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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

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UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

(ACRS)

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METALLURGY & REACTOR FUELS SUBCOMMITTEE

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THURSDAY

AUGUST 22, 2019

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ROCKVILLE, MARYLAND

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The Subcommittee met at the Nuclear Regulatory Commission, Two White Flint North, Room T2B10, 11545 Rockville Pike, at 1:00 p.m., Ronald G. Ballinger, Chairman, presiding.

COMMITTEE MEMBERS:

RONALD G. BALLINGER, Chair

WALTER L. KIRCHNER, Member

JOSE MARCH-LEUBA, Member

DAVID PETTI, Member*

JOY L. REMPE, Member

PETER RICCARDELLA, Member

DESIGNATED FEDERAL OFFICIAL:

CHRISTOPHER BROWN

ALSO PRESENT:

DAVE ALLEY, NRR

BRIAN HALL, Westinghouse

TIM HARDIN, EPRI

RAJ IYENGAR, RES

MARK KIRK, CRIEPI

LOUISE LUND, NRR

MATTHEW MITCHELL, NRO

RANDY NANSTAD, Oak Ridge National Laboratory

NATHAN PALM, EPRI

JEFF POEHLER, RES

PATRICK REYNAUD, RES

ROBERT TREGONING, RES

DAN WIDREVITZ, RES

*Present via telephone

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

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P R O C E E D I N G S

1:01 p.m.

CHAIR BALLINGER: This meeting will now come to order. Sort of. This is a meeting of the Advisory Committee on Reactor Safeguards Metallurgy and Reactor Fuel Subcommittee. I'm Ron Ballinger, Chairman of the Subcommittee.

Members in attendance are Walt Kirchner, Pete Riccardella, Joy Rempe, Jose March-Leuba, and on the phone, Dave Petti. Chris Brown is here somewhere, is the designated federal official for this meeting.

The purpose of today's meeting is for the Subcommittee to receive a briefing on the staff's development of a white paper on the adequacy of Revision 2 of Regulatory Guide 1.99. Today we have members of the NRC staff and EPRI, I think, and others to brief the Subcommittee.

The ACRS was established by statute and is governed by the Federal Advisory Committee Act, FACA. That means that the Committee can only speak through its published letter reports and we hold meetings to gather information to support our deliberations.

Interested parties who wish to provide comments can contact our office requesting time. That said, we set aside 10 minutes for comments from members of the public attending or listening to our meetings. Written comments are also welcome.

The meeting agenda for today's meeting was published on the NRC's public meeting notice website, as well as the ACRS meeting website. On the agenda for this meeting and on the ACRS meeting website are instructions as to how the public may participate. No requests for making a statement to the Committee has been received from the public.

A transcript of the meeting is being kept and will be made available on our website. Therefore, we request that participants in this meeting use the microphones located throughout the meeting room when addressing the Subcommittee, and in the front, make sure the little green light is on when you're talking.

Participants should first identify themselves and speak with sufficient clarity and volume so they can be readily heard. We have a bridge line established for the public to listen to the meeting. To minimize disturbances, the public line will be kept in a listen mode only.

To avoid disturbance, we request that attendees put their electronic devices, cell phones and other kinds of things in a noise free mode or off.

We will now proceed with the meeting and

I'll ask Ms. Louise, yes, Louise Lund, Director of the Division of Licensing projects, NRR, to make introductory remarks before we begin today's presentations. You've got to make sure the light's on as well.

MS. LUND: We were just looking at that, but it sounds like the microphone is on to me.

CHAIR BALLINGER: Yeah, it is.

MS. LUND: Okay, sounds good. All right, so thank you, and my name is Louise Lund, and as of this week, I just started as the Division Director for the Division of Engineering in the Office of Research.

So, that said, we're here today to talk about the Regulatory Guide 1.99 Rev 2, radiation embrittlement of reactor vessel materials, which is used by licensees in the operating fleet to determine the change in reactor vessel properties due to irradiation.

As such, the guidance of the Reg Guide is used to determine the adjusted reference temperature, which is used to determine the fracture toughness, a key input to pressure temperature limits.

The Reg Guide also provides guidance for assessing the change in upper shelf energy, which is related to ductal fracture resistance. Both of these properties are needed to show compliance with 10 CFR 50, Appendix G.

So it should be noted that the current Reg Guide dates from 1988. Since that time, a large amount of test data on irradiated reactor vessel materials has been obtained from tests of surveillance materials.

So, with licensees planning to operate plants out to 60 to 80 years, it is important that guidance for assessing embrittlement is adequate for the neutron fluence levels that are projected for these plants.

New plants will use reactor vessel materials with different chemistries than are typical of the operating fleet. Therefore, the NRC staff performed an assessment of the adequacy of Reg Guide 1.99, Revision 2 based on these considerations.

So today's presentation summarizes a multiyear effort to thoroughly assess Reg Guide 1.99 through a modern data driven approach.

At this time, the assessment does not address licensing basis or policy decisions, and discussion of next steps and regulatory implications has not been part of this assessment and will be the subject of further discussion, and the staff and also the management, so that's not, that will not be part of the presentation today as well.

So we do have the staff up here at the table, and of course I have Raj, the branch chief, with me, and also there is Dan Widrevitz and also Matt Mitchell, who will be representing the staff, and here is Dave Alley as well, so that concludes my opening remarks.

MEMBER REMPE: I had a question that I might as well bring up to you even though I know you just started this position, but the fact of this Reg Guide, I thought they were supposed to be revised every 10 years. Is this a problem that should be emphasized?

MS. LUND: And that's a very good point, okay. It's not so much that they get revised every 10 years in as much as they are looked at for whether revisions are necessary, and obviously, you know, depending on how extensive the revisions would be, that would dictate the schedule.

MEMBER REMPE: But this one should have been looked at every 10 years and it should have been acknowledged, and I thought some of the information I read said it was recognized it needed to be updated, but this is --

MR. IYENGAR: Yeah, it was --

MEMBER REMPE: -- quite a bit of time.

MR. IYENGAR: So we do a periodic review of all important Reg Guides, and this Reg Guide, a periodic review was done in 2014 if I am right. At the time, the staff concluded that at this moment, this Reg Guide is adequate at this moment, and then further we considered the revision given the next cycle, which is what we are doing right now.

MS. LUND: And I think also at the end of the presentation, they're also going to explain the time frame in which we expect to need additional information or, you know, when this could be necessary, so we'll discuss that as well.

MEMBER REMPE: Thank you.

MR. WIDREVITZ: All right, well, good afternoon, everyone. My name is Dan Widrevitz. I'm a member of the Office of New Reactors and I was, Raj gave me the opportunity to come over and spend some time in research to help them write the assessment.

Obviously there were many hands in this assessment. It's not the work of one person. Many of those hands are in this room right now, so I'd like to thank everyone who helped me get us here today, so with that, I'd like to begin.

Sort of reiterating on Louise's introduction, I really want to -- we have to emphasize this is the result of a multiyear effort attempting to assess the Reg Guide through a data driven approach.

The assessment does not, very specifically, we were careful, it does not address licensing basis or policy decisions. This is strictly a technological assessment.

In a sense, you could say that the question we were looking into is how accurate is the Reg Guide, not necessarily what the significance of any potential inaccuracies or accuracies is. Those are a little bit separated, so this is more of sort of a research technology context, a little bit less of a program office policy context.

In terms of discussions of next steps and regulatory implications, it's just not part of this assessment, and we really, we don't have much to share during this meeting today on that. That's really an ongoing effort that's very early.

So to give you an idea of what we're going through today, coincidentally it looks exactly like how the assessment is structured. We're going to go through a little bit of background, talk about the RTndt results, the delta upper shelf energy results, credibility criteria, plant specific data results, attenuation, common additions, and we'll wrap up with some conclusions and a very, very brief statement about next steps, essentially going through the contents of the Reg Guide and what our findings were.

Again, the assessment was focused on Reg Guide, Rev 2. Really it's applicable to operating in new reactors, and for the purpose of this Reg Guide, those two populations are a little bit distinct. They're sort of different in terms of chemistry, in terms of a few other factors, but ultimately they're both large light water reactors.

They have similar neutron fluences. They're still in the same realm of science, but the implications are a little bit different, especially since operating reactors are more focused on extended license periods. New reactors are looking at initial license periods.

In terms of where the assessment goes, again, the assessment was not focused on solutions or establishing regulatory positions, and that's why you really don't see it reaching out beyond the Reg Guide and the Reg Guide's results compared to measured data.

So a little bit of background, Reg Guide 1.99 is entitled radiation embrittlement of reactor vessel materials. It was issued in 1988 based on the data that was available then. It provides predictive curves and supporting calculations of RTndt, which is a measure correlated to the ductile embrittle transition of reactor pressure vessel steels and upper shelf energy, which is a measure of how much energy can be absorbed by those steels when they're of sufficient temperature.

It also provides methods that you may utilize to use plant specific surveillance data, including credibility criteria to judge whether that data is properly usable. It also provides a through wall neutron attenuation formula to estimate sort of neutron damage as you go through the thickness of the vessel.

And I think this is, one of our members has already pointed out, this is interesting. If you go back to the regulatory analysis that was issued with the Reg Guide -- and I would like to read this quote. I admit, I enjoy it.

It says, "There is, however, a strong probability that revisions will continue to be made over the lifetime of the plant as more data are added around the fringes of the database, high nickel materials, low copper modern steels, and high fluence conditions encountered in plant life extension."

I like to point this out with the understanding that really the Reg Guide was based on, in a sense, curve fitting to data, and very intelligent people who worked on that curve fit acknowledge that ultimately, you're beholden to the quality and the breadth of your data set for the results, and there was an expectation that over time, as we move beyond the applicability of the original data set, there would be updates.

So it really shouldn't be surprising to anyone that here, 30 years later, with dramatically more data than was available when the original Reg Guide was written, that we found that we could do better, so I just, I wanted to point that this isn't -- there is no new magical science understanding. This is ultimately a curve fit and what we have is more data.

In terms of what did they have? The RTndt curves were fit to 177 datum. The curves were a mix of Guthrie and Odette results with feathering for the low copper regime. Some of that feathering was essentially motivated by test reactor data. They didn't have data on very low copper steels. No one had it, so --

MEMBER RICCARDELLA: You use the expression "feathering?"

MR. WIDREVITZ: Yes, that's actually how it's described in a paper published by one of the original authors.

MEMBER RICCARDELLA: And --

MR. WIDREVITZ: So essentially they wanted to make sure that the chemistry factors didn't go to zero because of the way their curve fit worked, so they artificially had them saturated at a low value for low value copper. It's an odd description, but that's what occurred. In terms of upper shelf energy, that was -- sorry.

MEMBER RICCARDELLA: Would fudged be a better word?

MR. WIDREVITZ: Did what we could with what we had, yes, absolutely. The upper shelf energy was developed as upper bound curves. As far as we're able to tell, because you only have what has been left in the written record and these were hand drawn, the credibility criteria and use of surveillance data have no traceable underpinnings as far as we understand it.

These were produced by engineering judgment. If you want a fancier word, empirical Bayes comes to mind, and the attenuation formula was based on dpa studies, so this is our background to the Reg Guide as it stands.

Now, to analyze this, we really needed to get ahold of newer data, and the best aggregated data source available for this work was a data set called BASELINE produced by ASTM.

Many excellent people were involved and this is -- the data, I believe, is up until 2011-ish, so much more up-to-date than the original data set, something like 2,000 data points versus 177.

This includes both domestic and international data. About half of it was domestic, so even there, that's 1,000 data points instead of roughly 200, much bigger, more chemistries, more fluences, a very rich data set, and here, I have broken it down by pipes. This is again, just in the assessment report.

In terms of results, and I think this is the most significant and interesting plot for the assessment, this is a plot of the predicted shift for each material in terms of how much it embrittles, how much its ductal brittle transition shifts with neutron embrittlement minus the measured value.

These are various surveillance capsules and other tested material properties, so it's the residual predicted minus measured. The top plot is for base materials, forgings, and plates. The bottom plot is for welding materials. So the Y-axis is residual. The X-axis is your neutron fluence in our traditional units of neutrons per centimeter squared, energy greater than one mega electron volt.

What you see here is your zero is sort of that's what you'd expect if you had a very nicely behaved prediction curve. The two dotted lines are your two sigmas. The red dots are domestic data. The gray dots are international data.

What you see here is, certainly if you look at either of these plots, you know, initially at lower fluences, they look fairly well behaved as you'd expect. As we get to higher fluences, some interesting things result.

And in terms of the most dramatic result, what you see is that at high fluences for base materials, you start getting these very non-conservative predictions where the measured values are larger than the predicted values.

You see that in the domestic data. You see it even more so in the international data that has more high fluence data points. That's a pretty significant result because it's non-conservative and we're very interested in that result.

In terms of weld results, whether or not that trend is there, I certainly couldn't tell you. The truth is we don't have as high a fluence for the weld results as we do for the base results.

You also see a bit more data, particularly international data, where it's over-predicted compared to the measured data, but any sort of trends just aren't clear there, but certainly for the base data, we have something interesting there.

To analyze all of this, we ran it through a whole gamut of statistical tests. Sure.

MEMBER RICCARDELLA: The standard deviation lines, are they standard deviation lines based on this data or based on the NUREG 1.99?

MR. WIDREVITZ: I believe these are the 1.99 standard deviations --

MEMBER RICCARDELLA: Okay.

MR. WIDREVITZ: -- which I'm about to say are wrong.

MEMBER RICCARDELLA: Yeah.

MR. WIDREVITZ: So, yeah, but they work reasonably well at low fluences. Again, you know, there's always a question of adequacy. At what point does something become more concerning? And two sigma is generally accepted practice.

MEMBER RICCARDELLA: Each one of those is plus two sigma and minus two sigma?

MR. WIDREVITZ: Yes.

MEMBER RICCARDELLA: And refresh my memory. At one point, we take into account the standard deviation. What do we add in that? Do we add one sigma or something?

(Simultaneous speaking.)

MEMBER RICCARDELLA: When you're doing a 1.99 estimate of your radiation embrittlement and trying to shift your RTndt, you put back in a factor for the --

MR. WIDREVITZ: It's in the margin term.

MEMBER RICCARDELLA: Yeah, and what is the --

MR. WIDREVITZ: And it's sort of two sigma.

MEMBER RICCARDELLA: It's what? It is two sigma?

MR. WIDREVITZ: Yeah.

MEMBER RICCARDELLA: So you add two sigma back in, all right.

MR. WIDREVITZ: Yeah, it's a geometric mean between the uncertainty of your initial squared, the two times the square root of initial deviation squared plus the standard delta standard deviation squared --

MEMBER RICCARDELLA: Okay.

MR. WIDREVITZ: -- geometric mean.

CHAIR BALLINGER: But what's -- excuse me. What's not on this are the actual values themselves for both the weld and the base metal, and there's a significant difference between those two, right?

MR. WIDREVITZ: Yeah.

CHAIR BALLINGER: So this shows a significant deviation in the residuals, but as a practical matter, if it's plate material, how close are you to the 41, to the limits are you?

MR. WIDREVITZ: Part of the answer to that is that's next steps. The other part is there are high fluence plants that are base limited.

CHAIR BALLINGER: Okay.

MR. WIDREVITZ: There are some limiting materials up at that fluence and we really, that's where sharpening the pencil and policy implications gets to become key, so we did not want to answer that in the assessment.

So statistics, many, many interesting results all together. What you see here are three statistical tests that have been done on a number of bins. The left most column uses all of the U.S. and international data and baseline. The center column is U.S. only. The right column is international data only.

The top row is the mean residual. That's sort of the net bias of all results. The middle column is the root mean squared deviation, which is a measure of scatter in a sense, and depending on what mathematical assumptions you make, that's the same as your standard deviation. The bottom row is the log-likelihood, which I explain a little bit more when we get to there.

So I'd like to focus really on U.S. only results here for a number of reasons, one of which is one would expect the Reg Guide to perform more poorly for international results because they have different chemistries that really the Reg Guide wasn't built to cover, so it shouldn't be a surprise that it has some interesting effects there.

MEMBER MARCH-LEUBA: So you think the difference is the actual physical chemistry of the plant, not the way they reported the data or measured the data?

MR. WIDREVITZ: I would say that that's a larger factor.

MEMBER MARCH-LEUBA: It's a larger factor, okay.

MR. WIDREVITZ: Yeah, in terms of how they measured and reported compared to the fact that there's chemistries that are a fair bit outside of the original 177 data points. It's just second order.

So for the U.S. data, what we find is there is overall a mean residual, which is to say that when you sum up all of your residuals, the predictions tend to actually be a little higher than the measured values, which you can see if we -- I'll flip back real quick.

If you look at that top plot, it's difficult to see unless you're very close to it, but the residuals actually bow a little bit positive before they bow back down when you get to high fluence.

MEMBER MARCH-LEUBA: I say this in every single meeting. You can use the mouse to point and we can follow what you say.

MR. WIDREVITZ: You still probably can't see it, but they do. It's much easier to see when you've got much better screens than this. At home, it's totally clear. These monitors have some saturation effects.

And also if you look at, for that matter, welds, they have that same characteristic. Your average residual is positive, which means that your prediction is larger than your measured, and that's exactly what you see when you start -- here we have all of these sub-bins as well and there's a lot of texture here, but they're generally a positive bias.

MEMBER KIRCHNER: These are the averages independent of fluence is what you're saying?

MR. WIDREVITZ: Yes.

MEMBER KIRCHNER: Yeah.

MR. WIDREVITZ: Yeah, the bias is interesting. If you have a well-behaved prediction, you would tend to want your residual to be zero, which is to say that you've got a nicely, normally distributed prediction about, that is normal about your data, and clearly these predictions are not, so not the best result in the world, but again, they only had so much data, and now we're using -- we're fitting much -- we're throwing much more data into something that was fit for a smaller data set.

Root means squared deviation, I think, in some ways is a more interesting characteristic because it's telling you about how scattered your data is. It doesn't care whether it's positive or negative. It's interested in just generally what's your scatter?

Very tiny and hard to see, these two black lines in here are the standard deviations given in the Reg Guide 1.99 itself, and what you see is in those sub-bins, when you do the calculation using the baseline data set, you actually end up with a larger RMSD, which suggests that the standard deviation of the Reg Guide might be too low. The deviation of the original data set is not consistent with what we've seen as time has gone on.

You'll also notice there's two sets of markers, blue and red. I'm mostly talking about the blue markers. Blue markers are just the Reg Guide straight. That's you take the formula and you do your prediction.

The red markers have had what's called the degree for degree correction added, which is not common practice for most materials. Basically it was noted somewhat later on that as you go up and down in temperature, your shifts increase or decrease by roughly a degree.

So if you go up in temperature, your shift goes down about a degree per degree of going up. If you go down a temperature degree, your shift goes up by a degree, and that's roughly true near the operating temperatures of reactors.

This was added later to do some data adjustment and I'll discuss it very briefly in some later slides, but suffice it to say that the Reg Guide doesn't have a temperature term.

This is the only temperature adjustment that the NRC has ever discussed, and when you look at it in terms of statistics, it generally reduces the quality of results. It's not well modeling what's going on.

MEMBER RICCARDELLA: The degree for degree?

MR. WIDREVITZ: The degree for degree when you add it to the Reg Guide causes more modeling issues statistically.

MEMBER RICCARDELLA: It reduces the bias.

MR. WIDREVITZ: Well, in this case, the bias is higher. If you look at -- the red dots are all above the blue dots in the top row for U.S. data.

MEMBER RICCARDELLA: Okay, I had them crossed, all right.

MR. WIDREVITZ: Yeah, this is a very information rich set of plots and it's easy to.

MEMBER RICCARDELLA: And are there blue

dots in the second?

MR. WIDREVITZ: They're overlapping.

MEMBER RICCARDELLA: Oh, they fall right on top?

