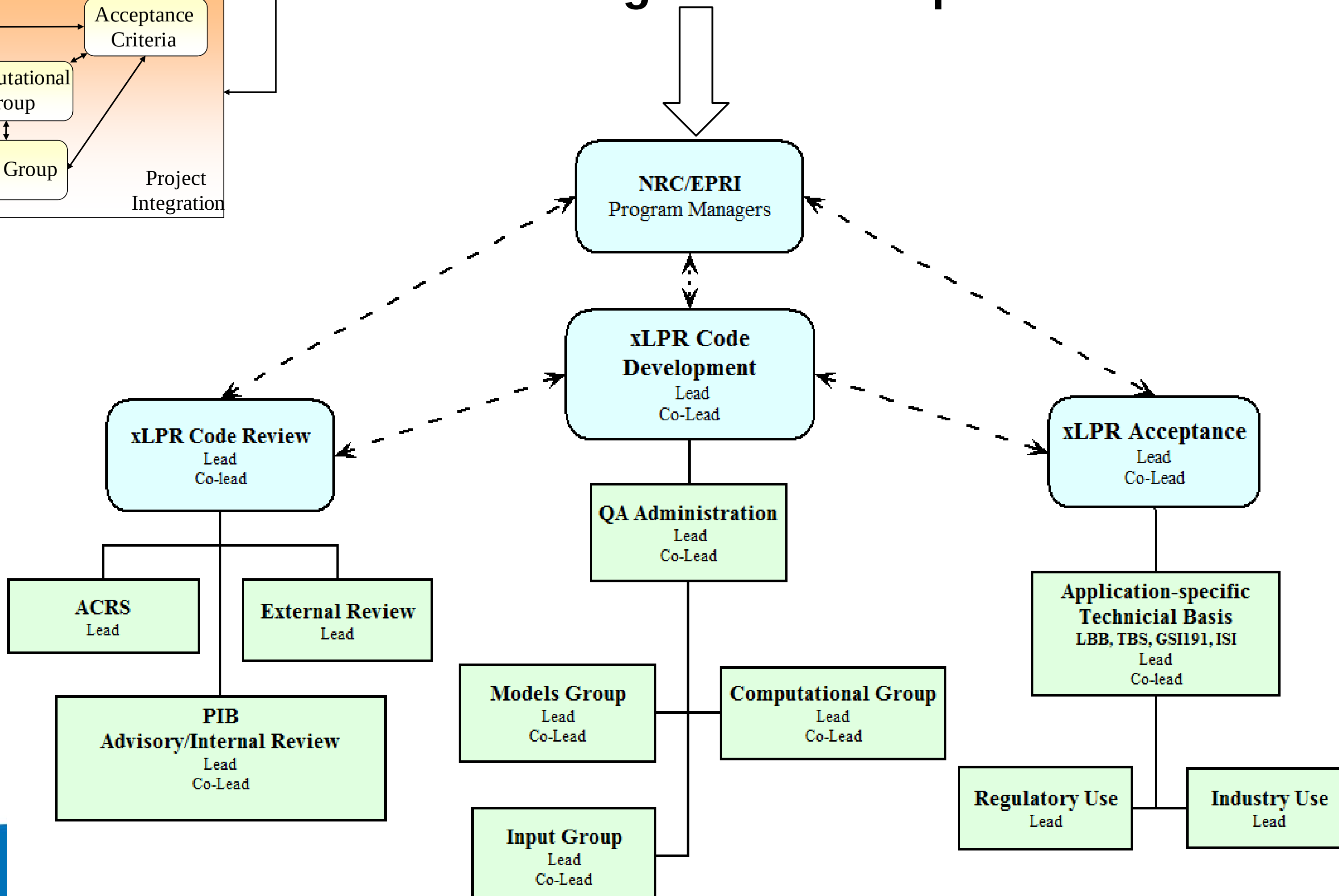
Program Document Hierarchy



xLPR Management



Pilot study structure circular in nature
Project Integration Board too large
Reorganization required



Version 2.0 Schedule

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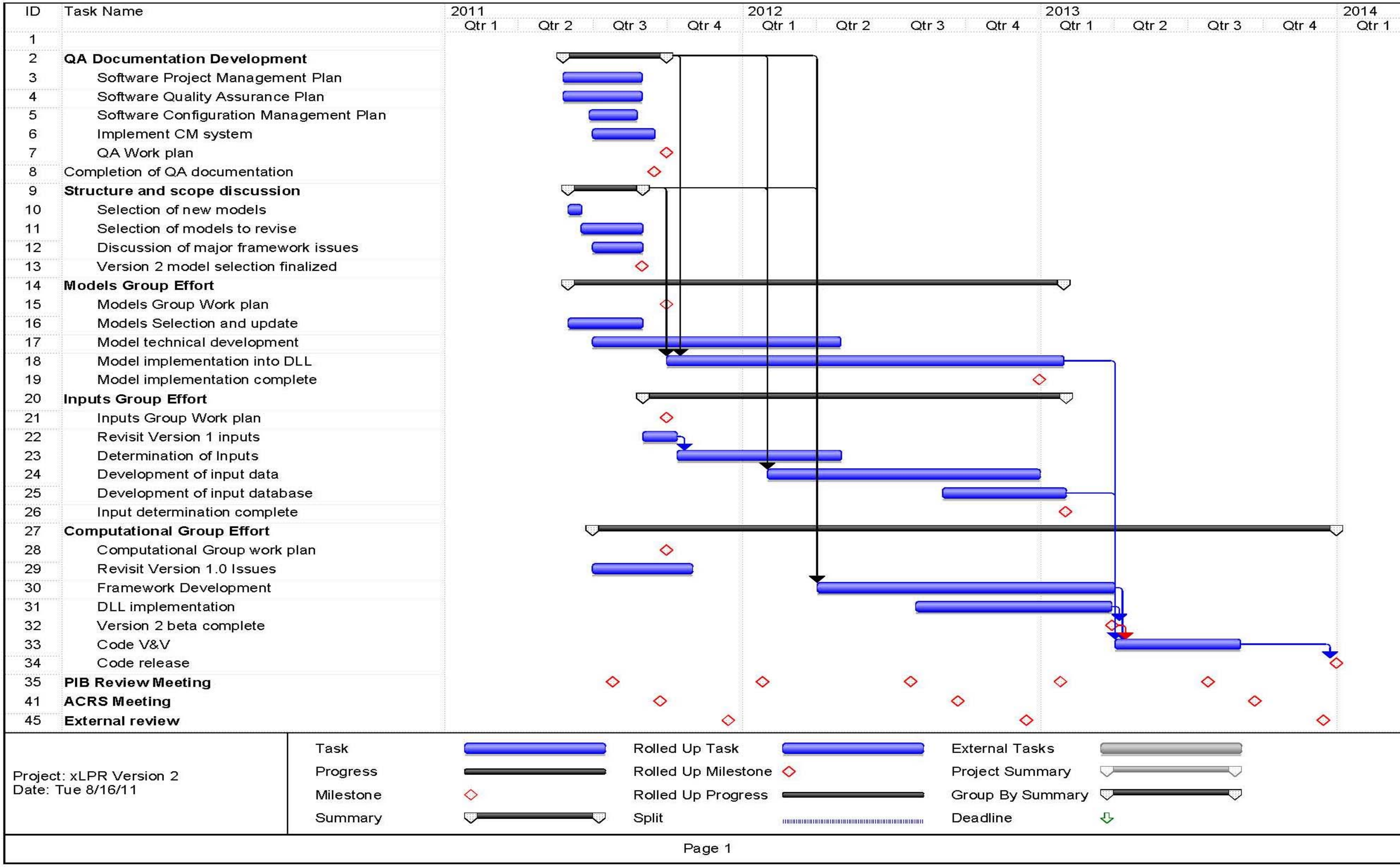

Version 2.0 Scope

- Pilot study demonstrated several shortcomings in Version 1.0 scope
- Version 2.0 scope under development by xLPR Team Leads and PIB – recommendations generated and prioritized
- xLPR Groups developing work plans that select scope recommendations that fit within available resources and overall xLPR timeframe – Scope decided by majority vote of team leads and PIB

Version 2.0 Scope Modifications

- Framework
  - Investigate advanced methodologies to improve sampling efficiency and solution accuracy
  - Revisit uncertainty propagation methodology
  - Modify code output structure
  - Update post processing
  - Modify GoldSim for additional user capability
- Models
  - Revisit PWSCC initiation – Expert panel
  - Update WRS model – more generic, better uncertainty
    - Weld repairs
  - Update K-solution to be consistent with updated WRS model

Red font represents high priority items

Version 2.0 Scope Modifications

- Models
  - Update mitigation to include FSWOL,OWOL, Inlay, surface treatment, and other chemistry (PWR and BWR)
  - Update ISI model – sizing, POD, simplified model
  - Update crack stability – Surface crack EPFM
  - Update leak rate model – QA SQuIRT, bound leak rate calc
  - Update COD tension and bending blended solution.
- Inputs
  - Update load definition to include transients

Version 2.0 Scope Additions

- Framework
  - Microsoft Access dB for inputs
- Models
  - Environmental fatigue (initiation and growth)
  - Axial Cracks
  - IGSCC
  - Surface crack-to-through wall crack transition
  - Manufacturing defects

xLPR Path Forward

- Pilot Study final report (NUREG/EPRI) drafted and in NRR review
- Version 2.0 development underway
- ACRS briefings (annually)
- External reviews (annually)
- Internal reviews (bi-annually)
- Version 2.0 release – End 2013
- Technical basis and Regulation Guide for LBB - 2015

xLPR Version 1.0
Pilot Study Results

David Rudland
Senior Materials Engineer
RES/DE/CIB

ACRS Meeting of the Subcommittee on Materials, Metallurgy, & Reactor Fuels
September 21, 2011
Rockville, MD

U.S.NRC
United States Nuclear Regulatory Commission
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Pilot Study Problems

U.S.NRC
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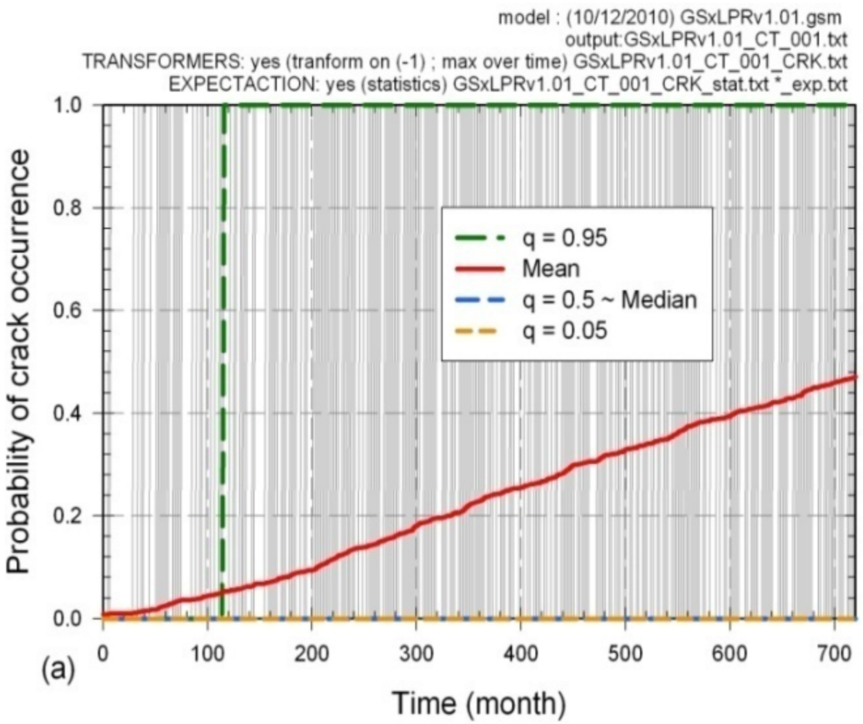
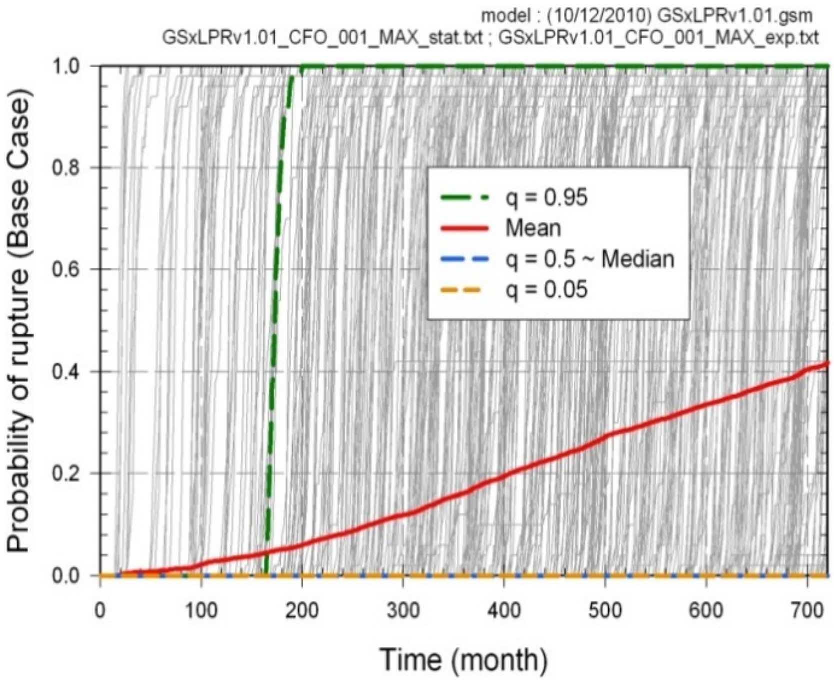
Analysis	Description
Probabilistic Base Case ★ (red)	Probabilistic base case analysis using Monte Carlo sampling.
Sensitivity Study	
Stress Mitigation	Analyses evaluate different mitigation times, for the same stress-based mitigation.
Chemical Mitigation	Chemical effects of increasing the hydrogen concentration in the water on the crack growth module. Three hydrogen concentrations were evaluated.
Crack Initiation	Considers the crack initiation model uncertainty.
Safe End Evaluation ★ (blue)	Considers stainless steel safe end weld, which causes a through-thickness bending stress that can reduce the tensile inner-diameter stress.