MR. WIDREVITZ: Yeah, the RMSD is not sensitive to that because it makes some of them -- it moves everything up.

(Simultaneous speaking.)

MR. WIDREVITZ: The likelihood is -- oh, sorry.

CHAIR BALLINGER: Who is this? Oh, it's Dave, okay.

MEMBER PETTI: The degree for degree stuff, is this an artifact of this overly complicit model or this is just about the underlying data itself, the fact that there's a greater bias?

MR. WIDREVITZ: I think that it's, depending on which material you're talking about, it's complex.

MEMBER RICCARDELLA: Dave, this is Pete. The lower temperature you irradiate at in general, the worse it is. If it gets colder, it gets worse, and so when you put this degree for degree adjustment in, you're making at least the lower temperature ones more conservative, right, than they would be without that correction.

MR. WIDREVITZ: Well, higher.

MEMBER RICCARDELLA: Hmm?

MR. WIDREVITZ: I mean, conservative implies you know truth, but generally, it has the effect of lifting up all of the shifts in the database.

MEMBER RICCARDELLA: Yeah, it's raising the bias.

MR. WIDREVITZ: Right. Yeah, and I think --

MEMBER PETTI: And something to get a sense on, is it really something in the data or is it something in the manipulation of the data, that if you, you know, plot it all over again and get everything in a Machiavellian approach, would you get better answers? Is it just an artifact of the construct or if it in the data itself?

MR. WIDREVITZ: If it was in the data, it wouldn't do this to the bias.

MEMBER RICCARDELLA: Well, it is a multi-variant approach with a whole bunch of variables. It's just that radiation temperature isn't one of them, that it should have been probably, but there's other variables, chemistry factors and those types of things. So it is a multi-variant approach in 1.99, but it's just that temperature wasn't one of those variables.

MR. WIDREVITZ: Yeah, I mean, this is moving a bit beyond the assessment, but I think you'll find if you look at nearly any more modern trend curve effort, they have either a temperature term or something that is equivalent to temperature in the data.

MEMBER RICCARDELLA: Yeah, yeah.

MR. WIDREVITZ: So that's something that's been recognized. And again, we're talking about 30 years ago, they only had 177 data points. When you add more variables to a fit and you attempt to fit it on your database, eventually you're running out of the quality degree of freedoms you need to fit, and so you get into mathematical convergence issues.

So this, yeah, I'm not going to sit here and tell you there shouldn't be a temperature turn. There should have been, but this one in particular causes statistical issues.

MEMBER REMPE: So for the temperature corrections, you can see, I guess, there's a point that's the fourth in the U.S. data only that has the largest variation because you did include that temperature correction. How much of a correction was there? Is it 20 degrees? Is it 100 degrees or do you have any idea on --

(Off microphone comments.)

MEMBER REMPE: Well, that's a residual, so is --

MR. WIDREVITZ: An average of seven --

MEMBER REMPE: So an average --

MR. WIDREVITZ: -- from the residual.

MEMBER REMPE: -- was the residual. So if you had something that you had a plant, like an advanced reactor running at considerably more, you might see a larger increase is what I'm asking that question for.

MR. WIDREVITZ: Well, advanced plants are much hotter than --

MEMBER REMPE: Well, one is maybe not. That's a PWR running at a BWR.

MR. WIDREVITZ: Well, the short answer is there's a DCD called NuScale that's outside the temperature range of Reg Guide 1.99 that's much cooler.

MEMBER REMPE: That's what I'm trying to get to. So it would have a much larger correction, right?

MR. WIDREVITZ: Degree for degree is not satisfactory for NuScale. It wouldn't give you accurate results.

MEMBER REMPE: Okay.

MEMBER RICCARDELLA: What's their vessel temperature?

MR. WIDREVITZ: I want to say 494, 96, and the Reg Guide states that it's accurate between, I believe, 525 and 590.

MEMBER RICCARDELLA: I've got to assume that they'd be pretty judicious in their material chemistry choices though.

MR. WIDREVITZ: Yeah, that's the flip side. All new reactors have very low copper. Copper is our main culprit here. So there is a very mix and match going on with NuScale.

MEMBER RICCARDELLA: Yeah.

MR. WIDREVITZ: Okay, so we'll get to log-likelihood. The log-likelihood is a very interesting statistic that brings in a lot of the characteristics of other tests. In essence, it answers the question of if I have a formula, what is the likelihood I would come up with this data set?

And the higher the number, the more likely your data set would have been generated by that formula. So what you see here is at the top, zero. At the bottom is negative 85,000.

The magnitude of log-likelihood is related to the formula's constructions. The magnitude is not meaningful. It's almost, in a sense, it's a qualitative measure in that, you know, a larger negative value is worse. It's less likely that you found a good fit.

People use log-likelihood as one of the parameters to make fits, and so that's part of why it's here is that it brings in a lot of interesting information, and what you see is generally the results across the board for USA are not great.

Degree for degree increases that trend for a lot of data sets, though it improves it a little bit for welds -- and high copper.

It's complex, but generally speaking, and certainly for the total baseline, Reg Guide 1.99 does not work well for international data, and you see that when you try to add U.S. and international data all together in a log-likelihood calculation, and for international, you see that degree for degree just absolutely doesn't work, which is interesting, but a little bit outside of our core concern here.

Any questions? Yeah, I find log-likelihood is sufficiently complex that you sort of have to just use it.

Okay, finally, because three is not good enough, we have a fourth statistical test, the student T test. The student T test essentially asks when I compare these two sets of information, what is the likelihood that their means are the same?

And so in student T, if you get a value of the T statistic below 1.96, then you've got a 95 percent confidence that your means are similar, that these two distributions may actually be related to each other strongly enough that you can consider them the same. This 1.96 is almost a two sigma kind of criteria.

So what you see in these plots is 1.96 is green. It's that green segment at the bottom. I'm not sure -- yeah, you can't see it on the televisions, but it's in the document. It's just below the two.

And what you do is, in this case, you take the T statistics of each input variable or potential input variable, which are on the bottom of these plots, copper, lot of fluence nickel, temperature, phosphorus, manganese, lot of flux, and we took a look to see, you know, does it seem likely that, looking at the residuals, that this modeling variable has been well modeled by what the T statistic is sensitive to by Reg Guide 1.99, and what we find is that some variables seem to do all right, nickel, phosphorus.

You know, again I'm going to the center column which is U.S. data only. Nickel, phosphorus, and manganese do all right. There is some concerning residuals in copper, in fluence, a big one in temperature, not a surprise. Reg Guide 1.99 doesn't have a temperature term, one for lot of flux.

As far as the T statistic is concerned, if you apply the degree for degree transformation, you get the bottom row of plots. That improves your residuals for the T statistic, except for copper, which gets worse, and given that copper is our primary contributor to embrittlement, that's an unfortunate result.

What you'll see in the T statistic is international data has a lot of bad residual behavior, which is what you'd expect because you really wouldn't expect the Reg Guide to handle the full gamut of international data particularly well because it wasn't designed to.

So there is also a great deal of subtlety. We've also plotted the sub-bins in other colors. It's very difficult to read on these screens, but suffice it to say that there is a great deal of texture in sub-bins, and that's something that is very difficult when you're trying to create one curve to cover many chemistries and potentially mechanisms and you'll find that it works better for certain materials than others when you've got this sort of broad general curve.

All right, so what are our results? Let's try to summarize. The primary deficiencies, the deficiencies that certainly me, personally, I think warrant a little bit of attention, number one, non-conservative high fluence results for the base metals.

I couldn't really tell you today whether there is something similar for welds or not, but certainly for the base metals, I'm concerned about the accuracy of the predictions for them at high fluences. I'm also, as a new reactor person, concerned about the low copper results.

If you ask me what does that mean, I would say the Reg Guide 1.99 assumes a certain shape function of embrittlement. What does the curve look like as you embrittle? Low copper materials have a different shape function from Reg Guide 1.99.

I'm a new reactor guy. I see a lot of low copper materials. There's an inaccuracy there that concerns me from a technological level. It's an accuracy question. I don't like the accuracy that I'm getting from that. Again, this isn't a policy significance thing. It's simply an accuracy statement.

In terms of secondary deficiencies, things that either go along or aren't quite as concerning, it seems that the standard deviations stated in the Reg Guide is a bit too low when you look at a more modern data set.

You've got a conservative bias in low to mid fluences, which means you're over predicting your embrittlement a little bit, and there's a lack of temperature adjustment. When you're talking about a degree for a degree, there's quite a lot of information that's being hidden by the fact that there isn't normally a temperature term in there.

For reactors that run hotter, that's to their detriment. For reactors that run cooler, that might push their values up, but in general, again, from an accuracy standpoint, this is a clear inaccuracy. It's reducing the accuracy of my prediction.

MEMBER RICCARDELLA: Do any licensees actually use the degree for degree method?

MR. WIDREVITZ: The degree for degree

method is used for adjustment for sister plant data.

MEMBER RICCARDELLA: For which?

MR. WIDREVITZ: For sister plant data. When you've got heat matched welds in different places --

MEMBER RICCARDELLA: Yeah.

MR. WIDREVITZ: -- and you want to pull the data together to use --

MEMBER RICCARDELLA: Yeah, but if I have a plant and I wanted to estimate what my shift is, and I know I'm at a different temperature than the mean temperature of the data, would I adjust for that?

MR. WIDREVITZ: If you have plant specific data, you probably wouldn't. If you have your own plant materials --

MEMBER RICCARDELLA: Your own --

MR. WIDREVITZ: -- and your own capsules, and you're within the temperature bands in the Reg Guides, you're not directed to use it.

MEMBER RICCARDELLA: Okay.

MR. WIDREVITZ: And so that's an accuracy -- obviously your accuracy is lower because of that.

MEMBER RICCARDELLA: Yeah.

MR. WIDREVITZ: I'm not saying significance. I'm just saying the accuracy of your prediction.

To give some context on a calendar year, and I have to caution everybody, the data used to produce these curves were, in a sense, the fluence of capsules that were marked as end of license capsules and not extended license capsules, those capsules are not required to match the end of license licensing basis fluence.

Those capsules could be a bit higher than what you predict to actually hit at the end of 40 or 60. So consequently, these results are a little bit ahead on average of the actual fleet's materials because the data was gathered from industry reports on capsules essentially because it was all in one place, and so this is a little bit ahead of what you're going to see in the plant's relative licensing basis. Having said that --

MEMBER RICCARDELLA: The capsules lead the vessel, right?

MR. WIDREVITZ: The capsules lead the vessel, but also the fluences you pick might be in excess of actually your 40-year fluence, so your 40-year capsule might be a 45-year fluence. That's allowable by the ASTM E-185, and so this is a little bit -- these dates are probably a little bit earlier than if you went through and went through all hundred-ish plants and looked at their actual licensing bases.

So what I've plotted here is three sets of when materials, when we're forecasting leading materials to hit three different fluences, 3e times 10 to the 19th, which I would call sort of the mean deviate, where if you look at the plot of base materials, that mean begins deviating from zero in a non-conservative way is around 3 times 10 to the 19th neutrons per centimeter squared. That's the white dots, and you can see there's already plants with materials at that fluence.

If you go to 6 times 10 to the 19th, which is about where the mean hits the two sigma line, that's still in the future, 2020 sometime, but plants will be reaching that, and this is all ID fluence.

And then I've plotted 8 times 10 to the 19th because it looked nice and it was sort of interesting to give you a little bit of character to the data and a little bit of context.

So really, you're looking at, in terms of accuracy, you're going to start getting concerned about how accurate your base metals are in 1.99 in the late 2020s give or take, which kind of helps you think about when you need to do what sort of work if you're concerned about those inaccuracies, and these are counts based, again, on these capsule fluences at the two different sort of arbitrary fluences that I picked to plot.

I'm not going to say there's anything mathematically magical about these. Again, you really have to think about what you're constructing in your guidelines, what do you want to call significant, et cetera.

So let's go to upper shelf. In terms of upper shelf, we took data from the data set, which is surveillance capsule reports essentially. We combined it with properties from baseline which has all of your various chemistries and such, and we came up with a dramatically larger data set than was available when Reg Guide 1.99 was developed. We're talking about on the order of 1,200 data points, the vast majority of which, 1,000, were U.S. data points, so very relevant.

The international data always is interesting because they're a little, some of them are outside of necessarily what Reg Guide 1.99 is. Some of them are more similar to what we'd expect with new reactors, so it's always interesting to gather a rich data set to get rich results.

The REAP data set, again, you know,

everything is a snapshot in time. The REAP data set has data included up to about five or seven years ago, so again, there's been a few added, but not a huge number in terms of data, so this is reasonably representative of what we understand today really domestically.

So in terms of results, this is a plot from, I believe, a PVP paper by Mark Kirk. The original construction of upper shelf energy was to be a bounding curve, and what we found is when you look at more modern data sets, in this case, he had 860-ish data at that point, about 19 percent of the data are above the curve. The measured is higher than the predicted.

So it's not working as was originally designed, but it's still certainly, by no means is it a mean trend, right. We're still talking about something that's a fairly conservative prediction to the data set.

In terms of results, if you look statistically, there's a significant positive bias when you look at the data. It's supposed to be a bounding curve, so that's exactly what you'd expect. The RMSD is positive, again, not particularly surprising given the design of the curve.

When you look at the T statistic, there's quite a bit of modeling residual along various involved variables. This isn't a surprise generally. Upper shelf energy is more difficult to predict with accuracy than RTndt. This is a result that we've seen many, many times. So could it be improved? Yes.

In terms of use results, when do we really get interested? So, again, this isn't policy. We had to, to a certain extent, find a curve, choose to believe it a little bit more, and look at the results.

What you're concerned about is when you're looking at upper shelf energy, your regulatory requirement is you'd like to remain about 50 foot pounds, and if you go below 50 foot pounds, then you have to go and do an equivalent margin analysis, and to date, no one has failed to succeed at equivalent margin analysis, so this is not a hard regulatory limit. It's more of a, "This is where you need to pay a little bit more attention," regulatory method.

So what you see in this plot is everything to the left of that red bar is materials that have been predicted to fall below 50 foot pounds at some point. The blue curve is sort of where your measurements are showing you things that are below 50 foot pounds.

And the materials of greatest interest are the materials where your measurements would tell you you're below 50 foot pounds or sort of your synthetic, whichever new slightly better curve you're hopefully finding tells you that maybe you should do an equivalent margin analysis, but the current one does not, and there's just a handful, a tiny percentage of the databases falling into that quadrant.

MEMBER RICCARDELLA: Everything to the left of that vertical red line would have required a margin analysis based on the prediction, right?

MR. WIDREVITZ: Yes.

MEMBER RICCARDELLA: And then -- okay, and then everything --

MR. WIDREVITZ: It's difficult to see on the television, but this quadrant here in dark blue is really where --

MEMBER RICCARDELLA: Yeah.

MR. WIDREVITZ: -- where --

MEMBER RICCARDELLA: Those are the ones of concern.

MR. WIDREVITZ: -- you might be in a space where maybe you should have done an equivalent margin --

MEMBER RICCARDELLA: Yeah.

MR. WIDREVITZ: -- but you have not yet, and you can see there's just a handful.

MEMBER RICCARDELLA: Yeah.

MR. WIDREVITZ: Very small numbers. So again, this is sort of a sort criteria too. So what is your -- at this point, you can draw your own conclusion in terms of level of significance.

MEMBER RICCARDELLA: You know, this type of a plot enables you to understand whether there are some safety concerns with the upper shelf prediction. Couldn't you do an equivalent plot like this for the delta RTndt?

I mean, what you did for the delta RTndt just estimated, you know, bias and accuracy, and didn't really give me a feel for whether there is a concern, whether someone who had been using 1.99, if one of these data points represented a plant and somebody had done the 1.99 evaluation, and they'd be off by a significant number of degrees from what the actual --

MEMBER MARCH-LEUBA: In a sense, the previous analysis, the student T test still uses a statistical significant error, but it can still be a one percent error and be completely irrelevant --

MEMBER RICCARDELLA: Yeah.

MEMBER MARCH-LEUBA: -- from a physical point of view.

MEMBER RICCARDELLA: Yeah.

MEMBER MARCH-LEUBA: So, yeah, I agree with --

MR. WIDREVITZ: There's a lot of interesting ways to approach the question. The first one is we were not looking at licensing effects.

MEMBER RICCARDELLA: Well, but you are with this plot.

MR. WIDREVITZ: Well, this one is very, very easy.

MEMBER RICCARDELLA: Yeah.

MR. WIDREVITZ: When you're using RTndt, you're talking about shifting pressure temperature limits --

MEMBER RICCARDELLA: Yeah.

MR. WIDREVITZ: -- which is a fairly sophisticated thing.

MEMBER RICCARDELLA: Yeah.

MR. WIDREVITZ: You're talking about your PTS criteria, so it's more complicated than the way that the NRC has traditionally used upper shelf energy results. If you'd really like to answer that question and you're starting to lean towards doing probabilistic fracture mechanics results like you see in the basis for 5061A for example, and so the size of the question grows very large and now you start talking about you have to get into licensing basis, of which there are roughly 100, for example.

MEMBER RICCARDELLA: Well --

MR. WIDREVITZ: And so it's certainly an interesting question and I think it's something that, as we move forward, we're thinking about.

MEMBER RICCARDELLA: But I predict the delta T RTndt based on 1.99 with the margin term and with everything in there, and then I say okay, now based on the real data, what is that real delta T RTndt for each specific data point, and --

MEMBER MARCH-LEUBA: Open to slide 10, the one with a lot of data. Keep going, keep going, keep going, that one. Okay, if we look at the USA data only, the middle one, and look at the difference between the black line, just the predicted, and this was the actual, that is the error, isn't it?

MR. WIDREVITZ: The difference between the black line and the actuals is the error in standard deviation.

MEMBER MARCH-LEUBA: Sure, which is the error.

MR. WIDREVITZ: Which is a measure of your -- yeah, a measure of how broad your normal --

MEMBER MARCH-LEUBA: So I'm reading it to be like five degrees? Would you agree?

MR. WIDREVITZ: Roughly.

MEMBER MARCH-LEUBA: Right, and what, I have no idea what five degrees in RTndt means, but what real data with 1,000 points means is five degrees higher than what the Reg Guide says.

MEMBER RICCARDELLA: Well, that's just the standard deviation.

MEMBER MARCH-LEUBA: On average, there is five degrees more error.

MEMBER RICCARDELLA: Yeah, but is that error conservative or not conservative? I think there would be a way to make a plot that would show that.

MEMBER MARCH-LEUBA: But what I have no idea is that the five degrees does --

(Simultaneous speaking.)

MEMBER RICCARDELLA: Well, the five degrees C is 10 degrees Fahrenheit. That can be -- that's significant.

MEMBER MARCH-LEUBA: Celsius, Celsius.

MEMBER RICCARDELLA: That can be significant.

MR. WIDREVITZ: This is all in Celsius.

MEMBER RICCARDELLA: Huh?

MR. WIDREVITZ: All of these plots are in Celsius.

MEMBER RICCARDELLA: Yeah, yeah.

MR. WIDREVITZ: So it's more in Fahrenheit.

MEMBER MARCH-LEUBA: And this is --

MR. WIDREVITZ: I agree with you. It would be very interesting, and I think that as we move forward, those are exactly the sort of questions that we need to answer internally in terms of when you get into licensing basis, you start seeing use of plant specific data. You see, you know, what are the methodologies used to generate the pressure temperature curves?

You know, I've had conversations about how thick is the line you drew on your pressure temperature limit? Is that your error bar? There's many, many factors and the complexity of the discussion increases geometrically.

MEMBER RICCARDELLA: Yeah, but, you know, I don't necessarily want to take it all the way to PT limit curve. I'm just thinking in terms of delta RTndt. Each one of these data points in this big scatter plot, you could assume that's a plant, or a base metal or weld metal in a plant, and then you say, well, for that data point, if I had used Reg Guide 1.99 to predict what its delta T RTndt would be, where does it lie relative to what the measurement actually shows?