★ (red) **- with and without inspection and leak**

★ (blue) **- with and without mitigation, inspection and leak detection**

Base Case Results



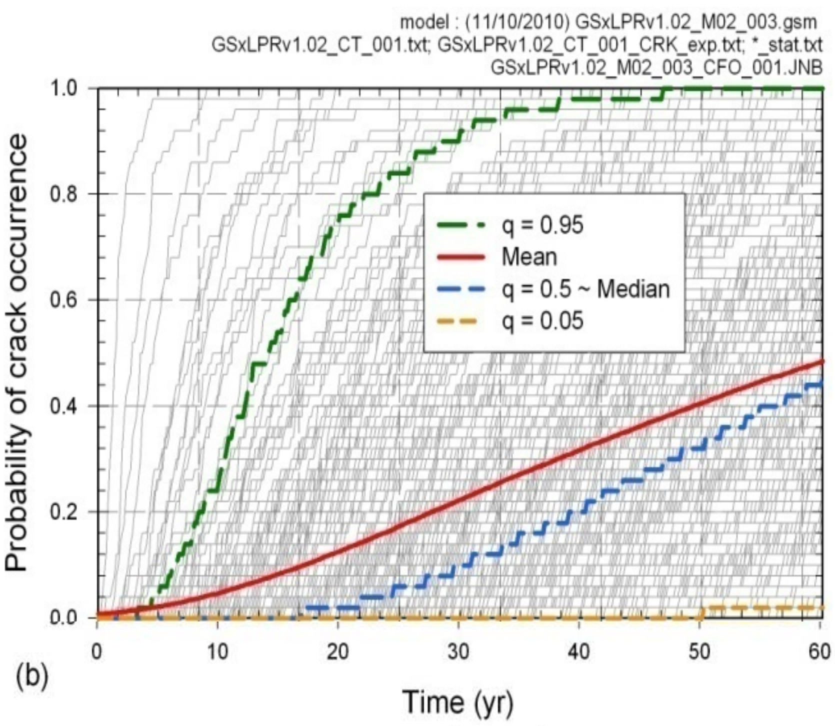


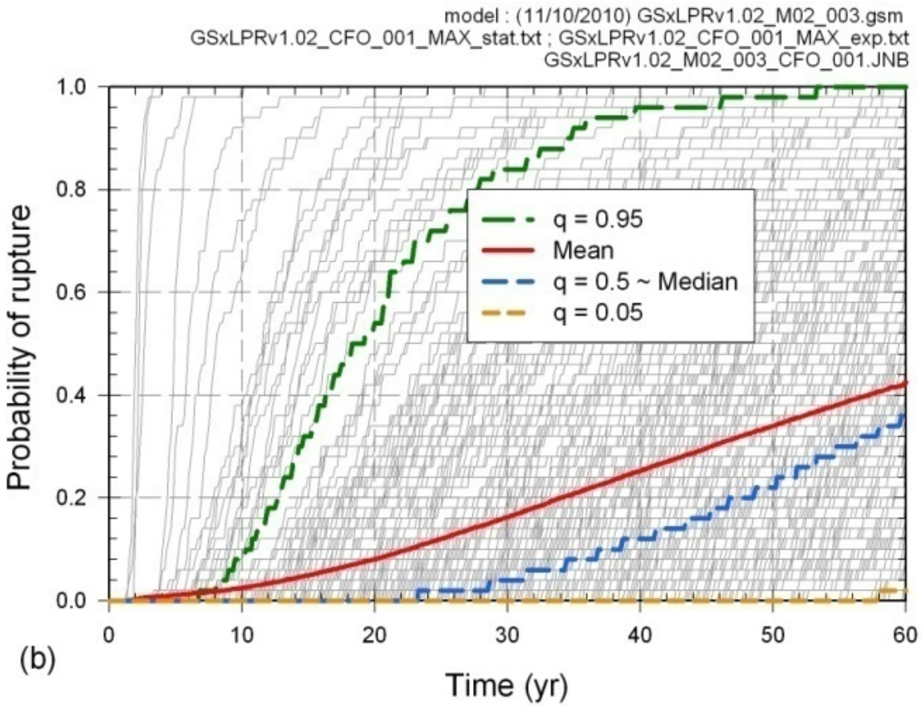
Crack Initiation categorized as epistemic by models group

Grey lines represent individual epistemic realizations

No inspection, no leak detection, no mitigation

Base Case Results





Crack Initiation categorized as aleatory

Problem is driven by crack initiation!!

Grey lines represent individual epistemic realizations

Base Case Results

U.S.NRC
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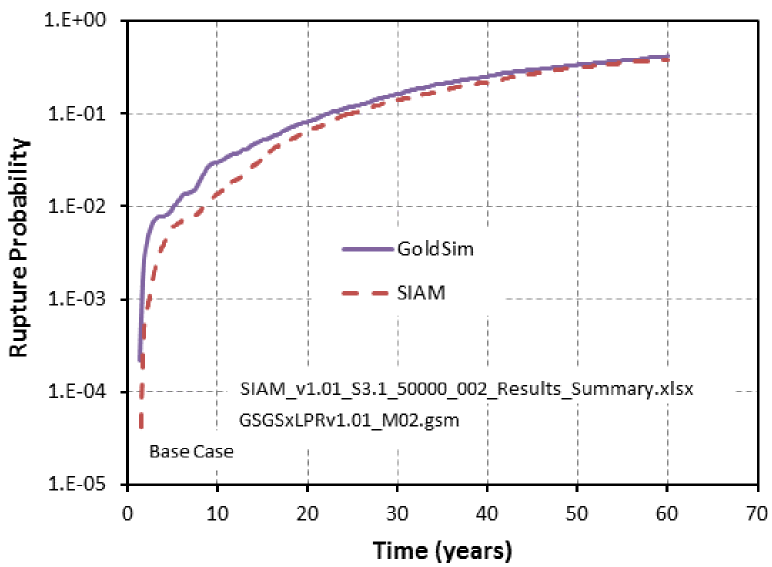
Sensitivity analyses were conducted to determine driving variables

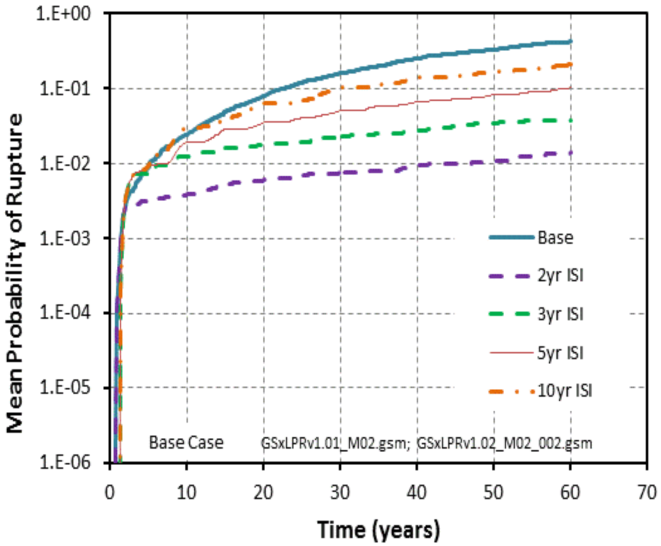
EXPCFO: 50 yr				EXPCFO: 60 yr			
var.	R^2	R^2 inc.	SRRC	var.	R^2	R^2 inc.	SRRC
SIG0WRS	41.80%	41.80%	0.5363	SIG0WRS	43.90%	43.90%	0.5764
B1	57.10%	15.30%	-0.3299	B1	60.70%	16.80%	-0.3568
FWELD	57.80%	0.70%	0.0701	FWELD	61.60%	0.90%	0.0853
RANDL17	58.00%	0.20%	0.0369	RANDP05	61.80%	0.20%	0.0391
				ODRAND	62.00%	0.20%	-0.0358

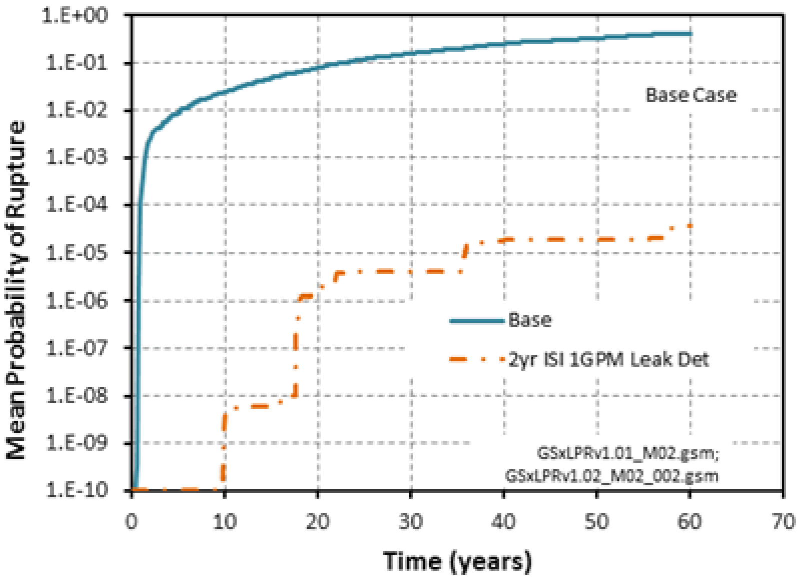
- R^2 - how much of the output variance is explained with the current input and all previous inputs
- The incremental R^2 - how much variance is explained by the addition of this input
- SIG0WRS – ID weld residual stress
- B1 – crack initiation parameter

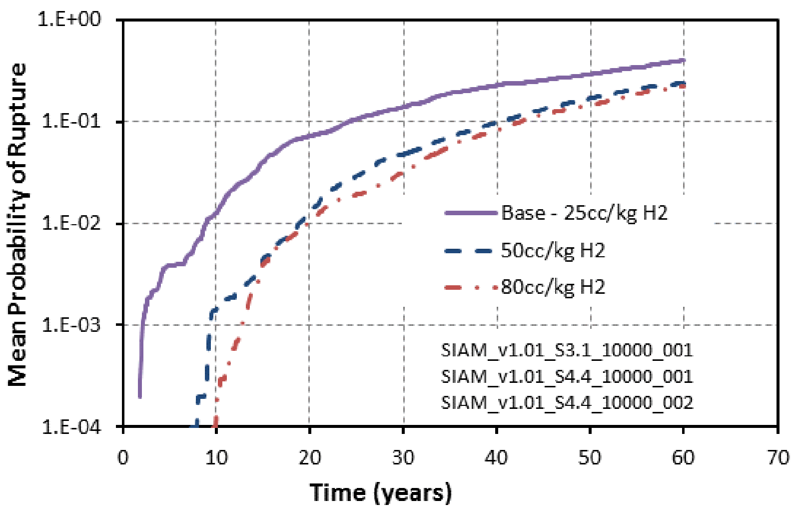


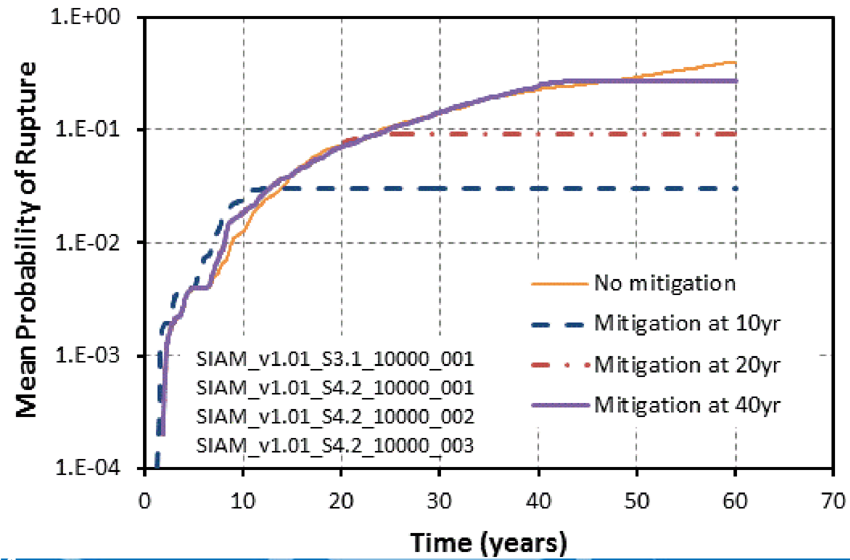
GoldSim and SIAM predicted similar results