MEMBER MARCH-LEUBA: That is the previous slide, the red dots provided there?

MEMBER RICCARDELLA: No, yeah, but, see, that's the residual. That's not the actual -- that's not the prediction. That's the residual.

MEMBER MARCH-LEUBA: That's the error on the calculation.

MEMBER RICCARDELLA: The error relative to zero, yeah, but is the error biased? You know, remember, there was a bias, and is the bias -- I don't know.

MEMBER MARCH-LEUBA: It's a little larger --

MEMBER RICCARDELLA: I'm not expressing myself well. I think you could make a plot which shows how conservative or non-conservative your predictions would be for each of these data points.

MR. WIDREVITZ: When you plot that off the raw data, you end up with a plot with 1,800 data points that's uninterpretable by eye, but I agree. I mean, there's certainly -- you can express that and we chose to use the residuals because it provides, number one, it gives you sort of an overall picture, and number two, you can actually understand it using the human eyeball.

MEMBER RICCARDELLA: I'm not arguing that the Reg Guide doesn't need to be revised. I think it should be revised. It was based on 180 data points and now we have 2,000. I mean, that's a no-brainer, right? But the question is do we have a significant safety concern --

MR. WIDREVITZ: Yes, absolutely, and that is --

MEMBER RICCARDELLA: -- at this point in time?

MR. WIDREVITZ: That is next steps.

MEMBER RICCARDELLA: And I think we should do some analyses. We could do some quick analyses to see that.

MEMBER MARCH-LEUBA: Yeah, the question on my mind is do I have to call these guys and say they need to find you tomorrow to do this because this is a serious concern or can we wait a couple of years?

MR. MITCHELL: And this is Matt Mitchell.

(Off-microphone comments.)

MEMBER RICCARDELLA: Okay, sorry.

MR. MITCHELL: I mean, this is Matt Mitchell, Chief of the Materials and Chemical Engineering Branch at NRO.

So, yes, I think we completely agree with what you're saying, that the assessment of the importance of the difference in the models between Rev 2 and any model that one might choose, a more modern model if you'd like to call it that, needs to be assessed, its significance from a regulatory application standpoint in terms of what does it mean for affecting potentially the safety understanding of some plants.

That will need to be assessed, but I think we're just saying we're not -- we haven't done that step yet. This is an evaluation. This was attempted to be a technology, if you will, centric evaluation to just look at whether the error might exist, but you're absolutely right. That step is essential in terms of where we go from here.

MEMBER RICCARDELLA: But it seems to me that you've taken that step for upper shelf energy by creating that plot with the blue zone, and you haven't tried to do something similar to that for delta RTndt.

MR. MITCHELL: And I guess it turns out that way because in a sense, upper shelf energy is sort of an isolated parameter, right? It's just a measure of where is the upper shelf energy?

When you get to understanding the shift and the models for the shift in the transition temperature, then you have to get back into coupling that along with the understanding of the initial RTndt, the margin term.

So it becomes a more complex calculus, if you will, to put it all together to end up with sort of a regulatory understanding, at least, you know, in relationship to our normally understood parameters for how we measure, you know, the imputed safety of a reactor vessel.

So because it's a little more complicated calculation, this ends up being just a piece of the greater overall picture, where when you look at upper shelf energy, you can't really represent it in any way other than basically to just represent the entire story.

So I think that's, I guess that's the fairest way I could say it, and we did not intend, or the intent, at least at this time, wasn't really to try to make a statement about the regulatory application part of it, but I think just in upper shelf energy space, I don't think there's any way you could represent the data without sort of making that obvious.

MEMBER RICCARDELLA: Okay.

MEMBER MARCH-LEUBA: There's a five-second rule around here. You keep going if we don't say anything.

MR. WIDREVITZ: Okay, so, yeah, it's -- that's how we judge upper shelf energy. It's really the only basis to talk about it in terms of the way that it exists and the way we use it, so.

MEMBER MARCH-LEUBA: And the conclusion you give for that is we don't have any problem with delta use?

MR. WIDREVITZ: I think my conclusion is that -- could it be more accurate? Yes.

MEMBER MARCH-LEUBA: But --

MR. WIDREVITZ: Am I going to spend money on it?

MEMBER MARCH-LEUBA: If it was your money, you wouldn't spend it.

MR. WIDREVITZ: Yeah, I wouldn't spend my money on it. Dan Widrevitz wouldn't spend his money on this.

MEMBER RICCARDELLA: Yeah, but if you go to the next slide, I look at your last bullet or the thing below the bullet. It says you evaluated to say that minimal impact to safety criteria as supported is known to be extremely conservative, and yet we haven't tried to make a statement like that about the delta T RTndt. Anyway, I've made my point.

So in terms of primary deficiencies, we have a limited number of materials that are projected to remain above 50 foot pounds and not trigger EMAs. The delta use predictions are not bounding as originally designed.

I feel very comfortable saying minimal impact from a statistical point of view. You know, there are so few materials that fall into the zone of interest that's built around this topic that there's no mathematical basis for me to tell you that there's issues essentially.

When I try to apply statistics, what I find is it more or less works as designed even though it's not doing exactly what they thought it would.

MEMBER RICCARDELLA: Even though there's just as much residual and scatter as there was in the other?

MR. WIDREVITZ: Well, and I'd say it was

worse for upper shelf, but it was worse back then too, and so they constructed --

MEMBER RICCARDELLA: Yeah.

MR. WIDREVITZ: -- broader criteria for it.

MEMBER RICCARDELLA: Okay.

MR. WIDREVITZ: So speaking of criteria, the credibility criteria, there are five paragraphs that are numbered in the Reg Guide called credibility criteria, and they're what you have to, in essence, weigh plant specific data against if you want to get a little bit of margin credit and to improve your fit potentially.

They're written fairly open-endedly. I use the word vague. They're open to interpretation the way they're written. If your data is not deemed credible, your data is not considered.

The criteria compare your measured data to a refit chemistry factor for Reg Guide 1.99's prediction result, which essentially says try to jam Reg Guide 1.99's shape function to your data and take a look.

Run it through my credibility criteria and if it comes out right, if your data ends up looking like it's got about the shape function of Reg Guide

1.99, all right, here's some credit to your margin, and that's it, and as a new reactor guy and as sort of a bit more of a technology focused person, I feel like that's maybe not the question I wanted asked.

In terms of how to even use it, it was sufficiently difficult. The staff had a fairly lengthy presentation in 1998, which has since been used by many people, that provided perspective on the information of vague credibility criteria among other data use issues.

One of the statements in that presentation which is not in the Reg Guide is that you can, if you have a single outlier in your plant-specific data, that's okay. It can still be credible, which is not in the Reg Guide, so clearly people have had problems with credibility here for quite a long time.

So to investigate this, we wanted to try and do something at least somewhat numerical other than pointing out that it's constructed to answer a question that maybe isn't the most interesting question, that it's got vague criteria.

We essentially said, well, we're going to do a single outlier test. We're going to do a Monte Carlo algorithm where you begin with material with properties defined exactly as the Reg Guide defines them, with a standard deviation exactly as the Reg Guide defines.

We're going to simulate a number of materials, of chemistries, low, medium, and high copper essentially. Here I have reproduced the high copper plot, and we're going to see how many of these simulated Monte Carlo data sets would have been deemed credible.

And these are materials that should be deemed credible because they're constructed exactly according to the Reg Guide. Now, obviously with standard deviation and normal curves, you'd expect some --

MEMBER MARCH-LEUBA: You used normal distributions?

MR. WIDREVITZ: We used normal distributions.

MEMBER MARCH-LEUBA: Yeah. That's the problem. Is the normal distribution is not physical when it goes to service under the agent.

But sometimes you roll a random number that has two other standard deviations.

MR. WIDREVITZ: You'd expect to have rejects.

MEMBER MARCH-LEUBA: The real -- real life does not go to 12 standard deviations. Normal distribution should be capped at three.

(Off-microphone comments.)

MEMBER MARCH-LEUBA: Yeah. Anyway, that's a -- a sore point with me.

(Laughter.)

MR. WIDREVITZ: I could -- we could speak for hours about my opinion about the flippant use of normal distributions.

MEMBER MARCH-LEUBA: Um-hum.

MR. WIDREVITZ: But suffice it to say that -- that I think for the purposes of this demonstration, it was adequate.

We did a thousand runs. And so, in this somewhat complicated plot, what you see, the most important part is in a high copper weld when you take surveillance capsules, those go to your surveillance program.

You're going to have five capsules at this copper due to your predicted embrittlement. As you pull them, the top line that says credible, so yeah, credible chemistry factors, would you actually use your own data for material that should be highly consistent with the Reg Guide's instruction.

And as you pull the capsules, what's the chance in a Monte Carlo simulation of you getting your data to be incredible?

When you pull your first capsule, you need two capsules to use your data at all. There's a 97 percent chance that, yes, your data will be credible, you fit it to your data. You get a result.

You pull your third capsule, now it's down to 86. That's interesting. Pull your fourth capsule, it's down to 65. That's not really what you should be expecting.

You get to your fifth capsule, you have a 40 percent chance of surviving the credibility criteria with the material that works perfectly according to the construction of the Reg Guide.

That just does not strike me as good behavior for a system.

MEMBER MARCH-LEUBA: Describe again the credibility test you're running. How do you do the -- that idea?

How do you know all the way the credibility continue?

MR. WIDREVITZ: So in this case the -- what you do is you take -- you take the stated -- you adjust your chemistry factors using linearly squares.

So you've refit, tried to refit your

shaped function to surveillance data.

MEMBER MARCH-LEUBA: You roll a thousand times the dice, --

MR. WIDREVITZ: Um-hum.

MEMBER MARCH-LEUBA: And get the thousand measurements. But --

MR. WIDREVITZ: At each capsule.

MEMBER MARCH-LEUBA: Yeah. For each capsule. You have a thousand capsules for each capsule, right?

MR. WIDREVITZ: I believe, so Matt Gordon actually performed the code. I believe that's how it worked, is that it sampled the distribution at each capsule using the standard deviation, using a normal function.

MEMBER MARCH-LEUBA: Correct.

MR. WIDREVITZ: And so -- and not the same normal function each time. So resample that each capsule pull for each Monte Carlo run.

MEMBER MARCH-LEUBA: You roll a random number and then sample from the distribution.

MR. WIDREVITZ: Yes.

MEMBER MARCH-LEUBA: But keep going.

MR. WIDREVITZ: Yeah. And so it's got the normal distribution. Share the same characteristics as assumed by the Reg Guide.

So you would expect much better, much better credibility results in the end.

MEMBER MARCH-LEUBA: How do you -- how do you determine the capsule is not credible?

MEMBER RICCARDELLA: Well, if you have a few outliers.

MR. WIDREVITZ: Okay. So to determine it's not credible is that the standard deviation is greater than that given in the Reg Guide in the credibility criteria.

So it's a very strict interpretation. Which is the strictest interpretation --

MEMBER MARCH-LEUBA: Okay.

MR. WIDREVITZ: Of the credibility criteria as written. And obviously Wichman tells you you can have one outlier for example.

So if you're following not the Reg Guide, but the presentation, these results would be somewhat better. But given that just from the very basic instruction of them, they're causing these mathematical issues.

This is sort of an interesting and insightful result. You know, and if you go in a -- sorry.

MEMBER RICCARDELLA: To me, you know, the credibility criteria is, how well does your data fit Reg Guide 1.99?

MR. WIDREVITZ: Yes.

MEMBER RICCARDELLA: And if it doesn't, then you have to use Reg Guide 1.99. It's counterintuitive.

MR. WIDREVITZ: It's the opposite of the question I would pose.

MEMBER MARCH-LEUBA: You might as well use Reg Guide 1.99 to start with. Because it either fits it, or you use it.

MR. WIDREVITZ: Sure.

MEMBER MARCH-LEUBA: Why bother with something?

MR. WIDREVITZ: Well, if you have credible data, and it's worse then Reg Guide 1.99, but has the same shape function, then you have to use that.

MEMBER RICCARDELLA: Yeah. You have to use it.

MR. WIDREVITZ: But if you have, you know, for example there's 50.61(a) that the NRC has endorsed. It has a different shape function.

And if you look in the assessment, we completed the same simulations but used 50.61(a) as our true, our state of true. And then sampled from it.

What resulted is that you reject even more credible data despite the fact that you generally have a material that's embrittling in a different way.

MEMBER RICCARDELLA: But 50.61(a), is that the PTS?

MR. WIDREVITZ: That's the alternate. Yeah.

MEMBER RICCARDELLA: The alternate, PTS rule.

MR. WIDREVITZ: And so we know for at least some material out there, that one's more accurate.

MEMBER RICCARDELLA: So have you tried to do this study with that prediction instead of 1.99? Just the stat -- forget the -- not the credibility criteria, just the -- all your other statistical comparisons?

Would it come out -- would that come out better?

MR. WIDREVITZ: The short answer, there's quite a lot of things in the public domain that have done those. For example, ASTM has an adjunct out in the public domain when they generated E900 that goes into a lot of statistical results that compare curves.

So, there's a fair amount of information out there about that.

MEMBER RICCARDELLA: And does it come out in general better that the -- did the statistical tests turn out better with that then with --

MR. WIDREVITZ: Everything is better than this Reg Guide.

MEMBER RICCARDELLA: Yeah.

MR. WIDREVITZ: All newer curves that I've seen evaluated, and one would expect that.

MEMBER RICCARDELLA: Yeah.

MR. WIDREVITZ: But it's -- there's more data. There's more advanced curve fits. There's more information out there.

And so, that's -- you know, I don't want to cast dispersions, because I think they did a wonderful job with what they had.

MEMBER RICCARDELLA: Yeah.

MR. WIDREVITZ: But at the same time, you're taking a snapshot in time.

(Off-microphone comment.)

MR. WIDREVITZ: Right. And that's just not part of this technical assessment. That's more of a next steps in terms of internal work.

Which we're not discussing today. Sorry, I know it's an unsatisfying answer, but.

MEMBER RICCARDELLA: No, it's just, you know, we're moving at our typical regulatory snail's pace. It will take us five years to get anything done.

MR. MITCHELL: We are very much hoping to do way better than that.

MEMBER MARCH-LEUBA: It's in the record. We'll hold you to it.

(Laughter.)

MR. WIDREVITZ: And that's, you know, part of that question is, if it takes the NRC five years, what calendar year are you going to really want it done?

I mean, and that's -- that's part of why -- where is it? There we go. Why you make plots like this. Because you want to -- you really want to understand where you are.

And this is, beginning of the answer to some of those questions.

MEMBER KIRCHNER: What's the answer? How many years do you have?

MR. WIDREVITZ: So, based on this --

MEMBER KIRCHNER: Based on your curves,

yeah.

MR. WIDREVITZ: Based on these curves, assuming it takes the NRC five years to do anything, we should have started last year. Give or take, depending on where you want to -- where you begin to get excited about the inaccuracy of your base metals.

And there, you know, I have a lot of qualifiers in there because as Dr. Riccardella mentioned, when you start looking at it, you know, what is significant?

Are these materials in front? Are these the limiting materials? If they're not, then you might have more time.

Will they become the limiting materials? Then you might have less time. So there's a lot of subtleties to answering that.

But I'd say based on this plot, which we know is a little bit ahead of truth, no. Now is when we want to start.

And that's me, Dan Widrevitz. Not speaking for literally everyone. But there is a working group, so.

I think we've beat this particular horse.

MR. IYENGAR: This is Raj Iyengar. I just wanted to -- I don't think it's going to take five years.

But, I think that's a number thrown at all of us. But it could be done faster. But we haven't fully, like Dan was saying, we haven't fully gone to the next steps yet to evaluate it.

To tailor the points, and the high points. To look if there's any mechanistic basis that would give us different opinions.

So, we haven't done that assessment yet. We are in the throes of it. But we wanted to provide this assessment to you at this time so that we can understand that move next.

So it's certainly not five years. We do things faster.

MEMBER MARCH-LEUBA: Well, but going back to what Peter was saying, if we knew what the impact of each of these -- there are errors.

MR. IYENGAR: Right.

MEMBER MARCH-LEUBA: Or inaccuracies.

MR. IYENGAR: Right, right.

MEMBER MARCH-LEUBA: If we know what the impact is, we can tell you, Dan, stop everything else you're doing and go to work now.

MR. IYENGAR: That's right. Exactly.

MEMBER MARCH-LEUBA: Or, oh, whenever you have time, work on it.

MR. IYENGAR: Right.

MEMBER MARCH-LEUBA: That would be a first step.

MR. IYENGAR: Right.

CHAIR BALLINGER: For me that's the key question. Which I don't have -- which this doesn't answer.

MEMBER MARCH-LEUBA: The question is, do we need to tell your boss that you cannot work on anything else?

MR. WIDREVITZ: I understand the question. I cannot answer with more information.

MEMBER MARCH-LEUBA: So that's the -- in my opinion, in our opinion that's the first step, is this here.

MR. WIDREVITZ: And I -- and that's really again, I -- in terms of the information we're providing, this is a little conservative, but this is really trying to answer your question.

And you can decide for yourself, three, six, eight, take a look at the data. Take a look at the results.

MEMBER MARCH-LEUBA: But when I look from -- when I look at that scale in a little tiniest time, 20 feet away, I'm not aware of 6 to the 19.

I mean, I have to look very carefully to see the deviation. Now, 10 to the 20, yeah.

CHAIR BALLINGER: I think he -- Pete was saying, he doesn't care about the -- going all the way to the pressure temperature curve.

I'd like to see an example of the effect on the pressure temperature curve for a plant that's, you know, likely to be in this situation. For say between -- after license renewal for example.

MR. WIDREVITZ: Two observations. The first is, 6 and 10/19 is when the mean of the predictions hits, give or take.

The two sigma lower bound of the current prediction. Personally, that's bad. From every rule of thumb that's not where you want to be.

MEMBER RICCARDELLA: For the base metal?

MR. WIDREVITZ: For the base metal. Right.

MEMBER RICCARDELLA: In general, will metals govern it?

UNKNOWN: Mostly, no.

MEMBER RICCARDELLA: Hum?

UNKNOWN: No.

MEMBER MARCH-LEUBA: Okay. Now, to make

comments you need to go to the microphone and say your name. If you want to be on the record.

MR. KIRK: Mark Kirk, CRIEPI. No. About 50 percent, and the NRC staff can say this too. I believe it's about 50/50 weld versus plant plate limit for iron plate.

MEMBER RICCARDELLA: For heat up and cool down though.

CHAIR BALLINGER: For heat up/cool down?

MEMBER RICCARDELLA: Yeah.

CHAIR BALLINGER: I didn't know that.

MR. KIRK: So the, yeah, the base metal is not significant. The base metal will have smaller shifts of course, but in a low shift plant, base metal can be limited.

MR. WIDREVITZ: Well, and that's again, for new reactors, those are the only plants I have, you know, are low shift.

And they've moved all their welds out of the belt line, you know. But, again, their shift is going to be low.

So, it's --

CHAIR BALLINGER: Yeah. They're all low copper.

MR. WIDREVITZ: Right. The second part of the question is, is yeah, I would have liked to have brought a bit more.

You know, if you look at some pressure temperature limit methodologies they take -- they just take in RTndt as sort of a linear term.

So there's, you know, some -- depending on what plant methodology they use to get different outcomes in terms of how sensitive they are and how they work and manipulate it with it.

So, it gets too complex very quickly. And I understand the interest. And I think that's something that's certainly worth thinking about in terms of next steps, what questions we need to answer to understand things.

MR. MITCHELL: Yeah. And I'll just chime in, Dan, along with you. And say that, I mean, I think the step that we're at is, discovering or confirming as we're going through and looking at how the model performs.

That we have reason, we have -- we think we have a reason to go to the next step of investigating exactly these questions. What is the significance of what we are discovering here about where Reg Guide 1.99, Rev. 2 may not perform appropriately? Or may not be as accurate as we would like?

Going forward as we hopefully proceed down that path, if we discover anything that suggests that it is a very significant -- that we are seeing significant from a regulatory and safety impact deviation, then we will have to consider what is the timing, appropriate timing of a regulatory step? When we get that information.

So, it is -- we understand it's dissatisfying right now. But we're just find -- what we're finding evidence of right now, I think, is that we need to ask that question.

And we need to continue to investigate that question of, what is the significance of how the Reg Guide is performing?

Now let's go find out what you're -- what it means. And then decide how to react at that point.

MR. ALLEY: So, to put it another way, the fundamental data analysis that starts the process appears to have that high fluence, some issues worth of consideration.

We now have to get to what's the implication to the fleet? Do we have an adequate protection issue?

And so, the Reg Guide review was supposed to get to the question of, is there enough of a difference between the knowledge that existed at the time that the Reg Guide was created and now to make it worth considering revising the Reg Guide?

And so you're getting the answer to the question of, is it worthy at this point in time to consider revising the Reg Guide?

MEMBER RICCARDELLA: Which and the answer to that is yes.

MR. ALLEY: Well, we'll let Dan get to his conclusion in a few moments.

CHAIR BALLINGER: But you've gone and used the AP words, adequate protection.

MEMBER RICCARDELLA: Well --

MR. ALLEY: In today's world, given that we have Commission direction, --

CHAIR BALLINGER: That's right.

MR. ALLEY: Relatively new on forward fits, back fits, --

CHAIR BALLINGER: Yep.

MR. ALLEY: Adequate protection becomes a key piece in all of our deliberations going forward. And we will proceed in accordance with those directions from the Commission regarding back fit, forward fit, adequate protection, as we proceed through our assessments as to where do we go from when Dan stops talking to where we have some sort of a final disposition?

MR. WIDREVITZ: Okay. So, critical consequence. For the benefit of fitting prediction service data is nullified by credibility criteria that rejected and did not conform in the shape function of Reg Guide 1.99.

And just sort of what does that mean in practice? High fluence and low copper data are not expected to form to the shape function of Reg Guide 1.99.

So, as a new reactor person, that's kind of an accuracy that I would tend to focus on. Other then the fact that they reject data more strongly as you have more data, seems like an unfortunate characteristic as well.

If by chance your credibility criteria, deemed re-creditable data is being creditable, then you're allowed to reduce your margin term.

Again, we couldn't find any apparent basis for doing this in the background material. Obviously it doesn't mean there wasn't any. But we didn't find it.

But it does appear to work with the data.

Data that had good scatteraker (phonetic) characteristics that are likely to pass through credibility criteria, also tend to have better statistical properties.

So, you loosen your margin based on uncertainties seems to be appropriate. And you see that on these plots where we've plotted sort of standard deviation by scatter, where each -- each gray dot is a material set of data.

And that orange line is what margin you would have based on applying either the margin credit with credibility criteria single outlier test, or just the generic Reg Guide 1.99 credit for the base and all materials.

In terms of the attenuation formula, the attenuation formula that is given in the Reg Guide matches very well to modern results. The critical factor being here is when the Reg Guide was written, your materials of interest were all essentially horizontally adjacent to the fuel.

And as we've continued to age, you've seen areas of the reactor where the fluence of interest creep up above and below the fuel. And this form of interest doesn't work there.

That's not a new result. And it's just,

there's no -- there's no caution in the Reg Guide towards that.

So, that's sort of a limitations deficiency. But technologically it works fine for what it was designed to do.

Here we have a couple of plots from a report where essentially your left had is what I call the geometric belt line. It's the belt line horizontally adjacent to fuel. It looks good.

When you look at a point above the core, you're not getting an accurate result. And that's well acknowledged. There's plenty of work going on about that, this Reg Guide sheet.

MEMBER RICCARDELLA: It doesn't attenuate as fast? Is that the --

MR. WIDREVITZ: Yeah. Yeah, your --

MEMBER RICCARDELLA: The dash curve is?

MR. WIDREVITZ: The dash curve is a, I believe, if my recollection is correct, it is a three dimensional neutron code result. I could be off a little bit.

Whereas the line is -- is your Reg Guide result.

MEMBER RICCARDELLA: Okay.

MR. WIDREVITZ: Obviously other members of the NRC are looking into this with great interest. So, we'll see where that goes.

Common additions, I already talked a little bit about the degree for degree, which is an attempt to bring some temperature information in.

Another common addition is what we've come to call sister plant. Essentially when you've got heat and action data in other capsules, and you need more data, you try to adjust it towards the circumstances of a particular vessel.

And then run it through your credibility criteria or other methods. What we find is, is that when you do this you tend to get standard deviations that are a little bit higher, which shouldn't be a huge surprise since you're doing a data adjustment.

In addition, as I've discussed, there's a whole lot of residuals in the Reg Guide. So, maybe some of this increase in standard deviation is coming from just the accuracy to the adjustment.

Didn't get into it too deeply. But the short answer is, is it's not entirely different from using plant specific data. Not critically different.

But obviously, not as sophisticated as some of the other portions of the Reg Guide. And its performance is a little bit worse than just using direct plant specific data.

So, conclusions, primary deficiency is the greatest sort of inaccuracies that get people interested. The high fluence RTndt predictions, particularly the base metals, the credibility criteria performance or even the part of base credibility criteria.

The embrittlement trend curve shape function, additional deficiencies, many gaps were filled by a presentation, which currently lives in Adams.

It's the presentation actually in a New Reg literally echoed, we had a presentation, here's what it said. Statistical treatments like the standard deviation also could use a little help.

So, I know there's a little bit more in the assessment itself. But I think these are the highlights.

Deficiencies exist in every aspect of the Reg Guide. From the technological from an accuracy standpoint, this is true.

I'm not talking about significance. I'm not talking as in -- as an NRC program office employee. I'm talking as a research employee who is really looking at the accuracy more then the significance.

And I believe from these results deficiencies become concerning for high fluence PWRs beginning in the late 2020s. Somewhere in there.

In terms of next steps. Well, I think you can read some -- read a little bit into the fact that we've convened a working group to look into exactly a lot of the questions that we've been discussing today in terms of licensing basis impacts and potential solutions.

Obviously the science community and the industry community and the standards community have not stood still for 30 years. So there's a great deal out there.

We're not, you know, this isn't a blank page investigation. But licensing basis are a very unique entity. It's not necessarily the same as best estimates, complexity, et cetera.

CHAIR BALLINGER: Now, with respect to the working group, and that's all we know. What's their schedule?

What's, you know, what's their charge? Is there a charge?

MR. WIDREVITZ: I defer to my betters to answer that question.

CHAIR BALLINGER: I mean, it's a kind of a pregnant statement, but.

MR. ALLEY: So, we have received -- this is Dave Alley, NRR. We have received from research the report that Dan is providing the information to you on today.

We have looked at the report, and we have determined that there is sufficient merit to go forward in considering a revision to the Reg Guide.

The -- we're trying to work on a very aggressive time table to make that initial determination. Which is probably better said weeks rather then months.

CHAIR BALLINGER: Okay.

MR. ALLEY: At this point. And that will be to make some assessments with respect to what does this mean as far as adequate protection goes?

And I have a couple of slides that we'll talk about later.

CHAIR BALLINGER: I was about to say, we're into your presentation now, is what you're saying?

MR. ALLEY: We almost are. We almost are. Let me let Dan finish --

CHAIR BALLINGER: Okay.

MR. ALLEY: Before I steal any more of my own thunder shall we say.

CHAIR BALLINGER: I don't see any more slides.

MR. WIDREVITZ: No. This is it. So, if you have questions for me.

CHAIR BALLINGER: That's it. I was about to say.

(Laughter.)

MEMBER KIRCHNER: Okay. Dan, just a point of clarification. Slide 24, so that's -- the second curve, the second thought on the right.

The DPA, that was done with MCNP? Or some other method?

MR. WIDREVITZ: Honestly, I don't recall the details of that report.

CHAIR BALLINGER: It's just a reflection of the fact that when you go straight through the vessel, you get a different kind of attenuate. You get streaming up the vessel.

MEMBER KIRCHNER: Yeah. No, I understand that.

CHAIR BALLINGER: Instead of the flux. The flux as to energy distribution changes that.

MEMBER KIRCHNER: No. I was just curious

how they created the --

MR. WIDREVITZ: Well, I don't think they even -- I don't think this is even high enough to worry about streaming yet.

CHAIR BALLINGER: Okay.

MEMBER KIRCHNER: No. This is just the upper portion.

MR. WIDREVITZ: This is above the fuel, but not -- I mean like --

MEMBER KIRCHNER: Yeah. The upper part.

MR. WIDREVITZ: I mean, like, yeah. I don't know exactly how much. But a --

MEMBER KIRCHNER: Three dimensional --

MR. WIDREVITZ: Yeah.

MEMBER KIRCHNER: It's a three dimensional effect. Yeah.

(Simultaneous speaking.)

MR. WIDREVITZ: Yeah.

MEMBER KIRCHNER: And so what you're saying is that some higher order method, whether it's MCNP or whatever, --

MR. WIDREVITZ: Yeah.

MEMBER KIRCHNER: Gave you the dash curve. But then this is the --

MR. WIDREVITZ: I believe all of that.

MEMBER KIRCHNER: This curve is what's in the Reg Guide.

MR. WIDREVITZ: I believe that's correct.

MEMBER KIRCHNER: Yeah. So that's non-conservative.

MR. WIDREVITZ: Which is wrong. It doesn't apply.

MEMBER KIRCHNER: Just wrong, yeah.

MEMBER RICCARDELLA: Except for the left-hand plot is pretty good. It's right straight up above.

MEMBER KIRCHNER: No. No, I -- this is what you go by.

MR. WIDREVITZ: Yeah. And if you go back into the Reg analysis and everything, they're very clear about what that curve is good at. They just were not concerned about these other areas.

So they didn't specify in the Reg Guide text, so.

MEMBER REMPE: So, with respect to potential solutions, somewhere in this presentation I recall you making a statement offhand about anything is better then this Reg Guide.

And do you want to elaborate more of what you're thinking about with potential solutions?

MR. WIDREVITZ: Well, I think a really interesting place to start is to -- the ASTM background information, 3900 had a huge amount of discussion about different curves and history.

And I think if you're feeling curious, there's some really good information I don't have to defend in there, --

MEMBER REMPE: Um-hum.

MR. WIDREVITZ: In terms of the NRC staff's position and our findings. And you can draw your own conclusions based on the author's.

MEMBER REMPE: Okay. Thank you.

CHAIR BALLINGER: Are we into the Alley?

MEMBER MARCH-LEUBA: Can I make one point --

CHAIR BALLINGER: Yes, now.

MEMBER MARCH-LEUBA: Before we go to Alley?

CHAIR BALLINGER: Yeah. You go ahead. Take your time.

MEMBER MARCH-LEUBA: It's a size, but I see you're not going to rush into it. No matter how much we prod you.

But, yesterday we had a review of historical facts correlation. And NRR has issued a knowledge management NUREG, KM0013.

Which it's under part review now, which deals with data driven models. How did you review and use them.

So, since this Reg Guide is going to be a data driven model, I would urge you to at least read it or consult with the CHR guys.

Because we were very impressed with the approach they used for reviewing the CPR original. And they produced a NUREG.

And this is how we're going to review particular -- that doesn't even model for now on. And this is how we were expecting to meet them.

So, it will give you some ideas of what to look for. It's not that long. But it has 25 items that you're supposed to follow. Check marks. It's really good. KM0013.

MR. IYENGAR: Yeah. This is Raj Iyengar. Thanks Dan for a good presentation. I know you, I think you stirred a lot of questions with the data that you've provided. And NRR and NRO management weighed in on that.

I wanted to emphasize to you that as stated in one of the conclusion slides that what they're looking at would be a concern in potentially the late 2020.

So, right now we're bringing it up way ahead of time of time so that it's not something that, you know, it's an immediate concern tomorrow.

So, we do have time. But we are also working to looking at the alternatives like Dave Alley was saying.

We have some ideas. And we have to flush out many different things, looking at licensing basis and all that stuff.

So, we are in, not in a snail speed, if that's what I heard. We are speeders in a different mode. We are bringing way ahead proactively, bringing all these issues up front.

So, I just wanted to emphasize that. Thank you.

CHAIR BALLINGER: Now it may -- it -- 2020, late 2020, or the late 2020s may not be an immediate concern.

But if you're sitting with a plant and you're thinking about lice -- or subsequent license renewal, and you've got financial considerations, that's tomorrow.

MEMBER RICCARDELLA: Well, but also I suggest that that estimate of the late 2020s was brought with a pretty broad paintbrush.

And that in fact, you know, if you -- when your working group gets into it, you might find that there's a plant or two out there that it's much more immediate then that.

MR. ALLEY: Something clearly we'll consider. And we certainly understand this concept that ten years from now is the planning horizon, or maybe even well into the planning horizon for certain plants for certain actions.

So, that's part of what I'm going to tell you here. If we go to the next slide, we might as well get started.

So, as I think we've been saying that NRR, and I should, I was remiss as I was writing these slides. NRO and NRR are reviewing the implications of the research findings that Dan has just presented.

And certainly if we get to a spot where we have an adequate protection issue, we will absolutely address that. And we will absolutely address that in a timely fashion.

Fundamentally, it's not clear to us at this point that all plants will fall into that category. As a matter of fact, many, many may not.

In many cases the existing Reg Guide as

far as adequate protection issues, may prove to be just fine well into the future.

As we saw in the -- in some of the plots that Dan presented, it's not until you get to high fluence that we start to see substantial deviations from the Reg Guide predictions in one particular direction or another.

Scattered, yes. But as we start to get out into higher fluences, we start to see some sort of systematic deviations. And those could conceivably get to be adequate protection issues at some point in the future.

So, the concept adequate protection, clearly something that the Commission wants us to address. They provided guidance to us concerning forward fits and back fits that we will be following as we consider where to go and how to deal with those issues.

They've also provided guidance that says that if we don't have -- don't meet certain standards such as adequate protection, that regulatory burden should be avoided where it's unnecessary.

And we will be considering that certainly. There are things that we may get into as was mentioned. There's a relationship between what we're doing with this Reg Guide and potentially 50.61(a). Potentially Appendix H. Potentially Appendix G.

So, we're not going to say at the present time that our efforts are strictly related to this Reg Guide. It could spill over into a rule making activity.

We're not saying that it will. But we're clearly not saying that it won't at this point.

So the message here is, we're looking. We're trying to figure out where we're headed as far as adequate protection.

And we're going to make sure as we proceed forward that we're not imposing any unnecessary regulatory burden. If we can shift to the next slide.

As Dan has pointed out, we don't have an immediate safety concern at the moment. Based on what we know now, as I was saying, the plants, the issue seems to be most -- the adequate protection issue seems to be most at higher fluence plants.

The plants are not yet there. The plants won't be there for a few years. On the other hand, as you have been inquiring of us, is it time to do something?

And the answer is, it's time at this point in time to consider what the adequate protection issues maybe here. To figure out to whom any changes that we would make should be applied.

To minimize the efforts, or the effects on those that are not affected, shall we say. And the time to do it is now, or as quickly as we can possibly do it, to provide regulatory reliability, regulatory stability to those plants who either will or will not have to adjust how they operate at some future date.

So, at this point we're not prepared to tell you specifically, this is going, this effort is going to apply to six plants, but not seven. We're not going to tell you at this point that it's going to be applicable in 2022.

I'm making all this stuff up as I go along. Because we just don't know precisely where we will wind up.

We do know that the technological assessment points to the concept that it is time to do a regulatory and safety assessment and adjustment where needed.

Do you want to add anything to that?

MR. MITCHELL: Just I'd add one thing to connect your final bullet Dave, to what Dr. Ballinger, a point you made just a few moments ago.

In that in terms of regulatory

reliability, certainly there would be a factor, right. If we were to determine that going to new models were to, but we would need to go to the new models because there could be questions about the protection.

Plants would need to potentially make decisions related to, do they want to impose a different core design to suppress fluence in a particular region by using absorber bundles.

So, knowing sooner that there may be an issue ten years from now, would be, I think, regulatorily appropriate to communicate that.

So that plants could take action potentially today that would avoid that difficulty down the line, if there were ways to manipulate their core design or other actions, which could alleviate that issue, or step it back from coming up in ten years. It may push it out to 20 years in the future, et cetera.

So, knowing sooner is certainly a good thing, I think, from everybody's perspective.

CHAIR BALLINGER: And all those actions would all be negative and involve costs. Lots of costs.

And you're familiar, I'm sure, with Loviisa Unit Number One?

MR. MITCHELL: I probably should be.

CHAIR BALLINGER: They made the vessel out of basically car parts.

MR. MITCHELL: Hum.

CHAIR BALLINGER: And they had a 270 Fahrenheit, I think, degree increase in NTD in one cycle. And they had to de-fuel the outer ring of the reactor.

And they converted a 700 megawatt reactor into a 400 megawatt reactor.

MR. MITCHELL: Wow.

CHAIR BALLINGER: So, interesting reading.

MR. MITCHELL: That's a -- wow, that's an interesting story I hadn't read up on.

(Laughter.)

CHAIR BALLINGER: So back to the serious part.

MR. MITCHELL: Yes.

CHAIR BALLINGER: The working group.

MR. MITCHELL: Yes.

CHAIR BALLINGER: Does it have a charter? Can we get it? Does it meet? Can we rely on you guys to come and brief us on a regular basis on this?

Because I -- now in my personal opinion, I think it's an important issue for us to be up to speed on, and not behind the curve.

MR. ALLEY: Okay. So the answers to some of your questions are, the working group is meeting on about a weekly or a biweekly basis.

They have a report to us biweekly, every two weeks. Twice -- semi --

MR. IYENGAR: No. It's twice a week.

MR. ALLEY: Semi-weekly basis.

MR. IYENGAR: Twice a week. And we have not written a charter yet. But, I did want to answer -- I'm sorry to interrupt Dave Alley.

We actually had wanted to have a full committee briefing done. And after that we were going to come back to you with a working group recommendation.

But the full committee briefing has been postponed, as I understand from Christopher Brown, until November.

CHAIR BALLINGER: Okay. Now I understand why. Yeah. I understand why that change was made. I wanted to be here, and I wasn't going to be here.

MR. IYENGAR: Yeah.

CHAIR BALLINGER: So, but that's separate then the working group issue.

MR. IYENGAR: It is -- it is separate but tied though. Because we wanted to get, as I told you in our meeting, we would like actually a letter from ACRS.

CHAIR BALLINGER: Yep.

MR. IYENGAR: Which will actually help us. And we also wanted to engage external stakeholders and the public about the working group findings and recommendations.

That's something we owe to the public, for transparency. So, we want to do all that. And having something from you would enable those things.

But we could actually, because of this postponement, we could consider doing that a little bit sooner. We don't have to wait until November.

MR. ALLEY: So anyway, thanks Raj, because I was going to mention that we were coming back to the full Committee in a month or two. And so if that's not going to happen, --

MR. IYENGAR: It's November.

MR. ALLEY: Events have overtaken my knowledge at this point. So, we are -- the working group is very active at this point.

As is the management oversight of that group. Trying to ensure that we keep a forward progress at the most rapid rate that we possibly can.

So, we're trying to make absolutely sure that we don't get into a tailspin on this one where we're not making progress.

MEMBER MARCH-LEUBA: Yeah. And that's perfect. I tend to oversimplify things. And that's why I get in trouble all the time.

But, Walt was saying the same thing this morning when we were talking. We overkill things. I don't know what the working group is doing.

I have no idea where the adequate protection or regulatory burden placed into this problem. We developed RG 1.99 is nothing short of but a sophisticated correlation where you input the number of data points, and it tells you what the output is.