Other Results

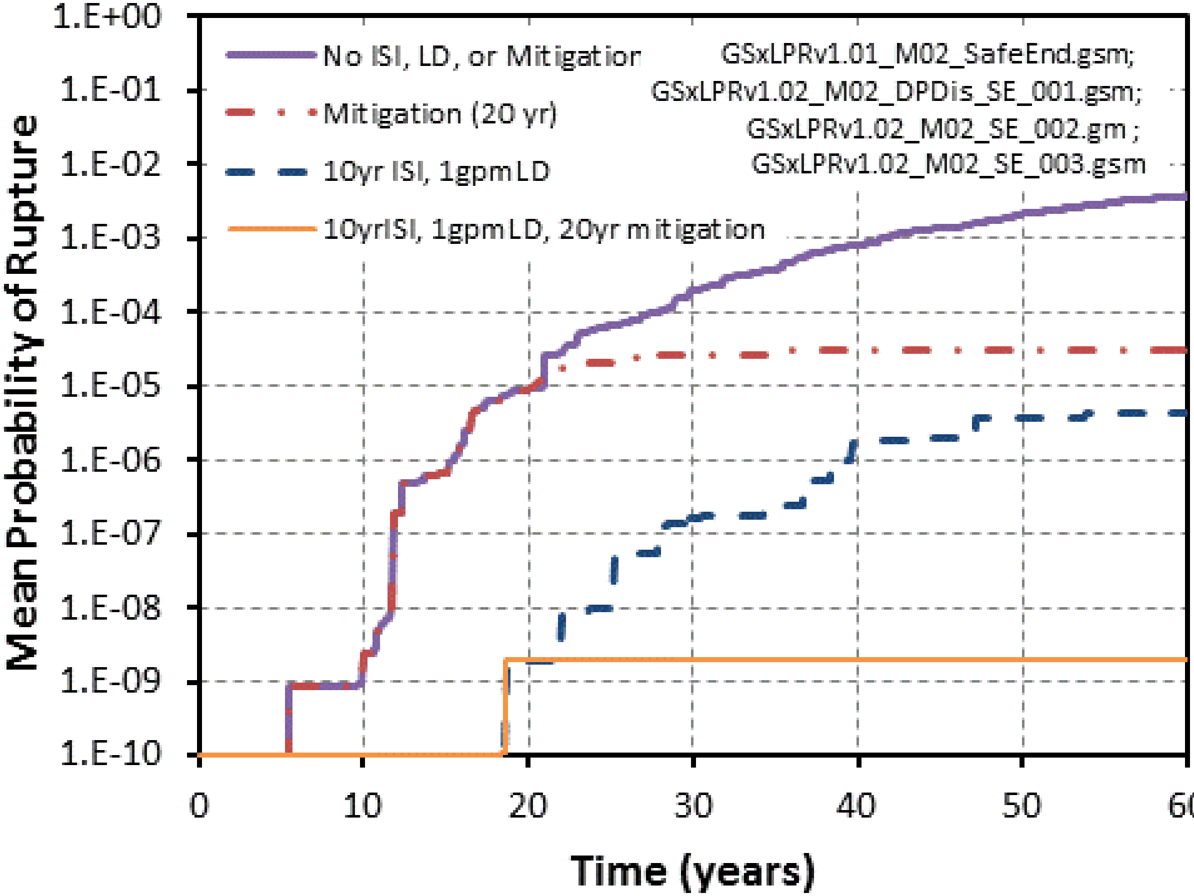


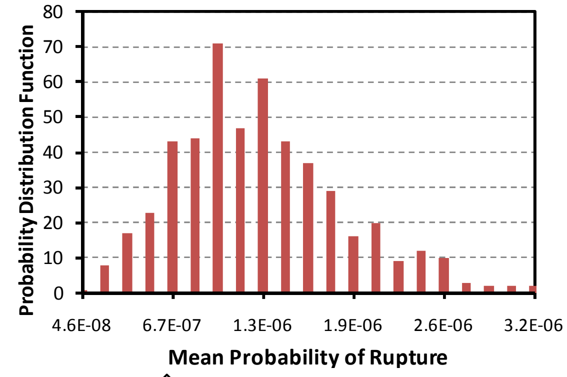


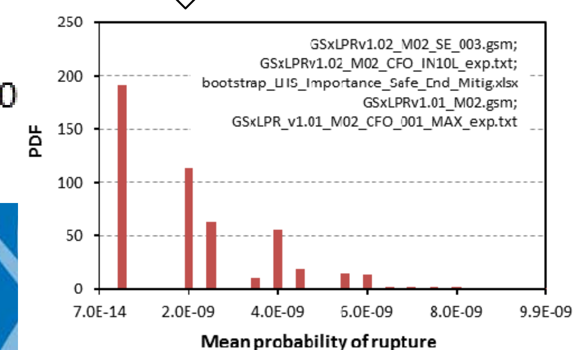




Safe End Sensitivity Case







Independent Review and V&V

- Contracted with Center for Nuclear Waste Regulatory Analyses (CNWRA) who will
  - Develop V&V plan
  - Initial pilot study code V&V
  - Conduct comparison of pilot study codes, i.e., GoldSim versus SIAM using pre-defined metrics
    - **Ease of Use**
    - **Run Time**
    - **User “Friendliness” of Interface**
    - **Flexibility / Adaptability of Software**
    - **Ease of configuration management**
- External review panel planned

Lessons Learned & Key Gaps

- Organizational Issues – *PIB membership too large, no clear leader*
- Communication Issues – *Intergroup communication difficulty*
- Framework Issues – *GoldSim selected*
  - Inputs and Outputs – *Not user friendly and time consuming*
  - Uncertainty Classification and Analysis – *Large impact, need to consider carefully*
  - Improved Sampling Techniques – *Defining variables to importance sample is difficult*
  - Data Storage and Handling – *Time consuming and cumbersome*
  - Post Processing - *Not user friendly*
- Models Issues
  - Expertise – *Need correct experts*
  - Modeling Scope – *Needs to be expanded for LBB systems*
- Software QA & CM – *Needs to be expanded for future versions*

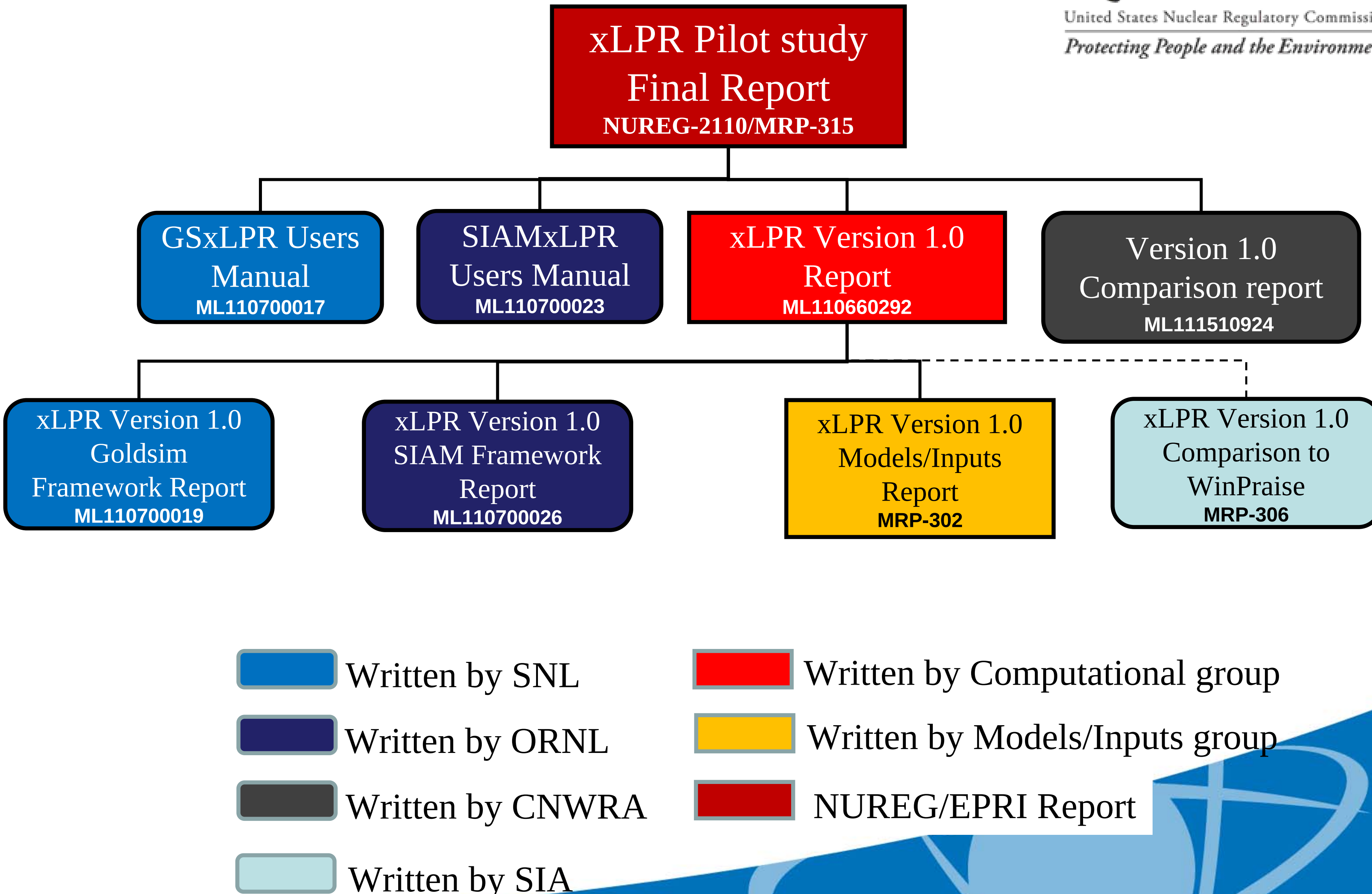
Pilot Study Results

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

- The project team demonstrated that the cooperative management structure was promising, but recommends a code development leader be selected and the PIB be restructured as an advisory committee

Pilot Study Results

- Based on the framework code comparison, a cost analysis, and long term prospects, the xLPR project team recommends that the future versions of xLPR be developed using the GoldSim commercial software as the computational framework



xLPR Pilot study Final Report
NUREG-2110/MRP-315
GSxLPR Users Manual
ML110700017
SIAMxLPR Users Manual
ML110700023
xLPR Version 1.0 Report
ML110660292
Version 1.0 Comparison report
ML111510924
xLPR Version 1.0 Goldsim Framework Report
ML110700019
xLPR Version 1.0 SIAM Framework Report
ML110700026
xLPR Version 1.0 Models/Inputs Report
MRP-302
xLPR Version 1.0 Comparison to WinPraise
MRP-306
Written by SNL
Written by ORNL
Written by CNWRA
Written by SIA
Written by Computational group
Written by Models/Inputs group
NUREG/EPRI Report

Extremely Low Probability of Rupture (xLPR) Project Subcommittee Briefing

David Rudland
Senior Materials Engineer
RES/DE/CIB

ACRS Meeting of the Subcommittee on Materials, Metallurgy, & Reactor Fuels
September 21, 2011
Rockville, MD

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Welcome

- Purpose of meeting
  - To brief the ACRS Subcommittee on Materials on the Extremely Low Probability of Rupture (xLPR) program
- Objective
  - Achieve a common understanding of xLPR status, objectives, priority and planned path forward
  - ACRS review and advice on project
  - Letter from Main Committee on the efficacy of the project with respect to the NRC safety goals
- Due to the complexity of this project, we seek ACRS review/advice at least once a year to ensure that we're on the right track.

Presentation Outline

- Regulatory need for xLPR
- xLPR project plan
- Version 1.0 technical details
- Pilot study goals and results
- Version 2.0 plans and path forward

RES Project Plan to Address NRR User Need

David Rudland
Senior Materials Engineer
RES/DE/CIB

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NRR User Need 2010 - 018

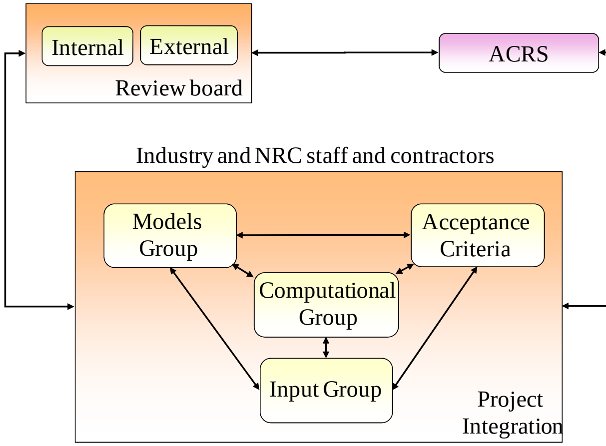
- NRR-2010-018 – Probabilistic Method for LBB
  - Deliver a flexible, modular probabilistic fracture mechanics code for evaluation of PWSCC in dissimilar metal butt welds - eXtremely Low Probability of Rupture (xLPR) code
    - Include active degradation modes
    - Include inspection/mitigation/repair strategies
    - Correctly quantify, characterize, and propagate uncertainties
  - Deliver technical basis and regulation guide for LBB
- RES developed detailed program plan to address this need
  - Updated biannually throughout program

xLPR Goal

- Develop a ***probabilistic*** assessment tool that can be used to assess compliance with 10CFR50App-A GDC-4
- Tool will be
  - **Comprehensive** with respect to known challenges and loadings
  - **Vetted** with respect to scientific adequacy of models and inputs
  - **Flexible** to permit analysis of a variety of in service situations
  - **Adaptable** – able to accommodate
    - evolving / improving knowledge
    - new damage mechanisms

xLPR Development

- NRC goal to develop “Modular” code for addressing issues related to Risk of Pressure Boundary Integrity Failure
- Currently focusing on piping issues (xLPR) to solve current LBB need. May be applicable to other needs
- Working cooperatively with EPRI through a Memorandum of Understanding Addendum



- NRC and Industry staff participation in all aspects of code development
- Initial pilot study to assess effectiveness of approach

xLPR Groups

- Computational
  - Integrate the computational elements into a robust, fully developed, tested, and verified computational tool
  - Develop the overall modular structure including uncertainty handling and appropriate sampling methods
  - Provide code documentation and training when necessary
- Models
  - Selection, documentation, and coding of the mathematical models for the prediction of probability of pipe rupture
  - Responsible for developing and using a comprehensive ranking system for the selection of appropriate models to use in the xLPR code
  - Aid in the quantifying of uncertainties

xLPR Groups

- Inputs
  - Identifying and collecting data and their associated distributions to quantify the various input parameters
  - Aid in determining the best format for supplying input data to the xLPR code, e.g., database
  - Aid in the quantifying of uncertainties
- Acceptance
  - Develop the application-based technical basis for
    - Results acceptability limits
    - Guidelines for using xLPR to obtain the application-specific results.
  - Determine form of results to support use of the xLPR evaluations as a basis for regulation and/or ASME code implementation

xLPR – NRC Intended Use

- Version 1.0 – Pilot study – Surge nozzle DM weld
  - To demonstrate feasibility
  - Determine appropriate probabilistic framework
  - Develop plan for future version
- Version 2.0 – Primary piping
  - Support LBB Regulation Guide development
  - Assess compliance with GDC-4
  - Prioritize future research efforts
- Version 3.0 – Reactor coolant pressure boundary
  - Combine piping with reactor vessel, steam generator, etc.
  - Analyze probability of failure for all coolant pressure boundary components