It is a correlation. We have run sort of statistic, which was still over 177 points. We now have two thousands. We've run sort of statistical tests and we know the correlation is wrong. Okay.

So stop doing, going in circles. Feed a better correlation and publish it. And the problem is solved.

And there's nothing to do with adequate protection. There's nothing to do with regulatory burden.

Everybody just uses the correct

correlation from now on. What's wrong with that? What are you doing in this working group?

MR. ALLEY: Okay. So, the working group is considering the implications of what happens to --

MEMBER MARCH-LEUBA: The correlation is inaccurate. We've seen it in several standard deviations.

So, I mean, the statistical test comes out like 20. Those are incorrect. Feed a new line and use it.

MR. ALLEY: Okay.

MEMBER MARCH-LEUBA: I mean, and be done in two months.

MR. ALLEY: And -- and --

MEMBER MARCH-LEUBA: You can be done by November.

MR. ALLEY: I'm not -- well, -- I'm not going to say that we'll be done by November, because there's public comments and there's publishing. And there's all of these other things that go along --

MEMBER MARCH-LEUBA: You can have the line fitting by November. You can have the line fitted by Sunday.

MR. ALLEY: Well, and one of my objectives is to make sure, as I said, that we try to do this in weeks, and not months, and certainly not years, from the technical standpoint.

The piece that we have to be careful about, all right, is the Reg Guide at the bottom says, if you follow this, we the NRC will accept it as in licensing actions. And --

MEMBER MARCH-LEUBA: Yeah. And if Part 21 will apply to you, you will go to jail. Because you now know that that recommendation that you're producing using the part, the current correlation, is inaccurate.

And so -- so establish -- a proper suggestion to bring it back into compliance.

MR. ALLEY: All right. So you made an assessment there that -- that I'm not going too quite accept in its entirety.

From a regulatory perspective, as Dan pointed out, we can have better correlations. And at high fluence, there appears to be a non-conservative deviation.

But, at the lower fluence plants, there is nothing, in my personal eyes, that at the moment would cause me to be able to say that plants that are using the current correlation at lower fluences, are unsafe.

And therefore --

MEMBER MARCH-LEUBA: And there's nothing wrong with that.

MR. ALLEY: And therefore, I have to be careful as I write a new Reg Guide, to say anything about, if you follow this, we will accept it. Or if you don't follow this, we will take -- have to take more time looking at it.

So, while -- while you're quite correct in saying it's a correlation, and we have potentially, potentially better correlations, it's the, and use it part, that goes from where Dan is to where I am, as far as what is the regulatory -- what is the regulatory burden or the regulatory advantage relative to adequate protection of making a change?

MEMBER RICCARDELLA: Could I talk?

MR. ALLEY: Go for it.

MEMBER RICCARDELLA: Given that we have to have this postponement of the full committee meeting, and the letter, because our esteemed Chairman is going to be out of the country in October, and the speed with which you appear to be going with the working group, would it be productive to have another subcommittee meeting before November, where we get to see some of the results of this working group effort?

And then we can build that into our letter as well.

MEMBER MARCH-LEUBA: Well, talk to our scheduling people. We're very -- I mean, we're completely full in November subcommittee wise.

CHAIR BALLINGER: No. But we're scheduled for November.

MEMBER MARCH-LEUBA: Not in the full committee.

MEMBER RICCARDELLA: November full committee.

MEMBER MARCH-LEUBA: To have a subcommittee.

MEMBER RICCARDELLA: No, it would be -- no unfortunately we don't have October subcommittee.

MEMBER REMPE: You have to. We still have that.

(Simultaneous speaking.)

CHAIR BALLINGER: That's what's complicating life.

MEMBER RICCARDELLA: We're working towards transforming ourselves a little bit here too.

MR. ALLEY: Okay. So, I guess --

MR. IYENGAR: I just want to say, you know, I want to tell you that we -- the working group is doing many things.

One is to verify all the data. Because if you go to slide 13 that the data is, needs to be rerun. The licensing basis document, we've got to do that. We're doing it very fast.

We could engage with you. Research is leading the working group. And we do have representatives from NRR and NRO.

We are open to coming to the subcommittee prior to November 3. And if we have in the next several weeks, we should be able to tell you where we are in the next several weeks to be able to come and brief you if needed.

CHAIR BALLINGER: Oh.

MR. IYENGAR: Yes. I we --

CHAIR BALLINGER: I'm looking at, and I'm going to walk way out on a plank here, and he's shaking his head already.

Subcommittee in September? Monday morning is open.

MR. BROWN: So that's a problem. We've got --

CHAIR BALLINGER: Monday morning is open too.

MR. IYENGAR: And I -- what date is that? It might be too soon in September.

CHAIR BALLINGER: The 16th.

MEMBER MARCH-LEUBA: That might be too soon.

CHAIR BALLINGER: But the working group issue, you're saying you're all over the working group. And that you're meeting every other, every couple of weeks.

That would be two cycles between now and September's subcommittee.

MR. BROWN: Okay. So, I could work with Raj. And we can see about that.

MR. IYENGAR: Yeah. And I also --

MR. RICCARDELLA: What about October's full committee?

MR. IYENGAR: And I also work with management to find out, you know, if it's a good time.

CHAIR BALLINGER: Oh -- oh --

MEMBER RICCARDELLA: Wait, wait, wait.

CHAIR BALLINGER: Oh, October full committee.

MEMBER RICCARDELLA: October full committee, we --

CHAIR BALLINGER: We have Monday and Tuesday.

MEMBER RICCARDELLA: Tuesday is empty.

That would be October 1st. Yeah. October 1st could -- do you think the working group could have a meaningful presentation for us by say the afternoon of October 1st?

MR. ALLEY: We can certainly put our heads together and see where they are. We're going to get at the branch chief management level, we're going to get an update from them next week, I believe.

And once we see that, we can see where we're likely to be. The other thing that we have to make sure that we're in our process for Management Directive 8.4, which is forward fits, back fits, to make sure that we have communicated appropriately through our management before we discuss with you things that can be forward fits and back fits.

MS. LUND: Yeah. And this is Louise Lund. And of course, I just arrived on the scene. But, I will weigh in on this.

And I think that what would probably provide more of a satisfying subcommittee discussion, is not only having the working group come to whatever resolution or proposals, recommendations, you know, that they want us to consider.

But also have a little bit of time to consider that through what Dave was talking about. To get more of an idea where we seem to be actually heading.

And it just seems like to me we're already, you know, what is this, the 21st? The 22nd, you know, of August, doing something in September seems rather short to me to actually have the fulsome dialog that we really need to have internally.

You know, I think that we're trying to lean forward here, I think. And we're trying to provide some information.

But this is the -- these are the obvious questions that would come up as to, you know, what are we going to do with what we know?

And I think that, you know, we owe a more, you know, fulsome look at that part. Because otherwise, we'll be having a lot of the same discussion again.

You know, so that's why -- that's why I'm a little concerned about just giving a month with that.

MEMBER RICCARDELLA: Yeah. Clearly the September is too short. But October?

MEMBER MARCH-LEUBA: Yeah. Can I ask a question? Assuming you guys got what you are, I mean, you wanted to have a full committee meeting October 2, and a letter issued by us that week.

Can you tell me what you want in a letter to say in will form? Because what I understand it would say is, we have heard concerns from the staff that Regulatory Guide 1.99 has inaccuracies.

And they are -- we have heard them trying to improve those inaccuracies. And we support that.

Is that what you want the letter to say?

MR. ALLEY: That would be helpful.

MEMBER MARCH-LEUBA: We can write that next week in September. Because we've already heard it. And we support your efforts.

MR. ALLEY: Oh.

MEMBER MARCH-LEUBA: We don't need to wait for that.

MR. ALLEY: All right.

MEMBER MARCH-LEUBA: What we want to see is, what we are asking is what is the path forward after that?

MR. ALLEY: And we certainly will endeavor to provide you where we're going. But it was our understanding that the full committee could issue a letter.

MEMBER REMPE: That's absolutely correct. But let's go back to what Raj said for a minute.

Yeah, the after a second.

You said you had hoped we would have a letter in October. We really can't do it in September. We have a schedule that's full.

But if we had done that letter in October, which is going to happen now in November, you had said, or I think I heard you say that it would help you to have something that would facilitate future discussions with ACRS about this topic.

Is that what I think I heard you say Raj?

MR. IYENGAR: Not really future discussions. But also we can engage external stakeholders. Which we really want to, because that's part of the things that we do normally with this.

So it would really speed this up for us.

MEMBER REMPE: So, could I suggest a compromise of what I think I'm hearing from you? And again, I appreciate, don't come and bring us piecemeal stuff.

But, could you add a couple of slides that talk about the charter that Ron was talking about for the working group?

Some ideas about its structure. I still don't know who all participates in it. How many people from industry and all that.

And that would be enough to support the letter that's planned for November. Instead of giving us ad hoc stuff and adding another subcommittee meeting and things like that.

Is that a compromise that's okay with everybody concerned?

MR. IYENGAR: Yes. We could do that. Or we could actually give you a kind of a one-pager of what you're asking about.

Something which outlines what we're applying to. We could do that as well.

MEMBER REMPE: Yeah. And then that would be available for the full committee. And does that kind of support what everybody wants to do that's a meaningful compromise?

MEMBER MARCH-LEUBA: Yeah. In a sense, full committees get an hour and a half. And I think you can summarize what you've done.

MEMBER REMPE: Well, we've not yet heard from EPRI. And some of the answers about why can't you just do a correlation?

I think if you look at the slides that EPRI's going to present, there's some industry concern, in that -- about how this correlation gets modified. And I think that that's the answer to your point.

And so --

MEMBER MARCH-LEUBA: Well, I'd like to hear what the -- what the argument is to keep something that is obviously statistically wrong.

MEMBER REMPE: Well, that's what they're saying. Okay. But anyway, this -- Mr. Subcommittee Chairman, it -- it's your turn.

CHAIR BALLINGER: Yeah. You know, if we're into compromises, or swags, we could actually have a subcommittee meeting on November 4. And a full committee meeting on November 7 or 8.

And that would give you folks two months at least to get this working group spun up. Or whatever you're doing, and have some meat there.

That's a possibility.

MR. ALLEY: It would certainly -- it certainly seems timing wise that the idea of coming to you twice in one week, maybe excessive?

CHAIR BALLINGER: Well, but again, what we're talking about is that we already have the information, the boilerplate, the nuts and bolts part.

MR. ALLEY: Okay.

CHAIR BALLINGER: What we don't have, is the working group issues and anything that happened.

So, that would be an addition to the, what we already have.

So it's not like a re -- a re -- it would be new material. But it would be material that's very easily incorporated into the letter, if we do, if we do one.

MR. ALLEY: Okay.

CHAIR BALLINGER: And when you go to the full committee, that's when you would present both pieces.

MEMBER RICCARDELLA: A very abbreviated version.

CHAIR BALLINGER: Yeah. A very abbreviated version. So again, you're right, if we were just to have a subcommittee meeting and a full committee meeting where exactly the same thing happened, that wouldn't make a lot of sense.

But in this particular case, you will have had the advantage of several months of this working group piece, --

MR. ALLEY: Um-hum.

CHAIR BALLINGER: That's non-technical.

MR. ALLEY: Okay.

CHAIR BALLINGER: All right? This is management related stuff, I guess. I don't know.

MR. ALLEY: Well, there's both. Both issues are being considered at the working group. Both technical issues and regulatory implications would have to go there.

CHAIR BALLINGER: Correct.

MR. ALLEY: As Dan mentioned, some of the projections about how many plants and when they will reach certain levels of fluence, are more sophisticated if you actually go to the licensing document.

CHAIR BALLINGER: Yeah.

MR. ALLEY: So, that's something that's under consideration.

CHAIR BALLINGER: That package makes it -- it's a much more satisfactory and complete package for a letter.

MR. ALLEY: Yes.

CHAIR BALLINGER: I mean, you know, I'm in the --

MEMBER RICCARDELLA: If we were to write a letter in November with only the information that we have today on this assessment, it would be kind of moot really, because --

MEMBER KIRCHNER: No. I disagree. We would probably then start filling in the blanks along the lines of questions we ask.

MEMBER RICCARDELLA: Yeah.

MEMBER KIRCHNER: And we would not be as informed as we could be in doing so. We would --

MEMBER RICCARDELLA: Right. Right.

MR. ALLEY: Okay. So, with respect to dates, well, with respect to the concept of, should we be coming back to you and speaking with you to provide additional information to make your letter to us better and more useful, I'm going to fully agree with that concept.

When we get to timing, given that research is running the group, and is in charge of the timing and the organization, I'm going to refer to Raj, or defer to Raj at this point as to make the arrangements.

MR. IYENGAR: So, I think Rob is going to weigh in on it a little bit. But, I did want to offer something that rather then making the decision on whether to have a subcommittee meeting briefing and a full committee, could we -- could I work with Christopher Brown to maybe find the optimal solution?

Because two briefings take a lot of effort for us, to be honest with you. Even if it's things that it's administrative, and it's technical and inventory.

It's going to take a lot of burden. And I think I'd rather use that time and staff if I'm going to effectively work through is what we need to complete it in the working group.

So we might offer a product like a one-pager, or something, a small white paper on what the working group is doing and stuff. And then have a pre-committee.

But I would rather work that through Christopher Brown, if that's okay with you?

CHAIR BALLINGER: Okay. You can go --

MR. IYENGAR: Rob is going to say something. Go ahead Rob.

MR. TREGONING: Yeah. Rob Tregoning, Office of Research. You know, I wouldn't be so presumptuous to try to guide you much in terms of a valuable letter.

But I would say in this environment, you know, resources are tight. And we need justification to do many things.

And even a letter that says, you know, it's -- we think it's useful and valuable to update the Reg Guide. And we recognize that there are still questions that need to be answered in terms of implications.

But believe -- we believe the technology could be updated and should be updated. And we believe the staff is in the right -- heading in the right direction to address the issues that need to be addressed from an implication standpoint.

Such a letter would be very valuable. And I would not undersell the importance of such a letter that would come from this august body.

MEMBER RICCARDELLA: I agree, if we could do it in say September. But I think to do something like that in November, it becomes moot.

You know, it -- hopefully the working group --

MR. TREGONING: We won't -- we won't have a draft Reg Guide on the street by November. So, I wouldn't --

MEMBER RICCARDELLA: I understand. But your working group.

MR. TREGONING: It would not be moot.

MEMBER RICCARDELLA: But the work group will have some, presumably made some significant progress by then.

MEMBER MARCH-LEUBA: Yeah. But if we're talking a five-year time constant, two months don't make much.

MEMBER RICCARDELLA: All right. If you want us to write a letter based on what we know today in November, I mean, we can do that.

MR. TREGONING: Yeah. Well, I think what Raj is saying, is we want you to write a letter in November based on the knowledge that you have in November.

And we're going to figure out -- we're going to get you as much information that we can by November.

MEMBER RICCARDELLA: And I can support that.

MR. TREGONING: But just recognize that it's still a work in progress.

MEMBER RICCARDELLA: Yes.

MR. TREGONING: And we won't have -- all the recommendations and all the implications may not be fully understood by November.

But we'll certainly be further along then we are today.

CHAIR BALLINGER: But Raj's proposal, or suggestion of a written document, as opposed to two meetings, --

MEMBER RICCARDELLA: A white paper.

CHAIR BALLINGER: A white paper kind of thing that summarizes something we can put on the record for a letter related to the working group and things like that, is a path forward.

MR. TREGONING: Sure. Sure.

CHAIR BALLINGER: Then you'd have to get it to us and all the time --

MR. TREGONING: Yep.

CHAIR BALLINGER: Schedules and all that stuff.

MR. TREGONING: We'd have to meet your normal schedule then.

MEMBER RICCARDELLA: And then your November presentation to the full committee could summarize what you do -- you know, a much briefer summary of what you did today. Plus, what's in that white paper.

MR. TREGONING: Correct.

MEMBER RICCARDELLA: That would be good.

MEMBER REMPE: I need a break with that.

CHAIR BALLINGER: Yeah. I'm -- I'm -- are we at a convenient point where? So Dave, do you have anything to add before we take a break?

MEMBER PETTI: Take a break.

(Laughter)

MEMBER REMPE: Good comment.

CHAIR BALLINGER: Good comment. Okay. Let's recess until 3:15. Then we're going to hear from EPRI, I think.

(Whereupon, the above-entitled matter went off the record at 2:57 p.m. and resumed at 3:14 p.m.)

CHAIR BALLINGER: Okay, we're back in session. You're not supposed to smile. Okay. So, Tim, you're the -- you've got to turn on the microphone or get closer to it or something.

MR. HARDIN: Good afternoon, everyone. I'm Tim Hardin from EPRI. I work in the Materials Reliability Program on reactor pressure vessel integrity, and I'm joined, kindly, by my colleague, Nathan Palm, who is the program manager for the BWR Vessel Internals Program.

So we've been invited to speak to you today about our assessment of the NRC TLR on the adequacy of Reg. I-199, Rev. 2. That line of my talk basically follows the table of contents from the TLR, and then I'll end with our comments on the TLR's comments and recommendations.

Raj asked us to come and address you today. The staff that had reviewed the TLR all have experience in evaluating the effects of neutron embrittlement; performing evaluations, PT curves, PTS evaluations, reactor materials surveillance, capsule evaluations, and upper-shelf energy evaluations.

I want to stress that this presentation offers the professional opinion of the EPRI staff. It is not a representation, should not be taken as a representation, of an industry position from the U.S. utilities. We simply did not have time to poll them and get a consensus input from them.

So first, talking about the shift train curve; I think we understand what the residuals are, the residuals being the predicted minus the measured values. The information in the TLR is largely consistent with evaluations that we at EPRI and MRP have performed to support our industry programs to try to increase the amount of high-fluence data that can support future development of train correlations that would be applicable to operation to 60 and 80 years.

But what I'm going to do is briefly go through those programs that we've been engaged in just so you understand the context, and then I'll present some of the analyses that will be useful for comparing to what Dan presented earlier.

So we have had a concern that we don't have sufficient high fluence data to inform an embrittlement train curve that would be applicable to these higher fluences. Just anecdotally, I've had some utility executives call and ask essentially, Can my reactor operate to X years; 60 years, 80 years?

And I try to politely say, Well, please tell me what the embrittlement train correlation is that we have to use at that time in order to be able to answer that question. So the embrittlement train correlation is very important to the commercial operation of the plant, as was pointed out earlier.

So we developed two programs to increase the amount of high fluence surveillance information: that was a coordinated reactor vessel surveillance program that's detailed in MRP-326, and the PWR supplemental surveillance program. Both of these programs have been previously briefed to the NRC staff, and they are very familiar with them.

In the coordinated program, we just took a look at the plants and their existing capsule withdrawal schedules, and we identified some that could significantly increase the fluence if we just deferred withdrawal for 10 years or so, while still maintaining compliance with ASTM E-185-82 and Appendix H.

We implemented that program, but after

implementation there were still some gaps, and that's why we developed the PSSP. Here, we've built two supplemental capsules. We selected about 27 materials to populate those capsules; those are previously irradiated surveillance materials that we have reconstituted into new charpy V-notch specimens. We loaded them into these two capsules. We are irradiating them for 10 additional years to add about three times 10 to the 19th neutrons per square centimeter to the existing fluence.

Two utilities have graciously volunteered to be hosts for those capsules. The first capsule was installed in Farley 1 in 2016, and the second was installed last year at Shearon Harris, and they'll be withdrawn in the 2027-2028 --

MEMBER RICCARDELLA: So you take a previously broken charpy specimen and weld some -- I'm having trouble making out this photograph.

MR. HARDIN: Yes. So we take the -- we start at the top with the broken charpy specimens --

MEMBER MARCH-LEUBA: You need to talk into the microphone and use the mouse.

MR. HARDIN: All right. So you start with the broken charpy specimen, and those were stored at Westinghouse. We obtained permission to retrieve those. You machine it and shave off the broken ends, and you have a specimen insert that you then weld to end tabs onto the insert, machine it, and you generate a new charpy V-notch specimen, which you can then load into capsule and re-irradiate to add even more fluence to the existing fluence.

MEMBER REMPE: So while we've interrupted you, is the program totally funded by industry, or is this part of the LWRS program, where you're collaborating with DOE? How does this program --

MR. HARDIN: This is totally funded by the Materials Reliability Program.

MEMBER REMPE: Okay, good. Thanks.

MR. HARDIN: The PWR Owners Group did kindly provide some financial help to the post plants to offset the costs, to defray the costs, of inserting the capsules, but the fabrication of the capsules was entirely an MRP project.

MEMBER REMPE: And you're going to keep funding the examination of those specimens solely with the industry-available funding? You're not depending on LWRS, is what I'm asking then.

MR. HARDIN: That's correct.

MEMBER REMPE: Okay, thank you.

MR. HARDIN: We would be open to receiving funding --

(Laughter.)

MEMBER REMPE: I heard that because the SLR was underway that some of that funding would be decreasing; that's why I was wondering. Thanks.

MR. HARDIN: Yes, we're not counting on that yet.

So this is a busy chart that shows the future availability of high fluence surveillance data relative to RPV material predicted fluence and time. So on the Y axis we have the fluence, and then in the years 2020, 2030, 2040, et cetera.

So the dark greenish data are the fluence data; the surveillance data that we currently have. The blueish squares are the 40-year RPV fluences projected.

MEMBER RICCARDELLA: The open blue square?

MR. HARDIN: The open blue, yes.

MEMBER RICCARDELLA: Okay.

MR. HARDIN: The open purple diamonds are the projected 60-year fluences for the RPV, and the open red triangles are the projected 80-year fluences for the RPVs.

The dark, filled-in blue diamonds around here are the fluences of the capsules that are to be withdrawn from now until 2030.

MEMBER MARCH-LEUBA: So somewhere around this year or next year, we're going to get a large number, half a dozen, between five and 10 --

MR. HARDIN: Yes.

CHAIR BALLINGER: So that data is the Shearon Harris and Farley?

MR. HARDIN: No, no. These are the regular capsules, Appendix H capsules, in many different plants, operating plants. The PSSP capsules from Shearon Harris and Farley are the green --

CHAIR BALLINGER: That's what I thought.

MR. HARDIN: Yes, the green triangles.

MEMBER RICCARDELLA: And those way up at the top?

MR. HARDIN: Yes.

MEMBER RICCARDELLA: So those two ones way at the top?

MR. HARDIN: Yes.

CHAIR BALLINGER: Well, plus all of the green triangles, right?

MR. HARDIN: Yes, correct.

MEMBER RICCARDELLA: Your eyes are better than mine. I only see those two.

MR. HARDIN: Okay. All right. So that

gives a perspective that we're going to be able to obtain bounding fluences well before the RPVs actually reach the peak fluences.

CHAIR BALLINGER: Are these typical copper and nickel plants?

MR. HARDIN: What, the PSSP?

CHAIR BALLINGER: Yes.

MR. HARDIN: Well actually, those were carefully selected, and I'm going to discuss that a little bit in subsequent slides.

But we looked at the regular capsules, the Appendix H capsules that were going to be available, and then we looked at gaps in terms of product forms and chemistries that were not well-represented, and we chose materials to fill those gaps. That's the materials we put on the PSSP so that those materials would more fully inform embrittlement train correlation.

So as I said, we looked at all the RPV surveillance materials in the U.S. We divided them according to product form and chemistries, and then we evaluated how well the existing embrittlement train correlations predicted that group.

And if we had a poorly-predicted group, we targeted that for inclusion in the PSSP in order to get some data down the road that more robustly will describe that. And that is published in MRP-364, which is not yet publicly available, but also this PVP paper, which is publicly available.

So we looked at Reg. I-199, Rev. 2, EONY, the Eason Odette Nanstad and Yamamoto correlation that is used in the alternate PTS rule, 61 alpha. At WRC 5, Rev. 1, which was a correlation developed by Mark Kirk, and I think it's fair to say that that was the forerunner to became ASTM E 900-15. And then more recently we've gone back, and in a few of the slides that I'll show, we actually indicated the results using the ASTM E 900-15, because it is most recent and accurate correlation.

So the slides only include U.S. PWR radiations, and only the 41 joule index temperature shift measures are shown.

So here we have an example for low copper but nickel-added, higher nickel plates. The red squares, solid, are the reg guide. The green circles are EONY, alternate PTS rule. And then the yellow triangles are E 900-15.

And for this particular product form and chemistry, all three, the mean of the correlations is pretty flat and around zero axis. However, one train that you can take away here is that scatter is increasing significantly as the fluence increases. That gets back to the points that Dan made earlier. Sir?

MEMBER MARCH-LEUBA: Do you have any gut feeling for what the safety significance of 40 degree Fahrenheit inaccuracy in your prediction? So I'm drawing the 2-sigma plus minus 40. Is that as significant safety impact on a plant or operational significance for a plant? Or you say, Oh, never mind? I have no idea.

MR. HARDIN: First, let me preface it. We have done a deliberate study of that, but I would tend not to think it is, for the reason that, even in cases where you have a significant underprediction, then you have -- we'll talk about the Whitman slides -- you have a provision where the higher chemistry factor that is determined by the surveillance data is required to be used for evaluational vessel material.

MEMBER MARCH-LEUBA: No. The question I'm asking is, say that you have older chemistry; you have older input parameters. Now, I'm also operating here, and now my number suddenly changes to minus 40 degrees Fahrenheit.

Does that take 10 years off the life of my plant, or does it require me to operate in a different domain? Or is 40 degrees, no, never mind; unless you get to 500 degrees, it's not an issue?

MR. HARDIN: Right.

MEMBER MARCH-LEUBA: It's not significant.

MR. HARDIN: Yes, I agree; it depends. It may affect the period of time for which the PT limit curves are --

MEMBER MARCH-LEUBA: -- useful. So it can't cut the life of the plant? Forty degrees can't --

MR. HARDIN: I wouldn't say life of the plant, but it might -- because typically plant doesn't do PT curves out to the end of its license. It does maybe 10 years in advance until it knows it has to redo another set of PT curves.

So if you have a significant non-conservatism like this, it might make the period of applicability for those PT curves shorter.

MEMBER MARCH-LEUBA: And then when you re-evaluated, you -- you're still in compliance?

MR. HARDIN: Well --

MEMBER MARCH-LEUBA: I have no idea.

CHAIR BALLINGER: Change the operation.

(Simultaneous speaking.)

MEMBER RICCARDELLA: You change the operation. The peak curve means what the maximum pressure you can go to at any given temperature, so you'd have to heat up --

MEMBER MARCH-LEUBA: So how close do we operate from limits? I mean, is 40 degrees significant? Does it eat into my limits?

CHAIR BALLINGER: It depends on where your starting point is, don't you think?

MR. HARDIN: Right. I mean, first off, it would have to be the controlling material on which your limits are based. So if it's a material that isn't controlling, then the question is, is the limiting material less than 40 degrees from that material?

And then even after that, okay, is it a plate, or is it an axial weld, or is it a circumferential weld? Because if it's a circumferential weld, it may not have as large an impact. And then at that point you would evaluate whether it would change the applicability.

And I guess, even if it's a fairly -- if it's a plant that does have high ART values, then the limits could be more restrictive, and you may be closer to operation. But if you're talking about a boiling model, well, this is PWR data; I don't know.

But if you were talking about a lesser irradiated PWR or a BWR, chances are you're going to be operating pretty far from the PT limits curve to begin with.

MEMBER MARCH-LEUBA: So it's applied to a specific number.

MR. HARDIN: Yes. And I think that's where the staff, when they had some of those questions, I think that was some of the difficulty they were having giving you a precise answer, because it really depends on so many various factors.

MEMBER MARCH-LEUBA: Just -- I'm not complaining, I'm asking you to educate me, okay? Because I don't know anything about it.

CHAIR BALLINGER: Remember that they are dealing in Fahrenheit; the staff is dealing in centigrade.

MR. HALL: I'm Brian Hall with Westinghouse. I might be able to help a little bit.

So the margin term in the reg guide is designed to deal with that uncertainty. And as the staff pointed out, the data shows that the standard deviation is probably a little bit higher than what is in the reg guide with the additional data, and that's what this is showing too, consistent with that.

So to answer your question, the uncertainty might be a little bit larger than what the reg guide says, but I wouldn't say it's a safety significance, at least not in the next decade or two.

MEMBER RICCARDELLA: So do I read this, that those yellow triangles are higher than -- I mean, it's showing improvements as you go from Reg. I-199 to the ASTE 900 one, I guess. Is that right?

MR. PALM: Yes, sir.

MR. HARDIN: And I think what Nathan pointed out earlier, the significance of it really does depend on if the specific material is your limiting material or not. In the vessel, you have welds; you have plates. And this is for a plate.

Well, if you have a significant non-conservatism in the plate, that plate's adjusted reference temperature may be 60 degrees below the limiting weld, and the plant already operates to that limiting weld. So this would have no impact at all on the plant operating limits.

Another example, low copper, low nickel welds. As we saw from Dan's presentation, welds are fairly well represented by the reg guide, as well as the other train correlations.

That is not the case for all product forms, however. We have an example here of medium copper forgings, where there seems to be a distinctly negative trend for the reg guide in the non-conservative direction.

The prediction of embrittlement by the reg guide; a little bit of a negative trend by EONY correlation. E 900-15 does a pretty good job all the way up until one times 10 to the 20.

But, again, it's a very complex situation. Here's also forgings, same as the previous slide, but now it's high copper. The reg guide fairly consistently overpredicts embrittlement, so it's going to be a very complex situation to figure out.

Here's a table that summarizes all the various groups, and this describes how we broke them up into 302B modified and 533 B1 plates, 302B plates, forgings, and then welds, high nickel and low nickel.

We've characterized it as using three symbols: an O for overpredicts, a U for underpredicts, and then in some cases we found that there was a distinct change in the capability of the reg guide to characterize the shift at about three times 10 to the 19th.

Once it got -- you know, sometimes it was overpredicting below three times 10 to the 19th, but underpredicting above three times 10 to the 19th. So in those cases where you see a slash mark, that's what that is indicating.

You can see the EONY fit is better than the reg guide in most of these instances. We did not have a full set of E 900 data, so that was not included on this chart.

But the main takeaway, I think, from these slides that I've shown is that the mean trends very significantly as a function of product forming chemistry, and overall, the scatter and the residuals for Reg Guide 199, Rev. 2 increase significantly with increasing fluence.

Some other comments on the TLR; Section 2 states that not all plants use the reg guide shift train curve directly as many supplement it with surveillance data or other adjustments such as the degree per degree.

We thought that this statement understates the use of the reg guide in the fleet. All plants use Reg Guide 199 directly for any materials where there is not surveillance data. And for most RPVs that's most of the RPV materials, because in RPV you can have six, eight plates and several welds.

In your surveillance program you typically have one plate, one weld, one HAZ. So you can use the surveillance data from the capsules for those matching materials in the vessel. But for all the other plates and all the other weld numbers, you have to use Reg. I 199, Rev. 2.

MEMBER MARCH-LEUBA: But is that because it has a different fluence, or because it has -- because it should be the same chemistry.

MEMBER RICCARDELLA: No.

MR. HARDIN: No, they're significantly different.

MEMBER MARCH-LEUBA: Okay. I don't understand how --

MEMBER RICCARDELLA: But in general, aren't the surveillance specimens intended to be the limiting materials, or no?

MR. HARDIN: When they are --

MEMBER RICCARDELLA: Intended; I used the word intended.

MR. HARDIN: They were intended to --

MEMBER RICCARDELLA: But they're not always?

MR. HARDIN: That's correct, because you have -- the surveillance program was established when the vessel is built, so a lot of these materials were established in the '60s and '70s under the original reg guide, and the guidance for prediction of embrittlement has undergone several changes.

MEMBER RICCARDELLA: We didn't know about copper back then.

MR. HARDIN: Yes, exactly. So now we know that other materials can be a limiting material.

Other comments, and these are really just observations. To currently apply a weld surveillance data to evaluate if that's a weld with the same heat number, if there is a significant difference in chemistry between the surveillance weld and the vessel weld of the same heat number, then we use the chemistry factors from Reg. Guide 199, Rev. 2, Table 1 in a ratio procedure to adjust the surveillance shift to what would be applicable to the vessel weld.

If a new reg guide is adopted that does away with chemistry factors, then it would be necessary to develop alternate guidance for how to make that adjustment to apply surveillance weld shifts to vessel welds.

The TLR references the Wickman-Hiser-Mitchell slides. Those were the three co-authors on those 1988 slides, but does not mention the same guidances available in summary form in NUREG 15-11, Supplement 2.

Charpy upper shelf energy train curve; EPRI has also done some work in this area. We saw the presentation many years ago by Mark Kirk; the slide that there was the Reg. Guide 199, Rev. 2, Upper Shelf Energy Decrease Prediction may be non-conservative.

We know that Dr. Kirk generated the UNM 6 correlation to achieve a 2-sigma pound, and we reviewed that. We're concerned with that correlation, that it might unfairly penalize non Linde 80 welds and cause significantly more materials to fall below 50-foot pounds than is really necessary.

So we started in a research project; Westinghouse was our vender on this work. Brian Hall in the audience was one of the authors. We published MRP-414 in 2017; that's not yet available, but we also published a PVP paper, which is publicly available and provides the upper-shelf energy prediction curve that we developed from this work.

We had over 1,500 upper-shelf energy change measurements in this database, only from LWRs from U.S., Korea, Germany, Brazil, Spain, Mexico, Sweden, and France. We screened that material or those data, and after screening had about 1,177 that was used for modeling.

We investigated two types of models: one that used ASTM E 900-15 as the primary input parameter, and one that did not. In the end, just to reduce complexity, we decided to go with the one that did not use the E 900-15 transition temperature shift correlation.

We evaluated the effect on the fleet and found that basically we were able, with this correlation, to attain a 2-sigma bound on the upper-shelf energy decrease data but have negligible increase in the number of PWRs that would be predicted to fall below 50-foot pounds.

In our correlation there were 30 PWRs in 92 materials that were predicted to fall below 50-foot pounds. The reg guide would be 30 PWRs and 82 materials.

So we do -- in our correlation in order to give that 2-sigma bound. We do have more materials, but the same number of overall PWRs. So our comment here would be if NRC desires to pursue a revision of the reg guide upper-shelf energy decreased prediction model, we would suggest consideration of the model that is in MRP 414. Yes, sir?

MEMBER MARCH-LEUBA: What's an EMA?

MR. HARDIN: An EMA -- sorry if I did not -- I thought --

MEMBER MARCH-LEUBA: No, I simply don't know these --

MR. HARDIN: Equivalent Margins Analysis.

MEMBER MARCH-LEUBA: And you do that once every 10 years?

MR. HARDIN: No. That is Appendix G, 10 CFR 50, Appendix G. It requires that all reactors vessel outline materials maintain at least 50-foot pounds upper-shelf energy through the end of license. And if you're ever predicted to fall below 50-foot pounds, then you have to do an analysis that shows that an equivalent safety margin exists, and that's what an equivalent margins analysis is.

MEMBER MARCH-LEUBA: Oh, so that MRP 414 is a correlation?

MR. HARDIN: It's a correlation.

MEMBER MARCH-LEUBA: That is not a real value; it is a screening criteria.

MR. HARDIN: Correct.

MEMBER MARCH-LEUBA: If you pass it, you don't have to do anything else. You fail it, you have to do more details.

MR. HARDIN: If you use it and it falls below 50-foot pounds -- if that were being used as a regulatory benchmark -- then just like with the reg guide, if you use a reg guide, fall below 50-foot pounds, then you would need to do an equivalent margins analysis.

MEMBER MARCH-LEUBA: I didn't realize that. So it is a screening criteria; it doesn't need to be active.

MR. PALM: Is that an EPFM electric plastic? The margins analysis, is that a --

MR. HARDIN: EMA is an elastic plastic fracture mechanics analysis that's governed by Appendix Echo and K and Reg. Guide 1.164.

MR. PALM: Yes. To clarify, MPR 414 does not include an equivalent margins analysis. It is just providing an alternate upper-shelf energy decrease prediction model.

MR. HARDIN: And the embrittlement train correlation for upper-shelf energy, basically.

MR. PALM: Yes.

MR. HARDIN: Then there's another section in Section 3 of the TLR. It states that the reg guide predictions for the shift in upper-shelf energy contain a conservative bias. Attention is called to the last sentence: Further work is needed to evaluate the regulatory significance of the current 68-joule criteria and to determine if it should be retained, modified, or eliminated.

Generally we agree with this overall paragraph in the TLR, but we do observe that the requirement for 68 joules or 50-foot pounds is established in 10 CFR 50, Appendix G, not the reg guide. So if you're going to talk about modifying or eliminating it, that suggests rulemaking to change Appendix G.

MEMBER RICCARDELLA: As I recall from a long time ago, RTndt was based on drop-weight ndt, and then a certain number of degrees above that you have to have 50-foot pounds, six degrees above that. And that's Rtndt. Is this 30-foot pound number kind of used as a surrogate for that as the actual Rtndt?

MR. HARDIN: I'm sorry, I'm not getting where you get 30-foot pounds.

MEMBER RICCARDELLA: No. We're using this charpy CVN of 30-foot pounds as basically a shift in RTndt. But that's a surrogate for the real RTndt, right, more or less?

MR. HARDIN: That's the transition temperature, index temperature on the charpy curve.

MEMBER RICCARDELLA: Yes.

MR. HARDIN: And that is used as a -- the difference between the T 41 joule or T 30-foot pound temperature for the unirradiated material and the irradiated material; that shift is assumed to be the shift in Rtndt.

CHAIR BALLINGER: Are you referring to the Polini -- the original Polini drop-weight test, where this was all derived from.

MR. HARDIN: Yes. The original --

CHAIR BALLINGER: They took a weld, put it in a plate, dropped something on the thing --

MEMBER RICCARDELLA: But you can't do a balance drop-weight test, so you use the 30-foot pound as a surrogate.

MR. HARDIN: But all that testing was the beginning of lack to establish the original values, the drop weight and the charpy.

Now, in continued testing that goes on is the charpy testing from the surveillance capsules.

On fleet impact in Section 3 of the upper-shelf energy train curve evaluation states that for this assessment, preliminary estimate of the number of reactors may fall below 68 joules, criterion of measure, but are not predicted to do so, was conducted.

So it goes on, and I think we discussed this a little bit earlier. That chart got a lot of discussion that Dan showed, that there were some plants that might be predicted to fall below 50-foot pounds, but are not predicted by the reg guide to fall below 50-foot pounds. In their statement, these plants warrant further review.

But we felt that that statement should be clarified or revised because it implies an inadequacy in the existing upper-shelf energy calculations for some four plants and could be interpreted as a regulatory challenge, questioning the plant license basis.

Those upper-shelf energy calculations are performed by the current NRC guidance; the current guidance is Reg. Guide 199, Rev. 2, so the post plants are fully in compliance, and those calculations have been reviewed by the NRC. So we felt it would be inappropriate to imply that there is some sort of regulatory action required for those plants.

MEMBER RICCARDELLA: Were these comments addressed? You're making all these various --

MR. HARDIN: No. I believe this is the first time the staff has seen this.

MEMBER RICCARDELLA: Okay, okay. So we reach out for comment? The status is, this is still out for public comment?

MR. IYENGAR: So this TLR was not for release for public comment; it was just released for us.

CHAIR BALLINGER: Yes, this is just for us.

MEMBER RICCARDELLA: Okay.

MR. IYENGAR: Normally it's not a process that we release every TLR for public comment, especially --

MEMBER RICCARDELLA: But you sent a copy to EPRI?