Current Team Members

Computational Group
David Rudland – U.S. NRC
Bruce Bishop – Westinghouse
Nathan Palm – Westinghouse
Patrick Mattie – Sandia National Laboratories
Cedric Sallaberry – Sandia National Laboratories
Don Kalinich – Sandia National Laboratories
Jon Helton – Sandia National Laboratories
Hilda Klasky – Oak Ridge National Laboratory
Paul Williams – Oak Ridge National Laboratory
Robert Kurth – Emc^2
Scott Sanborn – Pacific Northwest National Laboratory
David Harris – Structural Integrity Associates
Dilip Dedhia – Structural Integrity Associates
Anitha Gubbi – Structural Integrity Associates

Inputs Group
Eric Focht – U.S. NRC
Mark Kirk – U.S. NRC
Guy DeBoo – Exelon
Paul Scott – Battelle
Ashok Nana – AREVA NP Inc.
John Broussard – Dominion Engineering
Nathan Palm – Westinghouse
Pat Heasler – Pacific Northwest National Laboratory
Gery Wilkowski – Emc^2

Acceptance Group
Mark Kirk – U.S. NRC
Glenn White – Dominion Engineering Inc.
Aladar Csontos – U.S. NRC
Robert Hardies – U.S. NRC
David Rudland – U.S. NRC
Bruce Bishop – Westinghouse
Robert Tregoning – U.S. NRC

Models Group
Marjorie Erickson – PEAI
Gary Stevens – U.S. NRC
Howard Rathbun – U.S. NRC
David Rudland – U.S. NRC
John Broussard – Dominion Engineering
Glenn White – Dominion Engineering
Do-Jun Shim – Emc^2
Gery Wilkowski – Emc^2
Bud Brust – Emc^2
Cliff Lange – Structural Integrity Associates
Dave Harris – Structural Integrity Associates
Steve Fyfitch – AREVA NP Inc.
Ashok Nana – AREVA NP Inc.
Rick Olson – Battelle
Darrell Paul – Battelle
Lee Fredette – Battelle
Craig Harrington – EPRI
Gabriel Ilevbare – EPRI
Frank Ammirato – EPRI
Patrick Heasler – Pacific Northwest National Laboratory
Bruce Bishop – Westinghouse

Program Integration Board
Craig Harrington – EPRI
Aladar Csontos – U.S. NRC
Robert Hardies – U.S. NRC
Denny Weakland - Ironwood Consulting
David Rudland – U.S. NRC
Bruce Bishop – Westinghouse
Eric Focht – U.S. NRC
Guy DeBoo – Exelon
Marjorie Erickson – PEAI
Gary Stevens – U.S. NRC
Howard Rathbun – U.S. NRC
Mark Kirk – U.S. NRC
Glenn White – Dominion Engineering Inc.

Proposed User Need Schedule

	FY09				FY10				FY11				FY12				FY13				FY14				FY15			
UNR NRR-2010-018 Milestones	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
xLPR kickoff meeting																												
xLPR addendum to EPRI MOU																												
NRR User Need 2010-018																												
TLR - crack model, RV head pen												T	F															
NUREG - PWSCC mitigation rept												ND		NF														
xLPR pilot study/reporting																												
NRC to determine QA required																												
xLPR V2 framewk code selection																												
xLPR Version 2 development																												
xLPR Version 2 final report																												
Briefings (DCI=I; ACRS=A)									I	A	I		I		I		I	A	I		I		I	A	I			
Report* - surface mod on PWSCC																				T	F							
Report - Effects NDE on failure																T	F											
Assess EPRI xLPR participation																												
NUREG - alloy 52/152 issues																		ND		NF								
Assess NRR User Need Revision																												
xLPR V2 accepted regulatory use																												
xLPR Version 3 development																												
xLPR External Review Board																												
LBB Tech Basis/LBB piping anal.																												
Draft/Final Reg Guide LBB																												D
NUREG - Chemical Mitigation																			T	F	ND	NF						
Ni Alloy crack growth testing																T							ND		NF			

* Contingent on NRR request

T = Technical Report draft

F= Final Report

ND = NUREG Draft

NF = NUREG Final

I = Division of Component Integrity

A = ACRS

Communications and Review

- Program Integration Board – Internal advisory board
  - Reviews all aspects of development and makes recommendations
  - Meets twice a year and on as-needed basis

- External Review - Provide additional technical review for national and internationally recognized experts that are not affiliated with the xLPR project
  - One major review per year

- ACRS Review Briefings
  - Annual briefings

Summary

- xLPR is being developed under User Need NRR 2010-018
- Flexible, modular probabilistic fracture mechanics code for addressing issues related to Risk of Pressure Boundary Integrity Failure
- Initial application is evaluation of PWSCC in dissimilar metal butt welds with LBB-approved systems
- Working cooperatively with EPRI through a Memorandum of Understanding Addendum

Origin of the User Need for Extremely Low Probability of Rupture (xLPR) and Regulatory Uses

Jay Collins, NRR

Robert Hardies, NRR

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

September 21, 2011

Rockville, MD

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Purpose & Background

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Purpose of this meeting

- Provide information on the path forward for xLPR regulatory and research activities.

Background

- Double-ended guillotine breaks (DEGB) postulated in all high energy piping for design, e.g. ECCS & containment.

- Pipe whip restraints and jet impingement shields installed

Background

- Leak Before Break (LBB) review procedures formalized in Draft SRP 3.6.3 (1987).
  - SRP stipulates a **qualitative** screening review to establish candidate systems and a **quantitative** evaluation for flaw tolerance and leakage detectability

- GDC-4 modified to allow dynamic effects from DEGB to be excluded from design basis when analyses approved by NRC staff demonstrate extremely low probability of rupture (xLPR) under design basis conditions (1987).

LBB Historical Review

- All PWRs have LBB approvals for reactor coolant loop (RCL) piping
  - Some PWRs have LBB for RCL branch piping

- Leakage due to PWSCC occurred in 1993 and 2000.

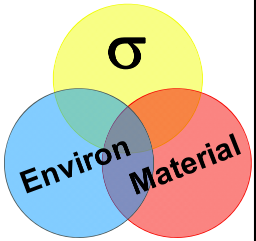
- Operating experience with PWSCC contrary to assumptions in original LBB evaluations performed in 1980s and early 1990s.

Near Term Approach

Active Degradation

Inspection Requirements
- Industry programs- MRP-139
- Rulemaking – ASME CC N-770

PWSCC Mitigation
- Mechanical stress improvement
- Weld overlays
- Weld in/on-lays



Operating Experience
- Circ cracking is limited
- Inspection basis effective

Adequate Near Term Justification for LBB

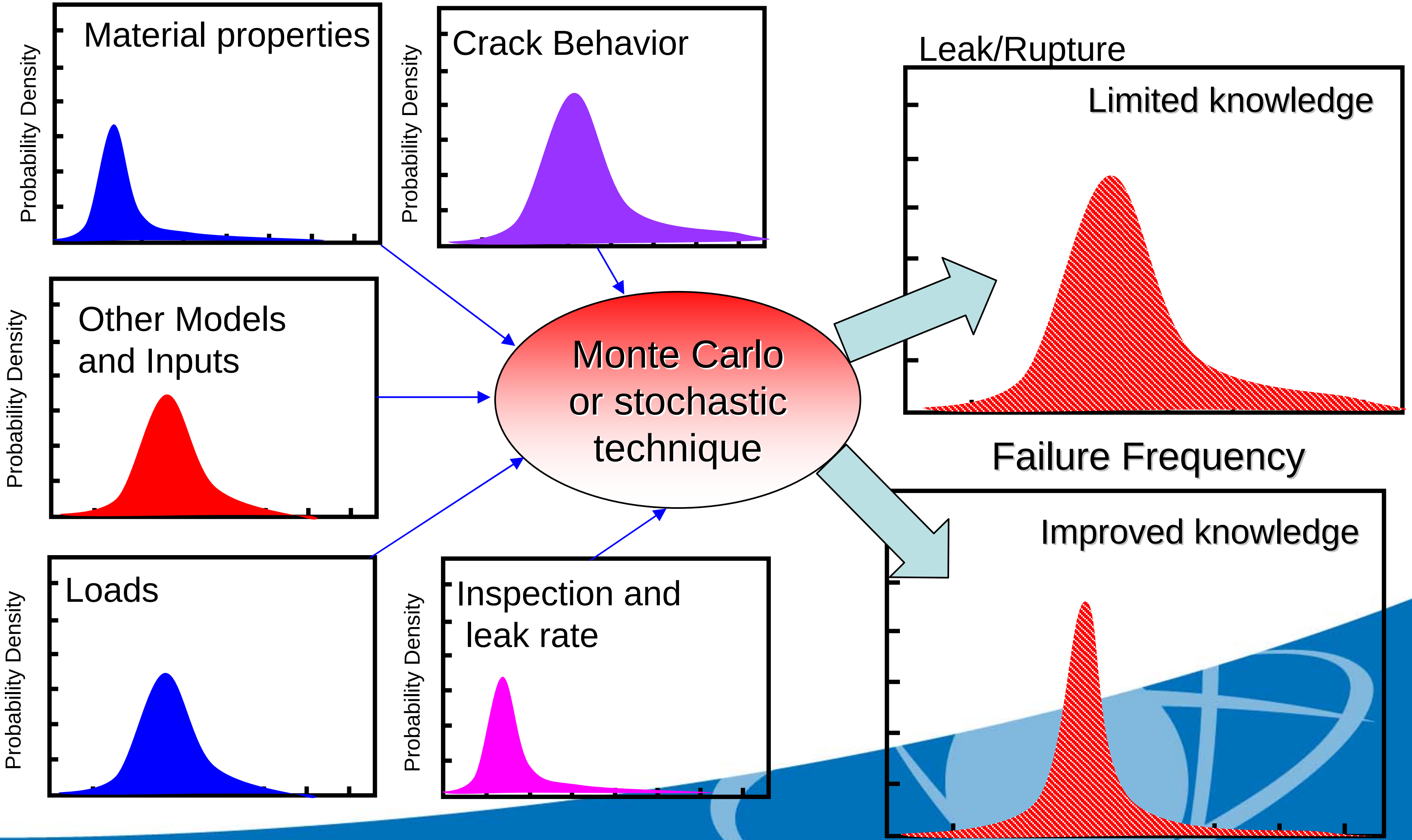
SRP 3.6.3 Issues

- 3.6.3 does not allow / account for
  - Active degradation … which is actually happening
  - Certain mitigation techniques … which are actually used
- 3.6.3 is ***deterministic***, yet seeks to demonstrate compliance with 10CFR50App-A, GDC-4 requirement of an extremely low ***probability*** of failure
  - Flaw stability approach

Longer Term

- Develop a ***probabilistic*** assessment tool that can be used to ***directly*** demonstrate compliance with 10CFR50App-A GDC-4
- Tool should be
  - **Comprehensive** with respect to known challenges and loadings
  - **Vetted** with respect to scientific adequacy of models and inputs
  - **Flexible** to permit analysis of a variety of in service situations
  - **Adaptable** – able to accommodate
    - evolving / improving knowledge
    - new damage mechanisms

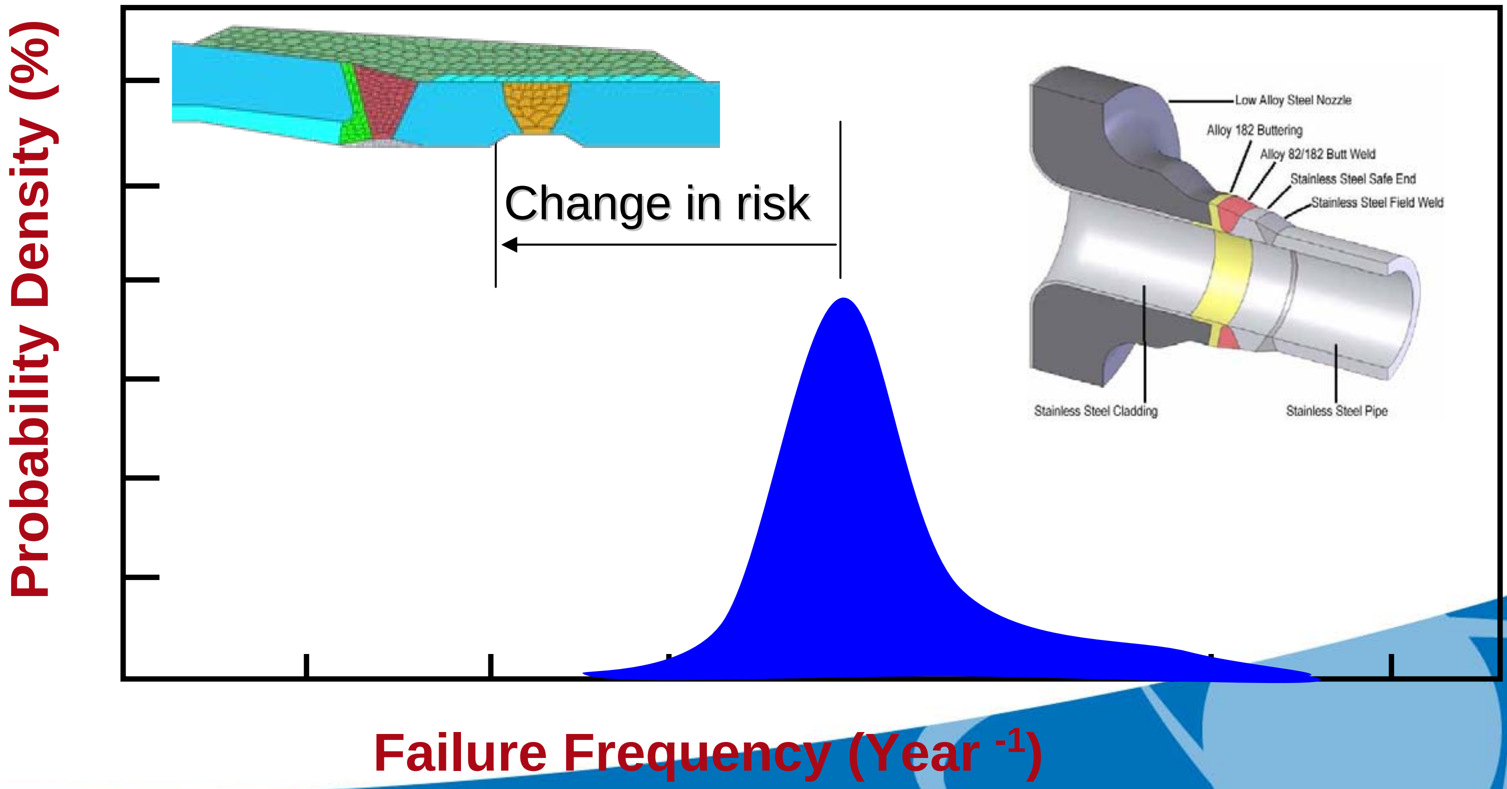
xLPR Process



Using xLPR

Conduct analyses with typical parameters

Conduct analyses with typical parameters and overlay



xLPR Regulatory Uses

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- Development of "Modular" code for addressing issues related to Risk of Pressure Boundary Integrity Failure.
- Initially focusing on piping issues (xLPR) to solve NRR current need
- Address effects of mitigation techniques and their effectiveness
- Assist in the validation of long term inspection frequencies for all reactor coolant pressure boundary components, (e.g. upper and lower heads, pressurizer, hot and cold leg temperature butt welds)
- Assist in assessing relief requests

xLPR Version 1.0 Technical Details

David Rudland
Senior Materials Engineer
RES/DE/CIB

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Introduction

- In this presentation, the technical details for the xLPR models and framework are described
- In some cases, for comparison purposes, the proposed changes for the models for Version 2.0 are presented
- As will be discussed later, these changes have not been approved by the group, and are still under consideration

Version 1.0 Scope

- xLPR Version 1.0 was developed for the pilot study to:
  - To demonstrate feasibility
  - Determine appropriate probabilistic framework
  - Develop plan for future version

- The pilot study focused on Westinghouse-type pressurizer–to–surge line dissimilar metal weld

- Geometry, loads, materials, etc. available through Wolf Creek Effort (MRP-216)

Version 1.0 Technical Flow

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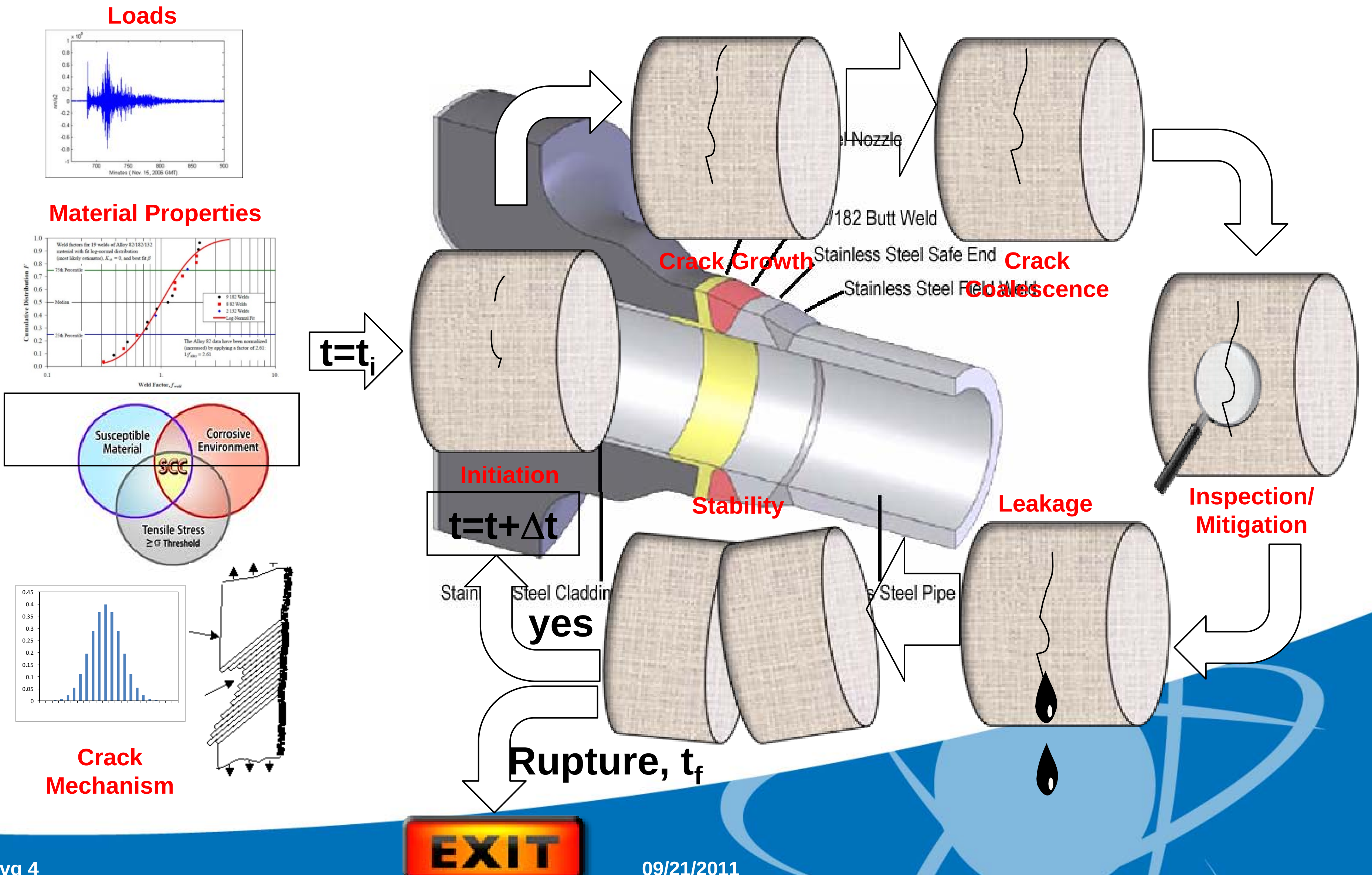
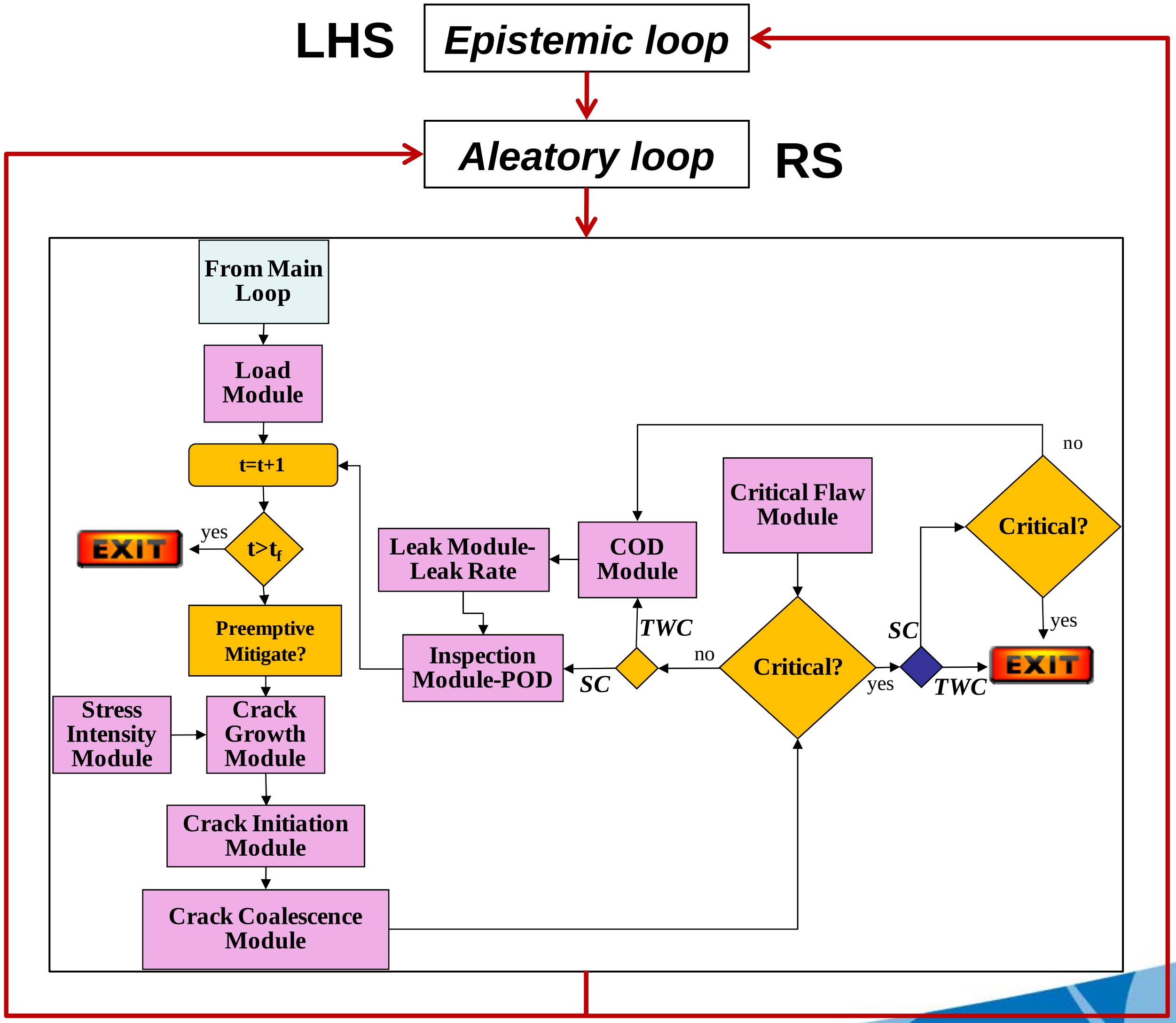


xLPR Process



Purple boxes represent self-contained, independent modules

Epistemic – Lack of Knowledge uncertainty

Aleatory – Irreducible uncertainty

Probability of leak/rupture

Importance sampling was demonstrated

Version 1.0 Models Description

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Crack Initiation

Several models are available for initiation probability

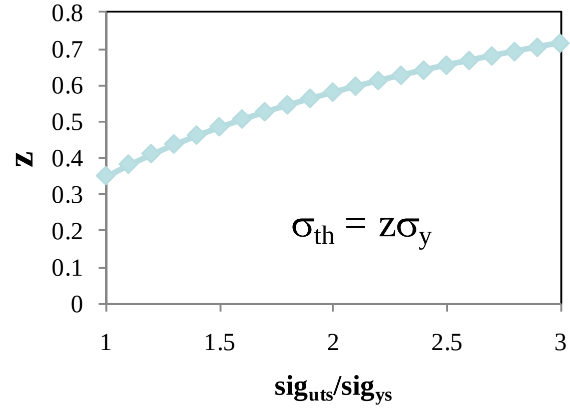
A.) Direct Approach

$$\frac{1}{t_I} = Ae^{-Q/RT}\sigma^n \quad (\sigma > \sigma_{th})$$

σ_{th} = 137MPa (20ksi)

$$t_I = Be^{Q/RT}\ln[(D-z)/(\sigma/\sigma_{ys}-z)]$$

$$where\ B = B_I m^q \ln[D]/\ln[(D-z)/(1-z)]$$



B.) Weibull

$$P(t_I < t) = 1 - e^{-(t/C)^3}$$

$$C = C_1 e^{Q/RT}\sigma^{-n}$$

- Capable of handling zinc/hydrogen changes, but not implemented

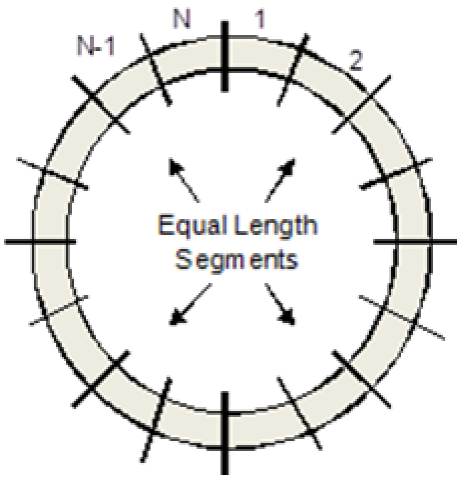
Models Description

Crack Initiation

- For Version 1.0, model is "calibrated" to MRP-216 surge nozzle data and base WRS

Pressurizer Nozzle DMW Inspections (mid 2007)			
Nozzle	# inspected	# circ cracks	# axial cracks
Surge	10	5	2
Safety	20	1	4
Relief	6	1	2
Spray	7	0	0

0.01 cracks/year



- Multiple circumferential crack initiation allowed
- Axial cracks proposed for Version 2.0

Models Description

Crack Growth from MRP-263

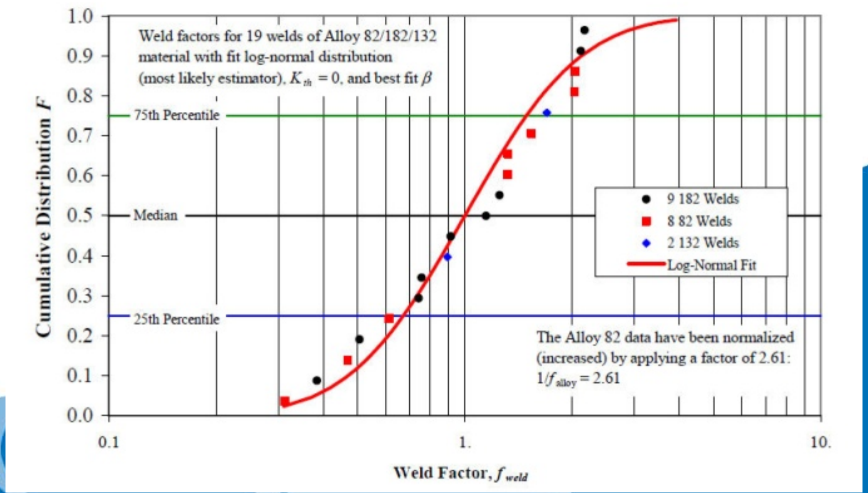
$$CGR = \exp\left[-\frac{Q}{R}\left(\frac{1}{T}-\frac{1}{T_{ref}}\right)\right]\alpha f_{weld}(K-K_{th})^{\beta}\left[\frac{1}{P}+\frac{(P-1)}{P}\exp\left(-0.5\left(\frac{\Delta ECP_{Ni/NiO}}{c}\right)^{2}\right)\right]$$