MR. IYENGAR: Right. And we would consider whatever comments we get from EPRI, as well as other stakeholders.

MEMBER RICCARDELLA: Okay. Thank you.

MR. HARDIN: Credibility criteria and use of surveillance data; the TLR states in Section 4.1 that should the data be deemed non-credible, the user is directed to discard the chemistry factor refit, losing what may be a superior data fit, Reg. Guide 199, trim curve.

Our comment here is that while this may be consistent with the reg guide as written, it is not consistent with how the NRC has implemented the guidance in the Wickman slides from 1998.

That is, if a fitted chemistry factor -- that is, the chemistry factor you calculate for surveillance data -- and it's non-credible, it is higher than the table base, the reg guide table base chemistry factor, then the NRC has required the use of the higher non-credible surveillance chemistry factor to be used in calculation of the adjusted reference temperature.

MEMBER MARCH-LEUBA: Higher meaning conservative or non-conservative?

MR. HARDIN: Conservative.

MEMBER MARCH-LEUBA: Conservative. Negative is bad, but --

MR. HARDIN: Right. So you take the -- even if it's non-credible surveillance data, if it's a higher chemistry factor, you're required to use it.

MEMBER RICCARDELLA: Okay. So it can hurt you, but it can't help you. Is that what you're saying?

MEMBER MARCH-LEUBA: So why do you put your samples in there?

MR. PALM: Because you're required. If

the data is credible and it's lower, you can use it. But if it's higher and it's credible or non-credible, you use it. The caveat is, if it's credible, you can use a reduced margin term, and if it's non-credible, you use the full margin term.

MR. HARDIN: So often surveillance data is very helpful to plants because it's often credible, and they can cut the sigma-delta by half and reduce the calculated adjusted reference temperature for that material.

MEMBER MARCH-LEUBA: But do you agree with the process of determining whether it is credible or non-credible? Because I thought that the sample they showed us an hour ago, they run a perfectly clearly -- statistical test, and it failed the reg guide.

They did a beautiful mathematically correct data, and the reg guide said it wasn't credible. So I think that's what they have, right?

So, I mean certainly in the -- your comment but it appears that the process specified in the reg guide to determine credibility of data has a hole in it. It projects more good than it should.

MR. HARDIN: I would not disagree with that. I do want to point out that in a later slide, credible surveillance data has been very helpful to the plants to resolve issues.

MEMBER MARCH-LEUBA: In my opinion, you should always believe an experiment over anything else unless you really, really have a reason to doubt it.

MR. HARDIN: So the credibility criteria is difficult, but it still has been very helpful.

Neutron embrittlement, neutron attenuation; EPRI has sponsored some testing activities on this, starting back more than 10 years ago, I think. There was an IAEA research program that was designed and run by Nuclear Research Institute, Czech Republic. NRI was in Czech Republic, and as a matter of fact, I think NRC was involved in some way, in that I think some materials were contributed by NRC for that experiment.

EPRI contributed a Linde 80 weld and a high-copper SA58 533B plate. Then after that experiment was conducted -- this was at a Russian reactor, but the Czech Research Organization performed the testing, and EPRI paid for various parts of that testing; hardness testing, master curve TZ0 testing, tensile testing, charpy testing.

And so there are a series of reports that I've listed here on the slide. The PLR references a server 210, which is a summary paper that was based on all those various MRP reports.

Anyway, this research basically supports the TLR regarding issued of attenuation. We've also conducted analyses of neutron attenuation in PBR nozzles. In 2012 we released MRP 345, and this is a publicly available report.

And this research also supports the conclusions of the TLR that the reg guide attenuation formula is not applicable in the extended belt line and nozzle region, because the peak DPA rate occurs on the outside surface of the nozzle, forging the bottom of the nozzle in the cavity regions.

So this plot here is a DPA rate versus fraction of distance through the nozzle, where the zero starts at the corner of the nozzle at this red line, and then continues at a 45-degree angle. So that's where this DPA rate is measured from, plotted from.

So you can see that actually the DPA rate increase through the thickness of the nozzle; does not attenuate as the reg guide would predict.

MEMBER RICCARDELLA: What's the difference between the blue and the red curve?

MR. HARDIN: Inlet nozzle, outlet nozzle. One curve, the red curve, is for the outlet nozzle;

the blue curve is for the inlet nozzle.

MEMBER RICCARDELLA: But it doesn't attenuate? It increased?

MR. HARDIN: Right. Because you have an albedo effect of neutrons leaking out the cavity and impacting the exit to reactor vessel laterally, maybe interact with a biological shield bounced up in the cavity and --

MEMBER RICCARDELLA: That's what is referred to as streaming?

MR. HARDIN: Yes. Now, of course it's plant-specific. You would not have this configuration or this concern if the vessel was supported by a shield tank, for example.

MEMBER RICCARDELLA: Okay.

MR. HARDIN: This is more applicable to something on support beams.

I will note that there is ongoing research that may impact the evaluation of neutron attenuation in vessels. There are experiments being supported by DOE: light water reactor sustainability program on the decommissioned Zion 1 RPV beltline. Material was removed from the beltline, shipped to Oak Ridge, and Oak Ridge has cut samples through thickness, measured through thickness properties, through thickness, charpy impact and chemistries --

MEMBER RICCARDELLA: Chemical harvesting?

MR. HARDIN: Yes. And so to my knowledge, this is the first time we've done something like this: taken actual RPV wall that has been in service and then doing -- testing. So it should inform future guidance on the effects of attenuation.

MEMBER MARCH-LEUBA: You need to, for neutron attenuation, you really don't need to run an experiment. You just take MCMP; wait sufficient -- enough samples. It might take you several weeks on a supercomputer, but you will get a neutron flux, and you know the standard deviation of the neutron flux.

MEMBER RICCARDELLA: What's MCMP?

MEMBER MARCH-LEUBA: It's the Monte Carlo Code.

MEMBER RICCARDELLA: A computer program.

MEMBER MARCH-LEUBA: Well, talk to the expert.

CHAIR BALLINGER: Transport.

MEMBER MARCH-LEUBA: It tracks the path of a neutron and into billions of neutrons, and you get the right -- for attenuation, there is no issue. You don't have to do the experiment. It can be an expensive operation.

(Simultaneous speaking.)

MEMBER RICCARDELLA: It can be very useful and accurate in complex geometries, and that's been demonstrated in many applications.

MR. HARDIN: That gives you a very accurate understanding of what the neutrons are doing, the flux is doing. It doesn't necessarily tell you what's happening to the material.

MEMBER MARCH-LEUBA: You need to have the responsive material to the neutrons, but it has nothing to do with attenuation. Attenuation, you can calculate it if you're willing to wait enough time, because it takes billions and billions of traces, you'll get it.

MEMBER RICCARDELLA: Yes. You get the neutrons, but then you try to correlate that with what the toughness is, and you get that huge scatter.

MEMBER MARCH-LEUBA: Well, I assume you people know what the neutron does to your material.

CHAIR BALLINGER: Yes, but going from neutron energy to actual displacements --

MEMBER MARCH-LEUBA: Well, it actually calculates the displacement of --

MEMBER RICCARDELLA: EPA?

MEMBER MARCH-LEUBA: -- what every

electron in the material ends up.

MEMBER RICCARDELLA: I don't care about electrons.

(Simultaneous speaking.)

MEMBER MARCH-LEUBA: If you want to, you can track every electron that gets displaced.

MEMBER REMPE: But I think what he's trying to tell us is that you may be able to understand what the fluence is, but you may not know what the material response is for that fluence.

So I think if the wording were changed here, that would help our colleagues here, but you are doing, just to make sure I understand, material property testing. You're not just doing evaluations of attenuation, right?

MR. HARDIN: Attenuation, that is right. That is what Oak Ridge is doing. That's an effort entirely funded by light water reactor sustainability program. EPRI is not involved.

MEMBER RICCARDELLA: The Zion --

MR. HARDIN: The Zion work, yes.

MEMBER REMPE: And that work is fully funded, and not -- there's no concerns about future efforts. It's going to be finished in 2019?

MR. HARDIN: It might not be fully funded yet. The charpy --

MEMBER MARCH-LEUBA: My point is, the reg guide uses a correlation for the attenuation of the neutrons. If you don't like the correlation, you can run MCMP and calculate the real one.

MR. HARDIN: The only reason I put it on here is because it pertained to a topic that's in the TLR. I've seen that presentation twice now, and I think it has information that NRC staff should consider. So I'm just trying to call it to their attention.

MEMBER RICCARDELLA: Is it charpy -- is it doing charpy tests? A Zion --

MR. HARDIN: It's charpy testing and chemistry.

MEMBER RICCARDELLA: Chemistry. Okay.

MR. HARDIN: Actually, one of the authors is here, Dr. Nanstad.

MEMBER MARCH-LEUBA: So for future reference, speak into the microphones so it ends up on the record. And your name, please?

MEMBER RICCARDELLA: We need to get your name on the record.

MR. NANSTAD: So I'm Randy Nanstad, RNS Consultants. I'm here representing the light water reactor sustainability program at Oak Ridge.

So the Zion work, yes, there are charpy specimens, tensile specimens, and fracture toughness specimens, as well as chemical composition specimens that are being tested mechanically through the thickness of that eight-inch thick vessel.

And then there are microstructual investigations, et cetera, that are being done to supplement the mechanical properties.

MEMBER MARCH-LEUBA: So that doesn't really agree with the information. Is there neutron flux fluence for were characterized for the sample?

MR. NANSTAD: Well, what we have is the information that was available from Westinghouse in terms of the flux and fluence on that vessel. We have not done any experiments to try and determine if the plant shut down in 1995 --

MEMBER MARCH-LEUBA: You'll have to do some calculations or believe Westinghouse. Hopefully, Westinghouse has not used the incorrect attenuation curve. What we've seen is that if you go off the horizontal plane, the attenuation curve is not correct.

MR. NANSTAD: I'm sure they did.

MR. HARDIN: Common additions to Reg. I

199; the TLR discusses the use of sister plant data. This is more of an editorial comment. We use this term repeatedly, sister plant data. To some extent, we feel it's a misnomer, and its concept not well-defined.

In practice, it's matching heat number data, because that's what you're doing. Surveillance materials with heat numbers that match vessel material heat numbers are considered when evaluating the integrity of those materials in the vessel, whether or not the data originates from a sister plant.

It could come from a supplemental surveillance capsule, for example, not necessarily a sister plant. So that was just an editorial comment.

The TLR also states that consequently, the addition of sister plant data increases the likelihood that plant-specific data would be rejected. I think we spoke to this, that there are some very high-profile instances where it has been very helpful to plants to have sister plant data and to apply sister plant data.

Comments about implementation of future revisions to Rev. Guide 199; obviously, the adoption of new guidance in predicting embrittlement will have a significant impact on all operating plants and also the international plants that use Reg. Guide 199, Rev. 2. That would affect PT curves, low temperature over pressure setpoints, et cetera.

When the last update, Rev. 2, was introduced in 1988, it was introduced with somewhat onerous requirements for a quick impact assessment and adoption. Now, at that time, that was probably justified, because there was so little surveillance data available, and the train correlation of Reg. Guide 199, Rev. 1 was notably non-conservative. So that's understandable.

But we do think -- our comment is that the data presented in the TLR that we discussed earlier, showing that plants only start to reach levels that are of serious concern in the late 2020s -- and those are only the earliest plants. There are many lower-fluence plants that will not reach that until much later -- suggests the phased implementation of any revision to Reg. Guide 199, Rev. 2.

And finally, our comments on the conclusions and recommendations; we do find the conclusions of the TLR succinct and their technical biases are thoroughly documented.

The only exception is that statement about the four plants with upper-shelf energy that need further review. That may be true on a research basis, but we felt it was worded sort of in a licensing basis. That was our concern there.

The recommendations of the TLR were reasonably supported by the analyses presented and were generally consistent with our research. The EPRI shelf energy prediction model is available for consideration if NRC wants to update that model.

A new high-fluence dataset will become available in 2028, 2030 when the PSSP capsules are tested. That will provide a means for future validation of the revised reg guide or to inform development in the future embrittlement train correlations.

And then finally, the data seem to support a phased implementation of any revision to the reg guide in order to minimize unnecessary burden on the operating fleet.

That's all we had today. Any additional questions? Sir?

MEMBER MARCH-LEUBA: Yes. Go back one. Why in that supports a phased implementation? That last comment. What in the -- you said the data supports a phased implementation. I think you would prefer to have a phased implementation, but what in the data supports a phased implementation?

MR. PALM: Yes. What he's referring to is the fact that we really don't see these larger residuals or scatter occurring until higher fluences, and there are many plants, lower fluence PWRs and most of the BWR fleet, will never come anywhere near those fluences.

If you go back to the slides that were presented by Dan and look at the left-hand axis; look at the data to the left of -- the scatter is still within the predicted scatter. We don't see any unreasonable deviations or trends in either direction.

So for those lower-fluence plants, there's no immediate need for them to update their PT limit curves. I think just as an example of what we were thinking in terms of phased implementation, they could update to the next reg guide revision perhaps when another licensing basis need arises.

So perhaps when they have another surveillance capsule that needs to be taken into consideration, they would use the new reg guide at that time.

MEMBER RICCARDELLA: If you've got five plants that are affected and that potentially have a regulatory issue, and 90 plants that -- yes, the correlation's not great, but it's not a safety concern, why should those 90 plants have to go back and revise their PT curves? I think that's what he said.

MEMBER MARCH-LEUBA: Okay. But I wouldn't call that phased-in implementation. What I see in the letter is that most of the used plants have to be below five to six times 10 to the 19th. That's what all the red dots in the famous -- they're all below five to six.

But when we go above five, and certainly when we went to 20, there is a real trend, most of them in foreign plants, that clearly we do not predict properly.

So the obvious solution to this on Reg. Guide Rev. 2 is for plants that have a fluence of less than five times 10 to the 19th, you don't have to do anything.

MEMBER RICCARDELLA: Right.

MEMBER MARCH-LEUBA: Is that what you mean by phased?

MR. PALM: You wouldn't need to do anything immediately.

MEMBER MARCH-LEUBA: Right. So I don't see tying it to a future action that the plant chooses to do, versus tying it to the condition of the plant. So if you are less than five times 10 to the 19th, the data suggests that new correlation and old correlation are going to give you the same number. You don't need to do anything.

MEMBER RICCARDELLA: Not the same; the new correlation might give you a better number.

MEMBER MARCH-LEUBA: It might, but if you go and plug it in, 50 percent of the plants will come up higher; 50 percent of the plants will come up lower. So you're better off not touching it.

MEMBER RICCARDELLA: Well --

MR. PALM: I mean, maybe it doesn't necessarily need to be tied to a licensing basis action, but if you give them the flexibility, and they come up on one of those actions, like a new surveillance capsule, and they can look out in the future and say, We're not at that fluence threshold at this point in time, but we're not going to have another licensing basis action before we reach that fluence threshold, then they would be able to go ahead and implement the new reg guide. Then they wouldn't have this update just for the sake up updating the reg guide.

MEMBER RICCARDELLA: They do update these periodically.

MR. PALM: I mean, there's no explicit just integral-based requirement to do updates. It's typically based on some other --

MEMBER RICCARDELLA: Well, if you pull a surveillance capsule.

MR. PALM: Right, right, or if you've done a fluence evaluation for another reason, operating something like that.

MEMBER MARCH-LEUBA: So when you do the evaluation and you extrapolate for the next 10 years where you expect to be. You calculate a PT for -- and don't touch it.

MR. PALM: Yes. I mean, typically, when plants do this, they will extrapolate until the end of their license period of operation.

MEMBER MARCH-LEUBA: So in my opinion, if I was to tie these phases to something, I would tie it to a state; what's your fluence? If your fluence is less than five times 10 to the 19th, don't touch it, because if you even dare to calculate with the new one, you might be better, but you might be off. And if you are off, R21 (phonetic) will require you to change it. So you're better off not touching it. But the phase I would tie it to the state of the plant, not --

MR. HARDIN: There are several ways you can --

MR. PALM: Right. I think our primary message is that if the staff is to revise the reg guide, we don't think an approach similar to what was done in the previous revision would be necessary.

(Simultaneous speaking.)

MEMBER RICCARDELLA: They would need a certain period of time to update their --

MR. PALM: Yes.

MEMBER MARCH-LEUBA: That would be abusive and certainly I don't think it is necessary. And I don't know think the staff, in a good environment, will even dare do anything.

MR. PALM: Okay.

MEMBER MARCH-LEUBA: But I'm looking at this figure. You remember it, right?

MR. PALM: Yes. That's the one I was referring to.

MEMBER MARCH-LEUBA: Above five we're not predicting right. And in my view, because they're foreign plants, include North Korean reactors, you know? When we have your sample, we will know better. But right now we have to assume it's wrong.

CHAIR BALLINGER: Okay. We'll go around at the last, but we should now take public comments. So around the room, if there's anybody in the room that is a member of the public, or can claim that they're members of the public and would like to make a comment, please do so now.

Five-second rule; are you done? The public line is open, I think. Open? Is there anybody, any members of the public out there that would like to make a comment? If there are, please state your name and make your comment. I thought there were three or four people on there. I guess not.

Okay, can we close the public line then? And now let's go around the table and get final comments from members. I think we've kind of settled on, and Chris will negotiate the path going forward and everything. Walt?

MEMBER KIRCHNER: No further comments at this time. Thank you.

CHAIR BALLINGER: Pete?

MEMBER RICCARDELLA: You know, I've seen a lot of excellent work here by both the staff and EPRI, and it's clear that the current correlation isn't as good as it could be. But at the same time, I'm understanding that changing that could be a delicate licensing issue that we have to address carefully.

CHAIR BALLINGER: Mm-hmm. Joy?

MEMBER REMPE: I also appreciate presentations, and I think, well, I get some credit for pushing to make sure this happened and we get the funds early on. I'll look forward to what we do offer in November. Thank you.

MEMBER MARCH-LEUBA: I just want to emphasize two things I said before, yes, repeating myself. I often say I'm a car salesman; you have to do it over and over again.

The solution I see for the licensing burden is to impose a limitation on fluence and maybe chemistry. Like if you don't have potassium, or you have copper less than 0.12, you don't have to do anything, because the old correlation feeds perfect.

And if you are outside those limits, that box where the staff determines that the statistics are too inaccurate, then you have some time to evaluate what your plan looks like. We don't want to get a surprise that we're outside the limit when we get the new sample 10 years from now.

The second thing I wanted to emphasize

again is, I was extremely pleased by NUREG KM 0013, which makes a very systematic, logical way of generating data-driven models. And it has 25 logical questions; that tells you how to judge how well your correlation is, and I would encourage all of you to read it, because it makes the review of this data easy to do. It's logical; it's step-by-step; it's instructional.

With that, I thank you very much for your talk; it was very interesting on a topic I didn't know very much about.

CHAIR BALLINGER: Well --

MEMBER REMPE: Don't forget the guy in the sky.

CHAIR BALLINGER: Oh, the guy in the sky. Dave?

MEMBER PETTI: I don't have much to add to what others said. I mean, it's clear the correlation doesn't work -- so I think it's something we'll have the staff pursuing technically, so that they keep abreast of what's been going on out in this community.

One way requires a licensing change, but that's sort of a different discussion. But it's worth research staying abreast of all that.

CHAIR BALLINGER: Okay. Then I can take

what everybody else has said, and we've got a path forward that we're going to work on.

For the committee, I'd like to thank you guys and the staff and everybody for spending the time to put this together so that we can get an understanding of this.

We look forward to putting a lot of pressure on you in the future. So we are adjourned.

(Whereupon, the above-entitled matter went off the record at 4:17 p.m.)