For $K<K_{th}$, CGR=0

$$\Delta ECP_{Ni/NiO} = 29.58\left(\frac{T+273.15}{298.15}\right)\log\left(\frac{[H_2]}{[H_2]_{Ni/NiO}}\right)$$

$$[H_2]_{Ni/NiO} = 10^{(0.0111T-2.59)}$$

CGR	=	crack growth rate at temperature T in m/s
Q_g	=	thermal activation energy for crack growth = 130 kJ/mole
R	=	universal gas constant = 8.314 x 10^{-3} kJ/mole-K
T	=	absolute operating temperature at the crack location in K
T_{ref}	=	absolute reference temperature to normalize data = 598.15K
α	=	power law constant = 2.01 x 10^{-12}
K_{th}	=	threshold crack stress intensity factor = 0.0 MPa-$m^{0.5}$
β	=	exponent = 1.6
H_2	=	25 cc/kg-STP



Models Description

Stress Intensity

- Surface Crack
  - Semi-elliptical surface crack
  - Anderson/Chapuliot solution curve fit through applicable regions
  - 4th order approximation for weld residual stress
  - Growth at deepest and surface points
- Through-wall Crack
  - Anderson solution, look-up table
  - Average K through-wall used
  - Linear stress distribution

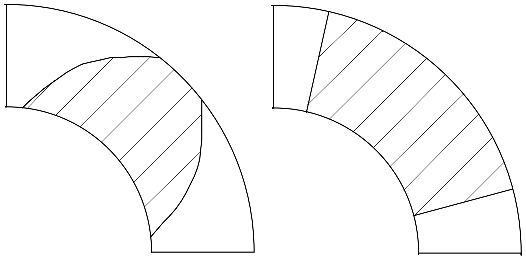
Proposals for Version 2.0 include

- Incorporating ASME curve fit solutions for surface cracks
- Non-idealized through-wall crack solutions for better predictions of transition from SC to TWC behavior and initial leak behavior
- Axial flaws

Models Description

Crack Transition

- As the surface crack penetrates the wall thickness, an idealized through-wall crack with the same crack area will be formed



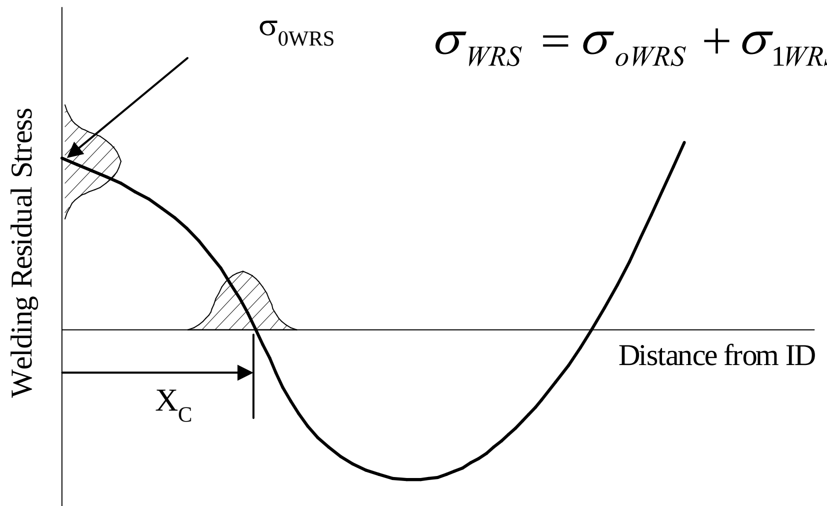
- In Version 2.0, the proposed plan is to develop the non-idealized stress intensity and COD solutions for more accurate transitions and leak calculations

Models Description

Weld Residual Stress

- The weld residual stress is assumed to be a 3rd order polynomial with uncertainty in ID WRS and distance when stress passes through zero

$$\sigma_{WRS} = \sigma_{oWRS} + \sigma_{1WRS}\left[\frac{x}{t}\right] + \sigma_{2WRS}\left[\frac{x}{t}\right]^2 + \sigma_{3WRS}\left[\frac{x}{t}\right]$$



WRS subgroup has proposed a plan for Version 2.0 that includes WRS defined piece-wise linear. Method for applying uncertainty still under discussion

Table 1 Stress Variability Table - xLPR

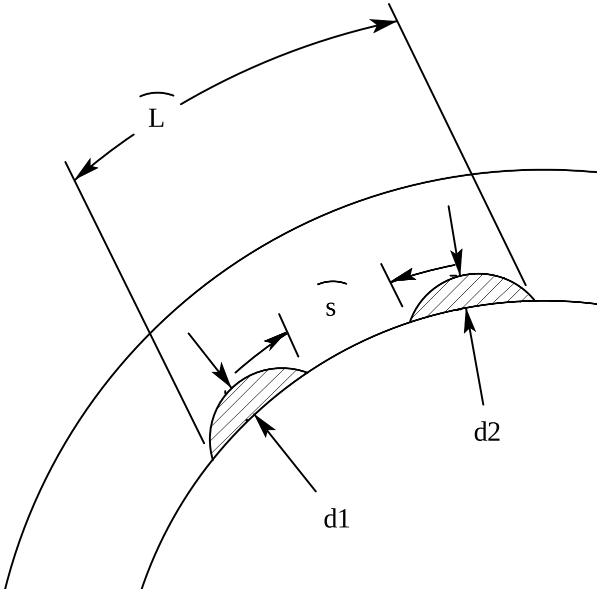
Mean Stress (Mpa)	Plus 2σ Stress (Mpa)	Minus 2σ Stress (Mpa)	x/t
σ_1	σ^+_1	σ^-_1	0
σ_2	σ^+_2	σ^-_2	0.05
σ_3	σ^+_3	σ^-_3	0.1
σ_4	σ^+_4	σ^-_4	0.15
...	...	...	...
...	...	...	...
σ_{20}	σ^+_{20}	σ^-_{20}	0.95
σ_{21}	σ^+_{21}	σ^-_{21}	1

Models Description

Crack Coalescence

Surface crack – surface crack

- Follows ASME rules



Surface crack – through-wall crack

- Only when tips touch
- Sum of lengths

Through-wall – through-wall

- Only when tips touch
- Sum of lengths

Models Description

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Crack Stability

Surface Crack

- Net section collapse based on stainless steel flow stress – semi-elliptical flaw
- EPFM proposed for Version 2.0
- Outputs failure and margin

Fracture Analysis Methods	Maximum Load Ratio[a]							
	All TWC Pipes Under Bending (12 Tests)		Short TWC Pipes Under Bending (5 Tests)		TWC Welded Pipes Under Bending (4 Tests)		All TWC Pipes Under Bending and Tension (6 Tests)	
	Mean	Coefficient of Variation[b], percent	Mean	Coefficient of Variation[b], percent	Mean	Coefficient of Variation[b], percent	Mean	Coefficient of Variation[b], percent
LBB.ENG2	1.04	12.93	0.96	16.27	1.08	7.61	1.18	11.06
LBB.NRC	1.01	10.50	1.02	9.02	0.94	12.74	1.17	15.45
LBB.GE	1.01	11.62	0.98	13.91	0.98	6.38	--[c]	--[c]
GE/EPRI	1.15	11.14	1.12	14.97	1.18	9.50	1.31	13.75
Paris/Tada	0.96	12.72	0.91	6.95	0.87	11.87	1.03	13.62
LBB.ENG3	1.00	12.48	0.90	11.58	1.02	5.83	1.18	11.06
ASME Section XI	1.34[d]	26.87[d]	1.47[d]	34.71[d]	1.28[d]	13.16[d]	1.58[d]	27.82[d]
- Austenitic	1.2[e]	12.96[e]	--	--	--	--	1.20[f]	21.64[f]
- Ferritic	1.78[f]	24.69[f]	--	--	--	--	1.95[f]	10.17[f]
NSC	0.91	15.36	0.89	9.11	0.84	15.92	1.06	13.64

(a) Maximum load ratio = experimental maximum load/predicted maximum load.
(b) Coefficient of variation = (standard deviation/mean) × 100.
(c) Not analyzed.
(d) Considering both the ferritic and austenitic experiments together.
(e) From nine tests.
(f) From three tests.

Through-wall Crack

- Net-section collapse
- LBB.ENG2 – J-T
- Code outputs the failure based on lowest critical crack size and margin.

Models Description

Crack Opening Displacement

The crack opening displacement is calculated using the GE/EPRI COD solution. Has been shown to make accurate predictions of experiments

- Considers elastic plastic behavior
- Separate tension and bending solutions
- Tension and bending solutions blended

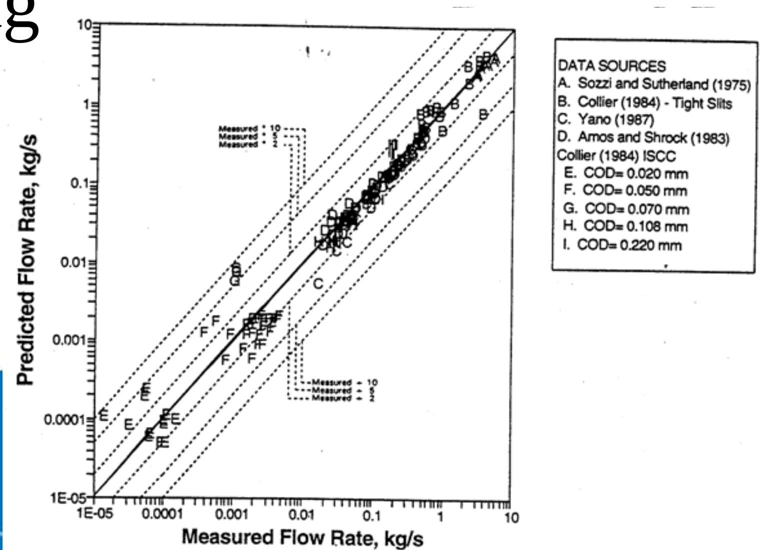
Fracture Analysis Method	Experimental/Predicted COD	
	Mean	**Coefficient of Variance (COV), percent**
Original GE/EPRI	1.01	72.8
Battelle-modified GE/EPRI	1.02	86.5
Tada/Paris	2.96	146

Models Description

Leak Rate

For leak rate predictions, the most recent version of SQUIRT was used. It has the following improvements:

- Improved 2-phase model solutions
- Includes single phase flow models – all water and all steam
- COD dependent crack morphology model.
- Allows for elliptical crack opening



Models Description

Inspection

- The inspection model calculates a probability of detection using the following equation (per MRP-262)

$$POD(x) = \frac{e^{\beta_1 + \beta_2 x}}{1 + e^{\beta_1 + \beta_2 x}}$$

- The probability of non-detection (PND = 1-POD) is tracked at each time increment. The effects of inspection are made post-processing by modifying the probabilities by the PND. This assumes that the simulation is complete when a flaw is detected.
- Sizing model
- Repair/Remediation
- Post-Repair crack distribution

Version 2 proposal

Models Description

Mitigation

- Mechanical mitigation is a pre-emptive mitigation which is defined by a change in the WRS at a fixed time (MSIP).
- Placeholders for mitigation by zinc and hydrogen are included. Models are not implemented

For Version 2.0 the following additions are proposed:

- Overlay (change in stress, material, and wall thickness)
- Inspection-based/material replacement mitigation
- Detailed incorporation of chemical mitigation

Pilot Study Problem Statement

- Base case – Higher WRS with no inspection, mitigation, or leak detection
- Sensitivity studies
  - WRS – with SS safe end weld
  - Mitigation – MSIP at 10, 20 and 40 years
  - Different crack initiation model
  - Adding hydrogen - 50cc/kg-STP, 80cc/kg-STP
- Post processing
  - Base case and SS weld case
    - With inspection at intervals of 30, 20, 10, 5 years
    - With leak detection at 1, 10 and 50 gpm

Inputs - Loads

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

All loads taken from MRP-216 and assumed constant

	Fx		Mx		My		Mz	
	kips	kN	in-kips	kN-m	in-kips	kN-m	in-kips	kN-m
Normal Thermal	0.87	3.87	577.96	65.30	-509.32	-57.54	468.98	52.99
Deadweight	0.07	0.31	11.63	1.31	1.90	0.21	8.99	1.02
Safe Shutdown Earthquake (SSE)	6.30	28.02	286.67	32.39	524.43	59.25	839.86	94.89
Normal Thermal Stratification	3.91	17.39	22.26	2.51	-715.11	-80.79	778.04	87.90

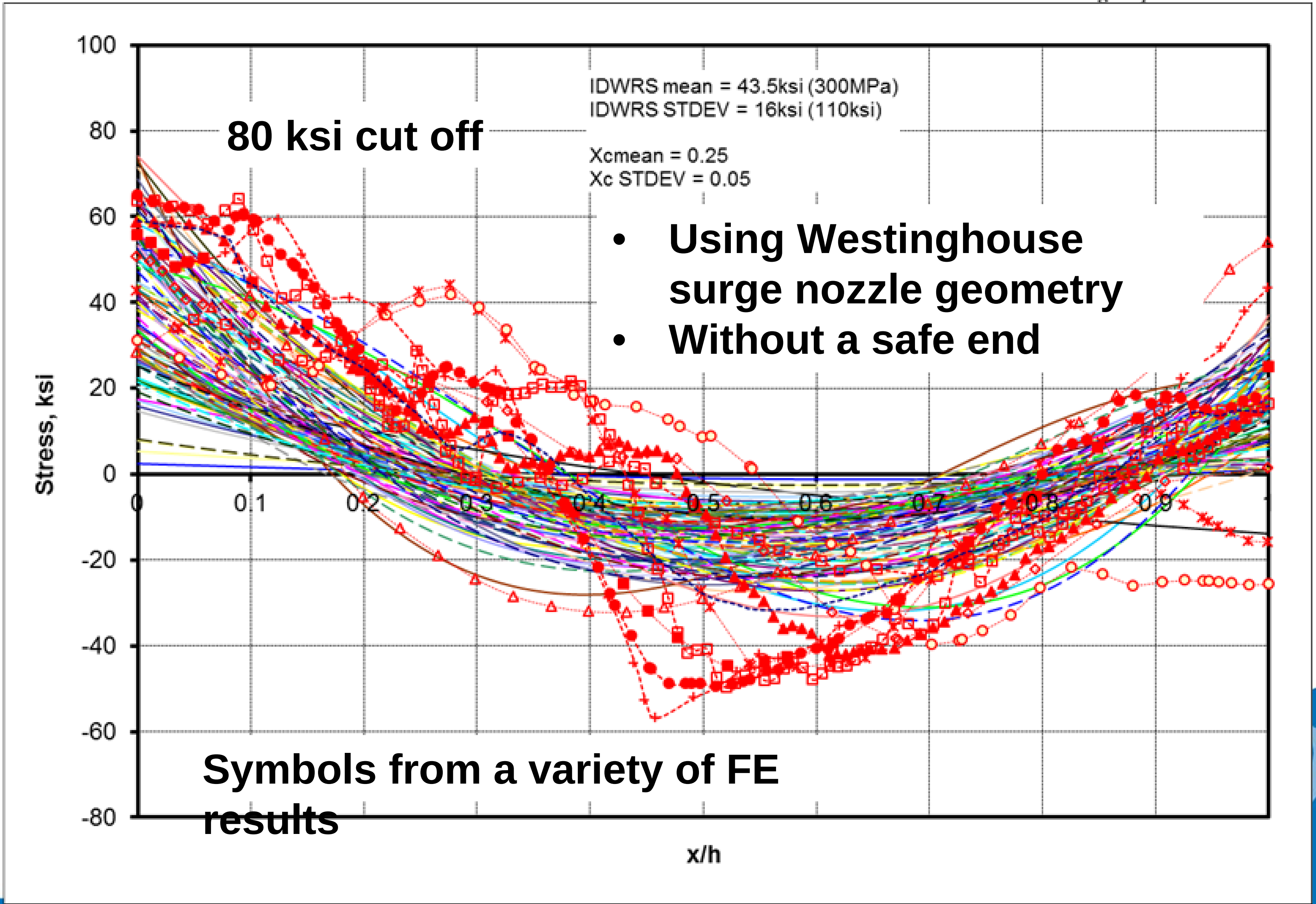
σ_M(N)= 35.1 MPa (5.1ksi)
σ_M(N+SSE)= 35.9 Mpa (5.2 ksi)

σ_B(N)= 72.7 MPa (10.5 ksi)
σ_B(N+SSE)= 93.0 MPa (13.5 ksi)

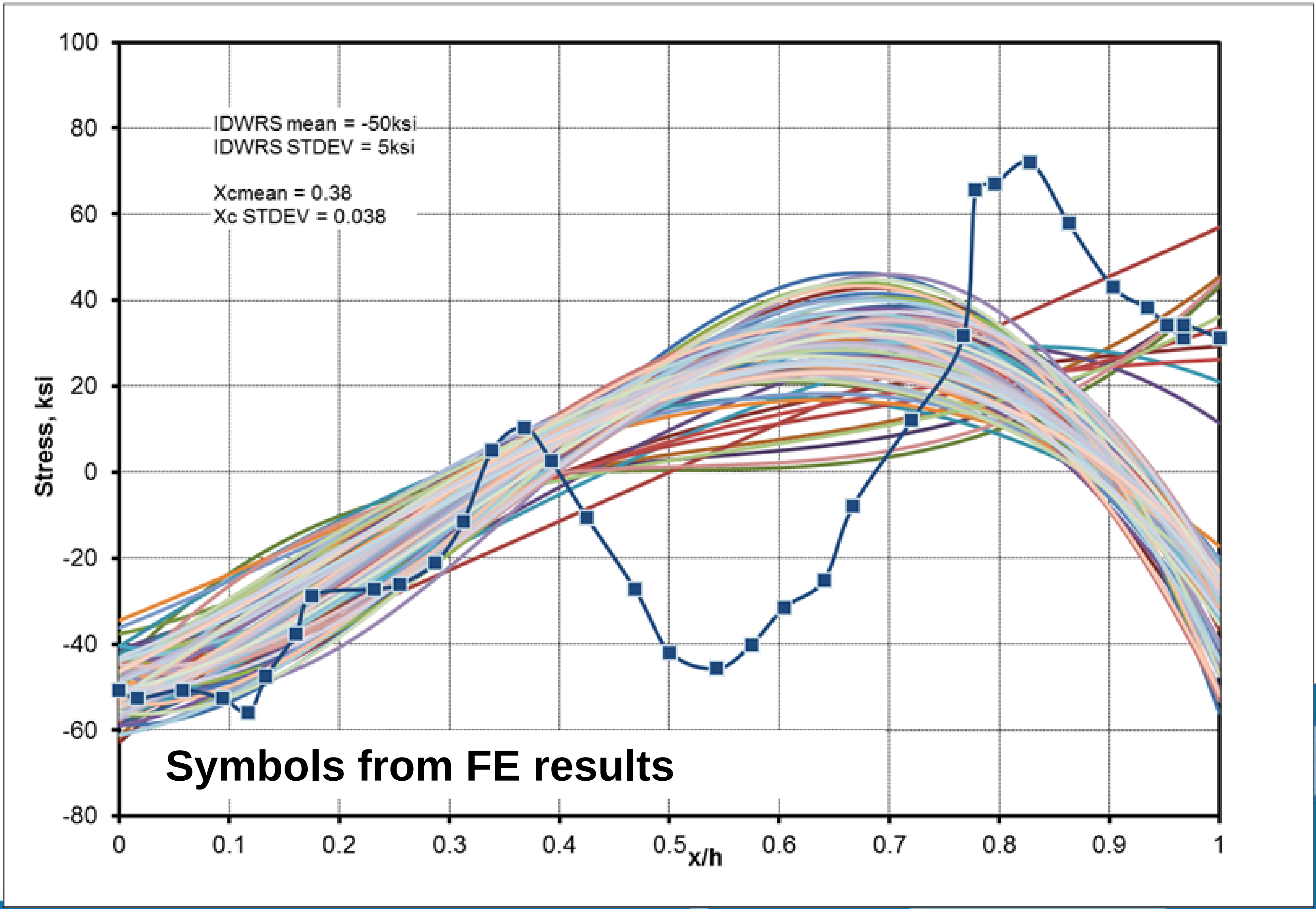
Inputs - Material

Material	Property	Mean	Stddev	Distribution type	Correlation
A516 Gr 70	Yield strength, MPa	228.5	21.7	Lognormal	0.4866
	Ultimate strength, MPa	519.9	28.7	Lognormal	
	Elastic modulus, GPa	186.3	0	Constant	N/A
	F	915.2	82.3	Lognormal	-0.8565
	n	4.322	0.538	Lognormal	
TP304	Yield strength, MPa	172.5	36.5	Lognormal	0.6066
	Ultimate strength, MPa	453.7	53.2	Lognormal	
	Elastic modulus, GPa	177.1	0	Constant	N/A
	F	563.8	43.6	Lognormal	-0.6047
	n	4.298	0.571	Lognormal	
Alloy 182	Yield strength, MPa	372	90.1	Lognormal	0.5
	Ultimate strength, MPa	583	58	Lognormal	
	Elastic modulus, GPa	203.1	0	Constant	N/A
	J_{Ic}, kJ/m^2	570.7	360	Lognormal	0.9
	C	292.34	150	Lognormal	
	m	0.62	0.1	Lognormal	

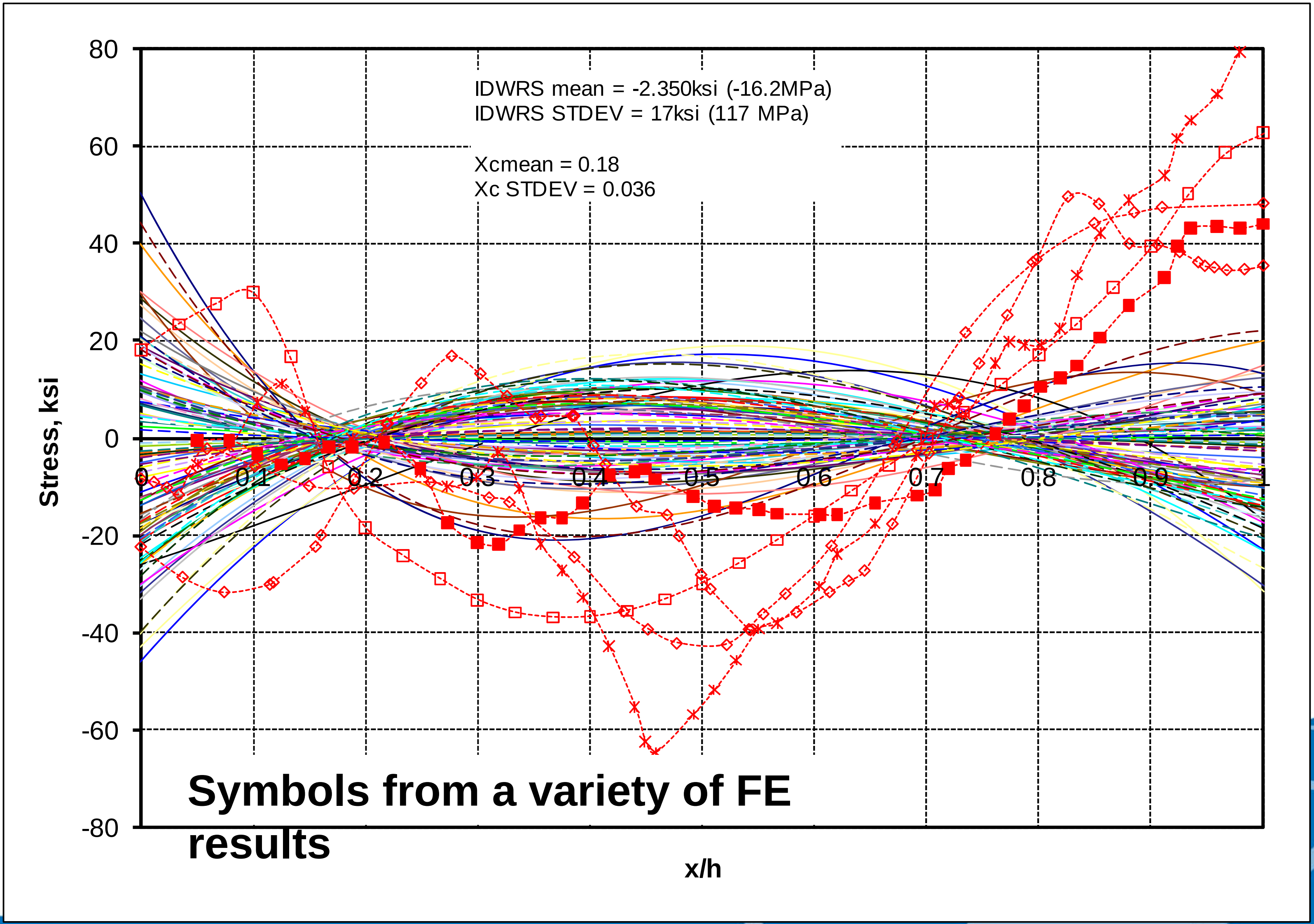
WRS base


80 ksi cut off
IDWRS mean = 43.5ksi (300MPa)
IDWRS STDEV = 16ksi (110ksi)
Xcmean = 0.25
Xc STDEV = 0.05
• Using Westinghouse surge nozzle geometry
• Without a safe end
Symbols from a variety of FE results
Stress, ksi
x/h
100
80
60
40
20
0
-20
-40
-60
-80
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

WRS Mitigation



WRS with SS Safe End



Uncertainty

- Uncertainties were classified by models/inputs group
- More discussion needed, but satisfactory for pilot study

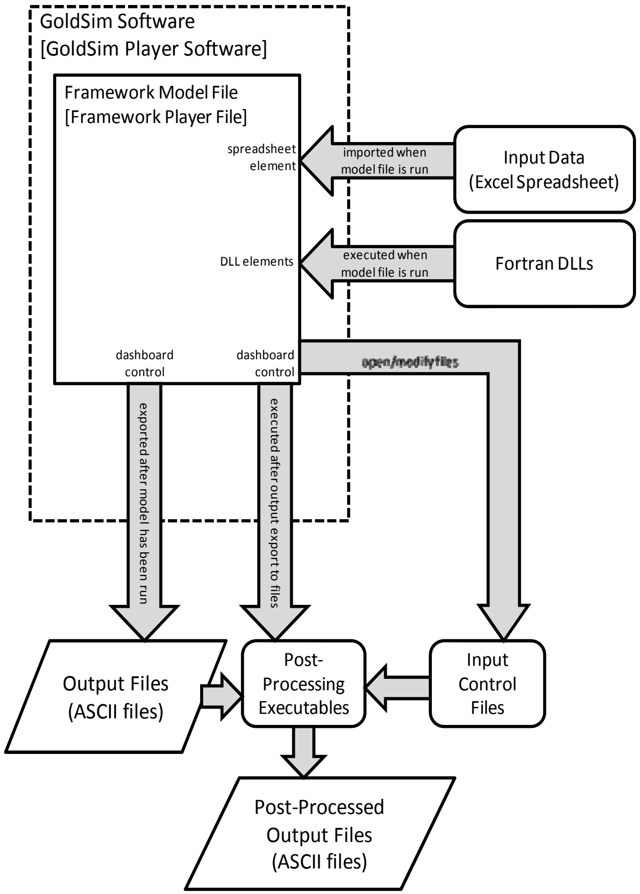
Epistemic (Lack of knowledge)	Aleatory (Irreducible)
• Loads • WRS • Crack growth (fweld) • Crack initiation parameters • POD parameters	• Crack size • POD detection • Material properties • Crack growth parameters (Q/R,c,P)

- Currently uses LHS (epistemic) and MC (aleatory)
- Discrete probability distributions also available.
- Importance sampling was demonstrated

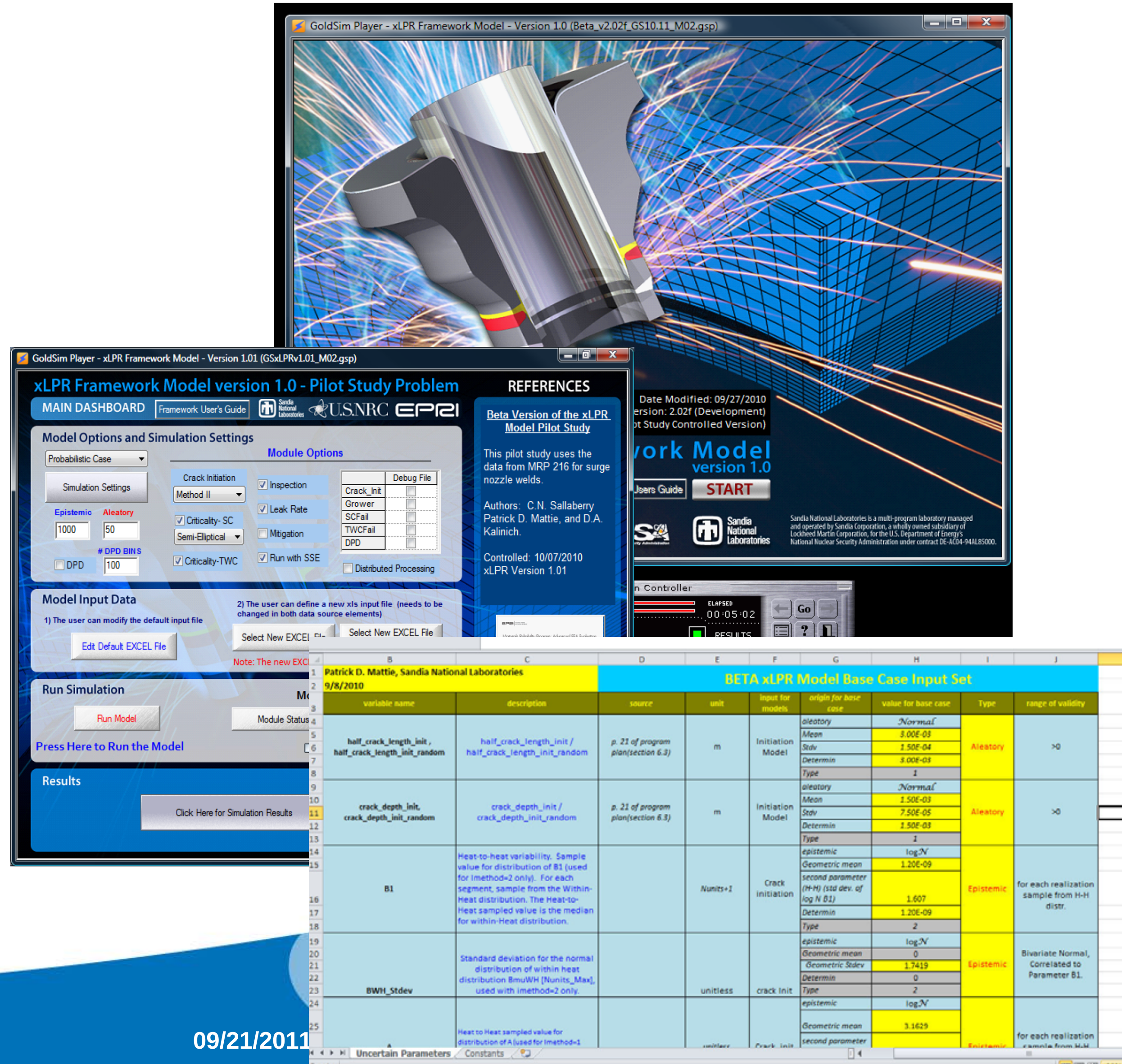
xLPR Version 1.0 Framework

- One of the objectives of the pilot study was to determine the "best" probabilistic framework for this effort
- Considered commercial software and fully-open source software
- Developed independent framework codes using same complied modules
- Metrics for choosing framework consider technical and cost considerations

GSxLPRV1.0

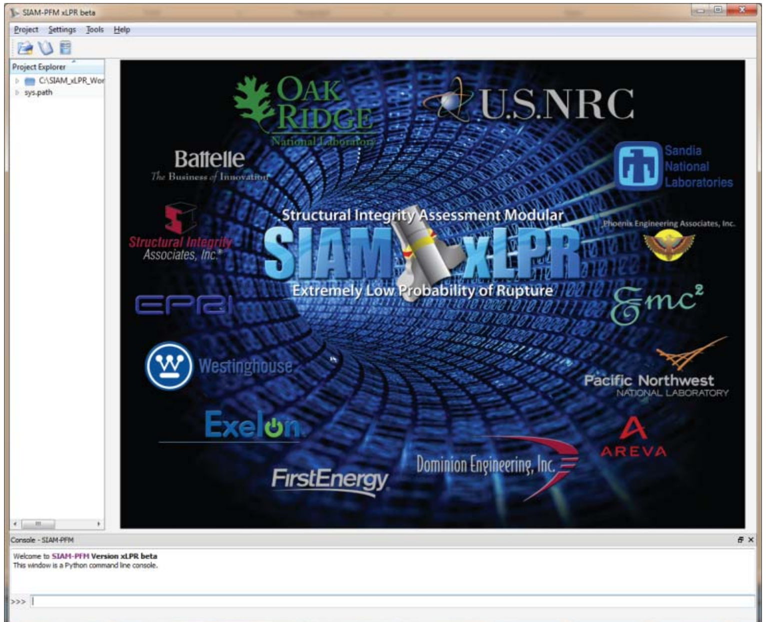


GoldSim Software
[GoldSim Player Software]
Framework Model File
[Framework Player File]
spreadsheet element
DLL elements
dashboard control
dashboard control
imported when model file is run
Input Data
(Excel Spreadsheet)
executed when model file is run
Fortran DLLs
open/modify files
exported after model has been run
executed after output export to files
Output Files
(ASCII files)
Post-Processing Executables
Input Control Files
Post-Processed Output Files
(ASCII files)

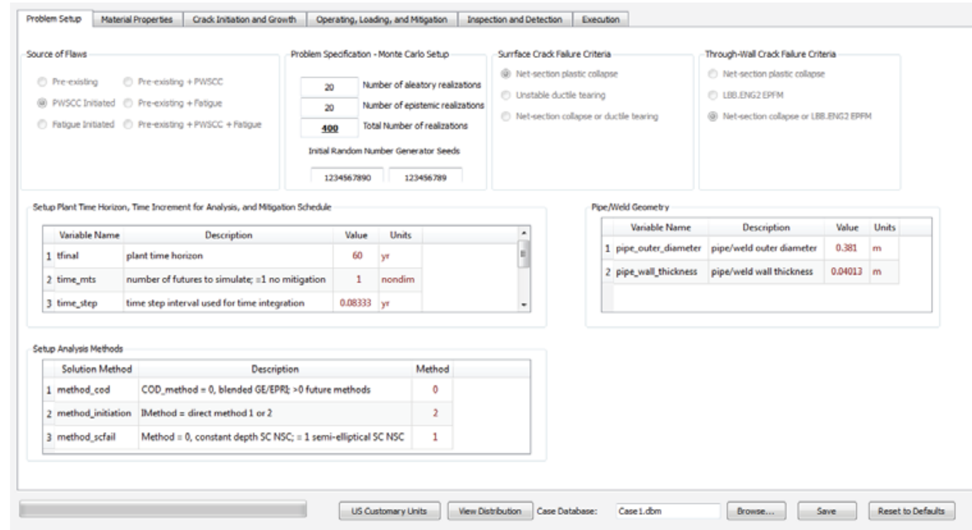


GoldSim Player - xLPR Framework Model - Version 1.0 (Beta_v2.02f_GS10.11_M02.gsp)
GoldSim Player - xLPR Framework Model - Version 1.01 (GSxLPRv1.01_M02.gsp)
xLPR Framework Model version 1.0 - Pilot Study Problem
MAIN DASHBOARD
Framework User's Guide
REFERENCES
Beta Version of the xLPR Model Pilot Study
This pilot study uses the data from MRP 216 for surge nozzle welds.
Authors: C.N. Sallaberry Patrick D. Mattie, and D.A. Kalinich.
Controlled: 10/07/2010
xLPR Version 1.01
Model Options and Simulation Settings
Module Options
Probabilistic Case
Simulation Settings
Epistemic
Aleatory
1000
50
Crack Initiation
Method II
Criticality- SC
Semi-Elliptical
Criticality-TWC
Inspection
Leak Rate
Mitigation
Run with SSE
Debug File
Crack_Init
Grower
SCFail
TWCFail
DPD
DPD BINS
DPD
100
Distributed Processing
Model Input Data
1) The user can modify the default input file
Edit Default EXCEL File
2) The user can define a new xls input file (needs to be changed in both data source elements)
Select New EXCEL File
Run Simulation
Run Model
Module Status
Press Here to Run the Model
Results
Click Here for Simulation Results
Date Modified: 09/27/2010
START
Patrick D. Mattie, Sandia National Laboratories
9/8/2010
BETA xLPR Model Base Case Input Set
Uncertain Parameters
Constants

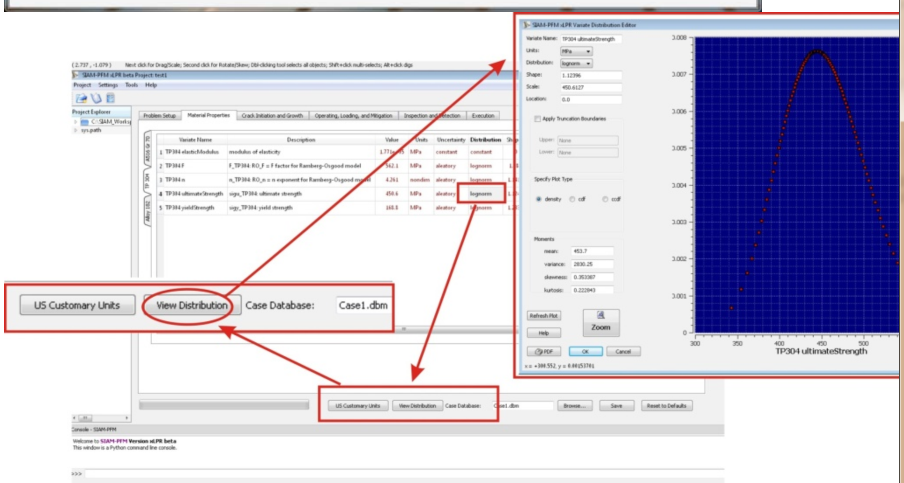
SIAMxLPR1.0



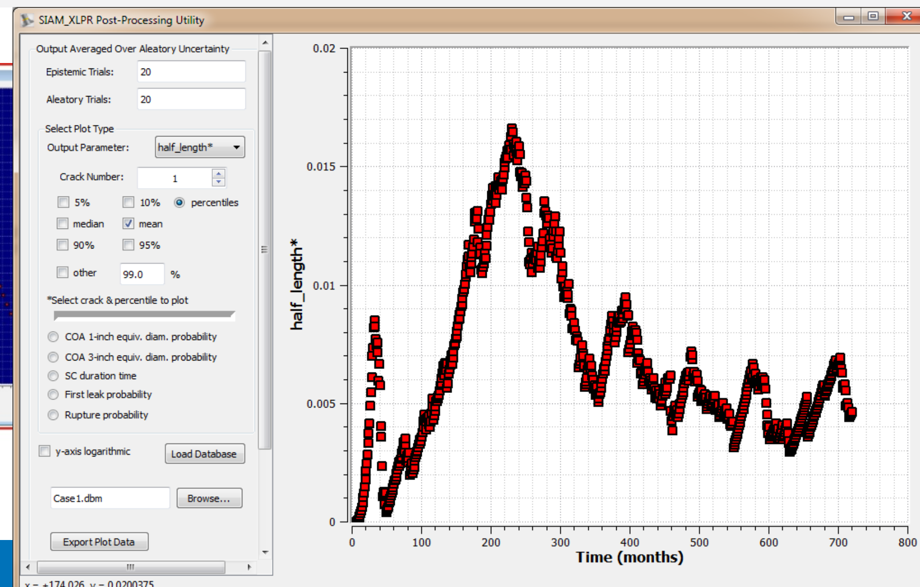
SIAM-PFM xLPR beta
Project Settings Tools Help
Project Explorer
Structural Integrity Assessment Modular
SIAM xLPR
Extremely Low Probability of Rupture
Console - SIAM-PFM
Welcome to SIAM-PFM Version xLPR beta
This window is a Python command line console.



Problem Setup
Material Properties
Crack Initiation and Growth
Operating, Loading, and Mitigation
Inspection and Detection
Execution
Source of Flaws
Problem Specification - Monte Carlo Setup
Surface Crack Failure Criteria
Through-Wall Crack Failure Criteria
Number of aleatory realizations
Number of epistemic realizations
Total Number of realizations
Initial Random Number Generator Seeds
Setup Plant Time Horizon, Time Increment for Analysis, and Mitigation Schedule
Pipe/Weld Geometry
Setup Analysis Methods
US Customary Units
View Distribution
Case Database:
Case1.dbm
Browse...
Save
Reset to Defaults



US Customary Units
View Distribution
Case Database:
Case1.dbm
TP304 ultimateStrength
Zoom



SIAM_XLPR Post-Processing Utility
Output Averaged Over Aleatory Uncertainty
Epistemic Trials:
Aleatory Trials:
Select Plot Type
Output Parameter:
half_length*
Crack Number:
5%
10%
percentiles
median
mean
90%
95%
other
*Select crack & percentile to plot
COA 1-inch equiv. diam. probability
COA 3-inch equiv. diam. probability
SC duration time
First leak probability
Rupture probability
y-axis logarithmic
Load Database
Case1.dbm
Browse...
Export Plot Data
half_length*
Time (months)

Summary

- xLPR Version 1.0 was developed to test feasibility of concept and to choose appropriate framework
- Only pressurizer surge nozzle DM weld considered
- Models chosen by team experts – coded into self-contained, compiled modules
- Two framework structures considered – open source and commercial