Regulatory Guide 1.99, Rev. 2 Assessment Results

Dan Widrevitz

August 22, 2019

Introduction

- This presentation summarizes a multi-year effort to thoroughly assess RG1.99 through a modern data-driven approach.
- The assessment does not address licensing basis or policy decisions.
- Discussion of next-steps and regulatory implications is not part of this assessment.

Today's Presentation

- Regulatory Guide 1.99 Background
- RT_{NDT} results
- ΔUSE results
- Credibility Criteria/Plant-Specific Data results
- Attenuation results
- Common additions
- Conclusions
- Next Steps

Today's Presentation

- Assessment focused on RG1.99, Rev. 2, as applicable to operating and new reactors.

- Assessment was <u>not</u> focused on "solutions" or establishing regulatory positions.

Regulatory Guide 1.99 Background

"Radiation Embrittlement of Reactor Vessel Materials"

- Rev. 2 issued May, 1988
- Provides predictive curves supporting calculation of RT_{NDT} and USE*
- Provides methods to utilize plant-specific surveillance data including "credibility criteria"
- Provides through-wall neutron attenuation formula

RT_{NDT} – A measure of brittle-ductile transition temperature (considered equivalent to T_{41J});
USE – Upper Shelf Energy

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

Regulatory Guide 1.99 Background

Regulatory Analysis for RG1.99, Rev. 2 states,

There is, however, a strong probability that <u>revisions will continue to be made over the lifetime of the plants as more data are added</u> around the "fringes" of the data base: high nickel materials, low copper "modern" steels, and high fluence conditions encountered in plant life extension.

Regulatory Guide 1.99 Background

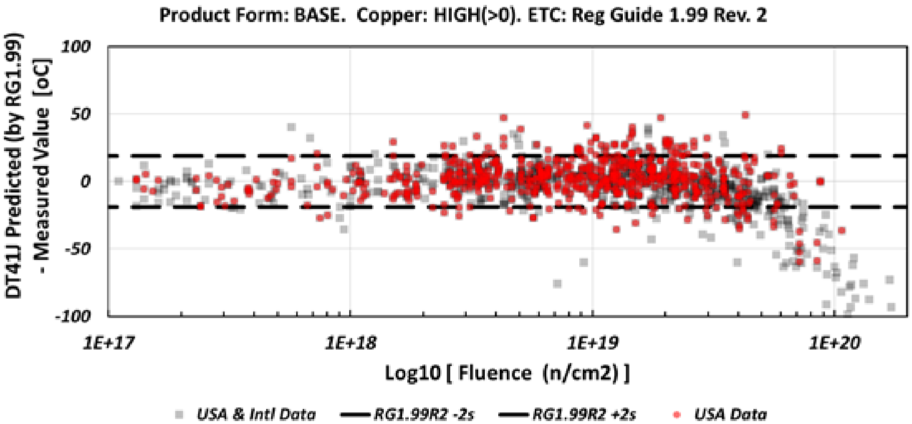
- RT_{NDT} curves fit to 177 datum. Curves are a mix of Guthrie and Odette results with "feathering" for low Cu regime.
- USE developed as upper-bound curves. Appear to have been "hand-drawn."
- Credibility criteria and use of surveillance data have no traceable underpinnings, "engineering judgment."
- Attenuation formula based on dpa studies.

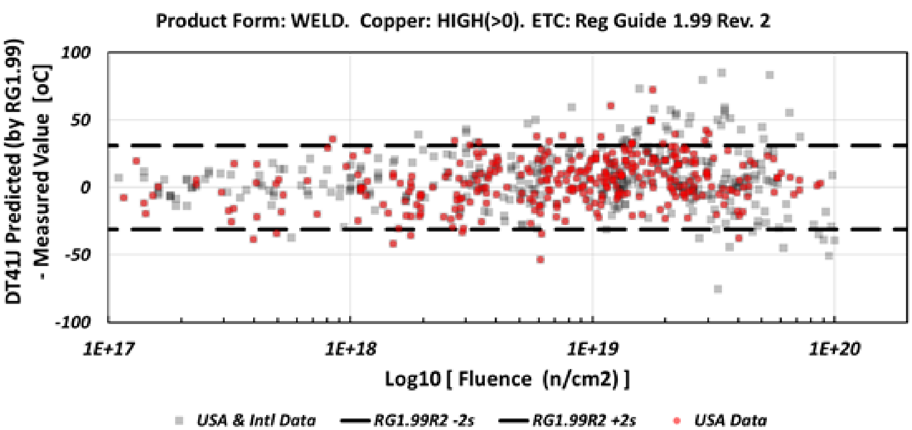
RT_{NDT} Results

Product Form	ΔT_{41J} Data	
	PWR	BWR
Weld	509	165
Plate	499	147
Forging	377	44
SRM*	153	7
Σ	1538	363

Assessment based on BASELINE dataset generated by ASTM E10.02. Dataset includes domestic and international power reactor data (~55% domestic).

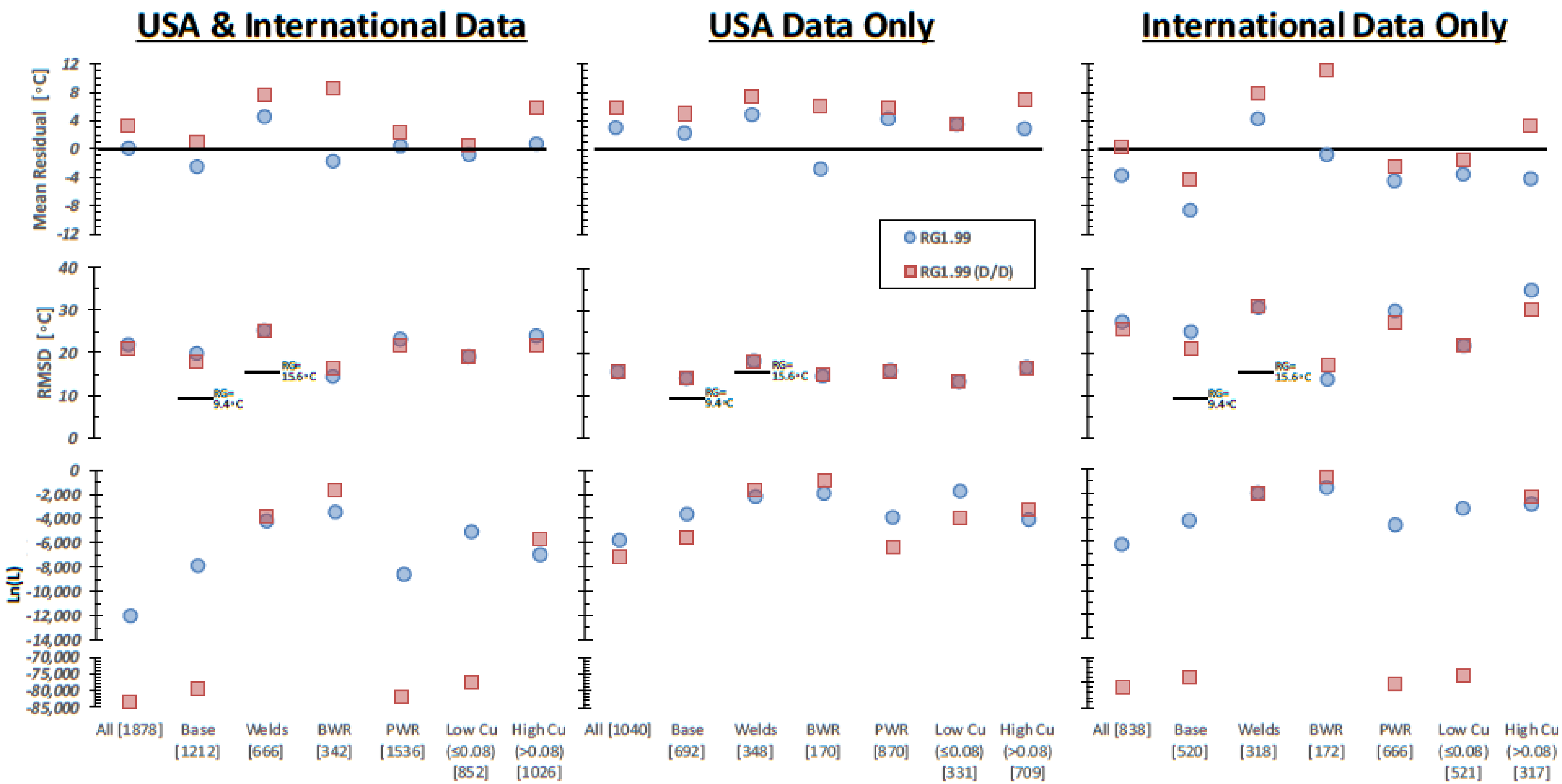
RT_{NDT} Results





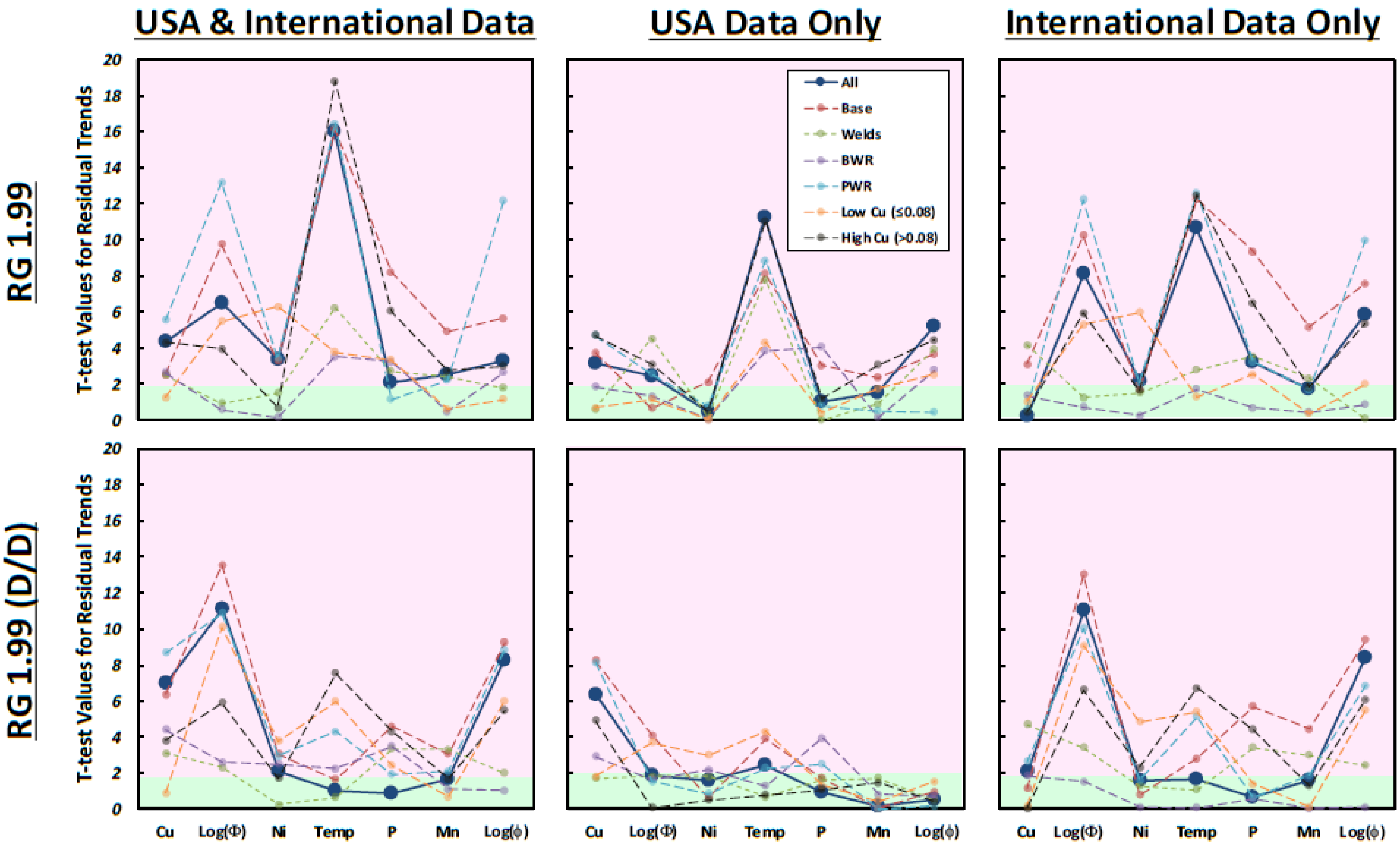
Limited weld data at high fluence precludes assessment of whether weld trends with base metals at high fluences.

RT_{NDT} Results



Good statistical behavior classically minimizes mean residual (bias), RMSD (bias and scatter), and maximizes ln(L) (commonly the log-likelihood; this means values closer to 0 are superior).

RT_{NDT} Results



For Student's T tests, a value of 1.96 indicates that 95% of the data falls within 1.96 standard deviations of the mean, which is conventionally considered an acceptable fit.

RT_{NDT} Results

Primary deficiencies:

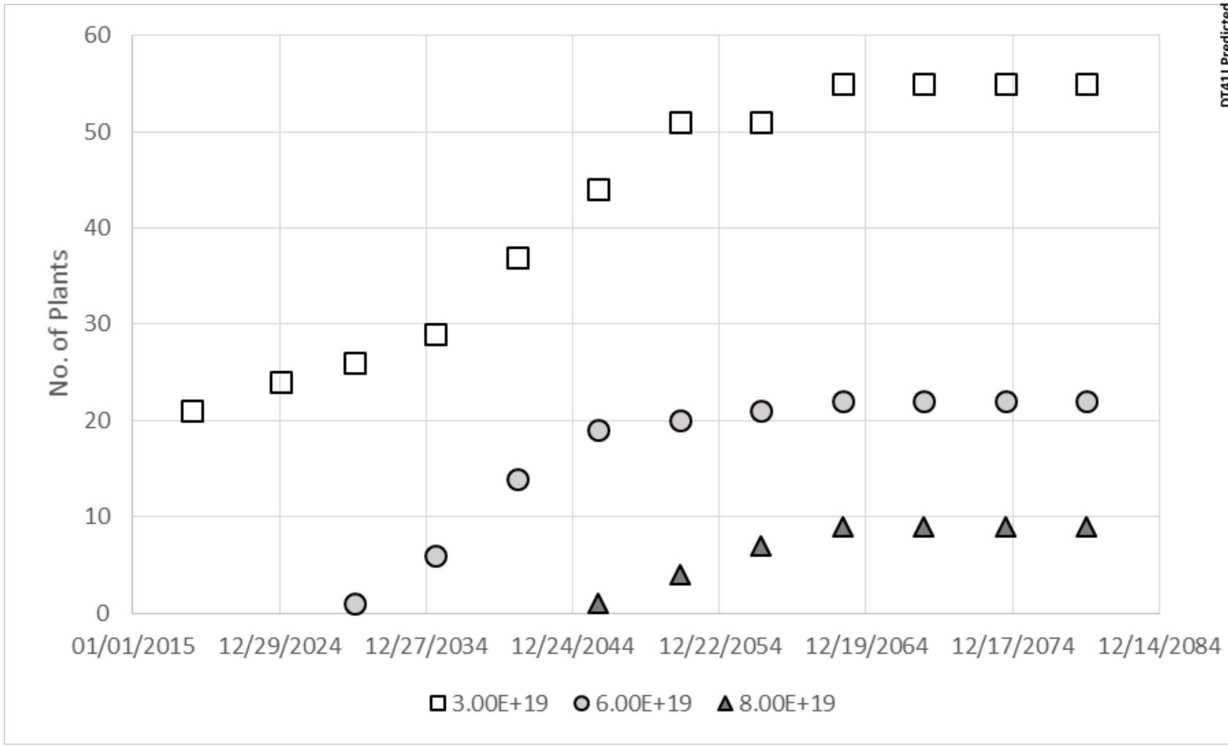
- Nonconservative high fluence results (base metals)*
- Inaccurate low Cu results

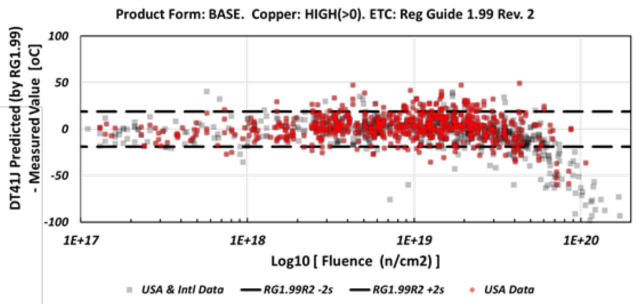
Secondary deficiencies:

- Too low stated standard deviation (margin term)
- Conservative bias in low-to-mid fluences (burden)
- Lack of temperature adjustment (inaccuracy)

*** Limited weld data available at fluences near or above $1x10^{20}$ n/cm^2 (E > 1MeV)**

RT_{NDT} Results





Total Number of Reactors > $3x10^{19}$ n/cm^2		
40 Year	60 Year	80 Year
19	41	55

Total Number of Reactors > $6x10^{19}$ n/cm^2		
40 Year	60 Year	80 Year
0	5	22

Peak ID fluences estimated from BWRVIP and MRP reports – not verified recent licensing basis values. Values represent capsule fluences "approximately" at EOL and EOLE values.

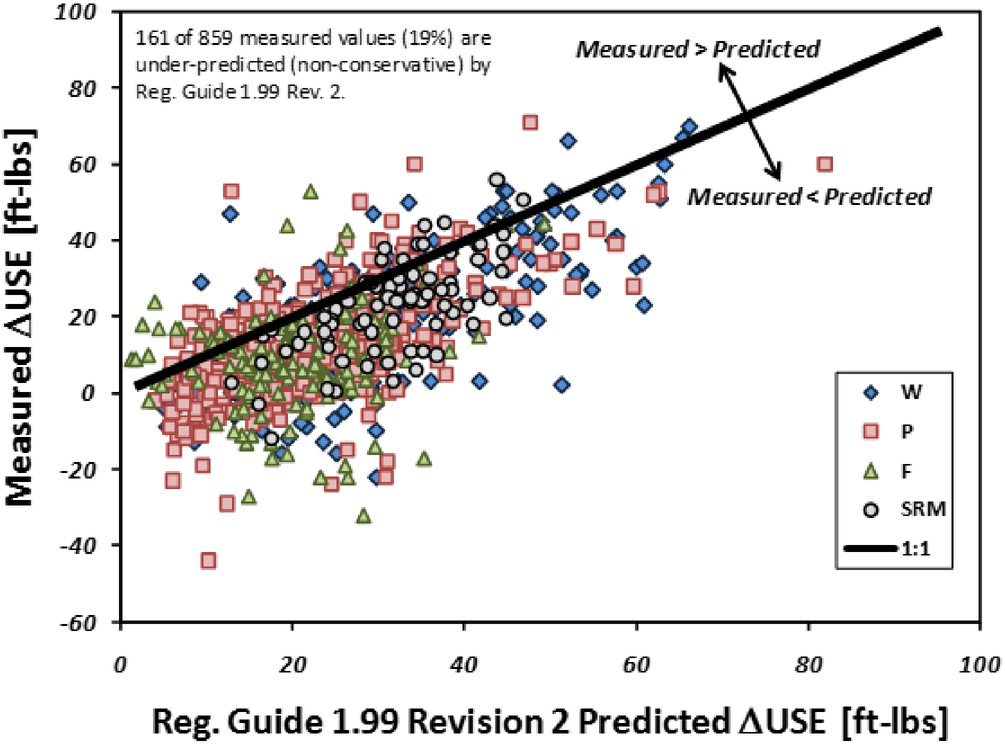
ΔUSE Results

	USA & International Surveillance	Just USA Surveillance	Just International Surveillance
All	1,223	1,016	207
Weld	399	329	70
Base	824	687	137
PWR	1,068	861	207
BWR	155	155	0
Low Cu (≤ 0.08)	495	328	167
High Cu (> 0.08)	728	688	40

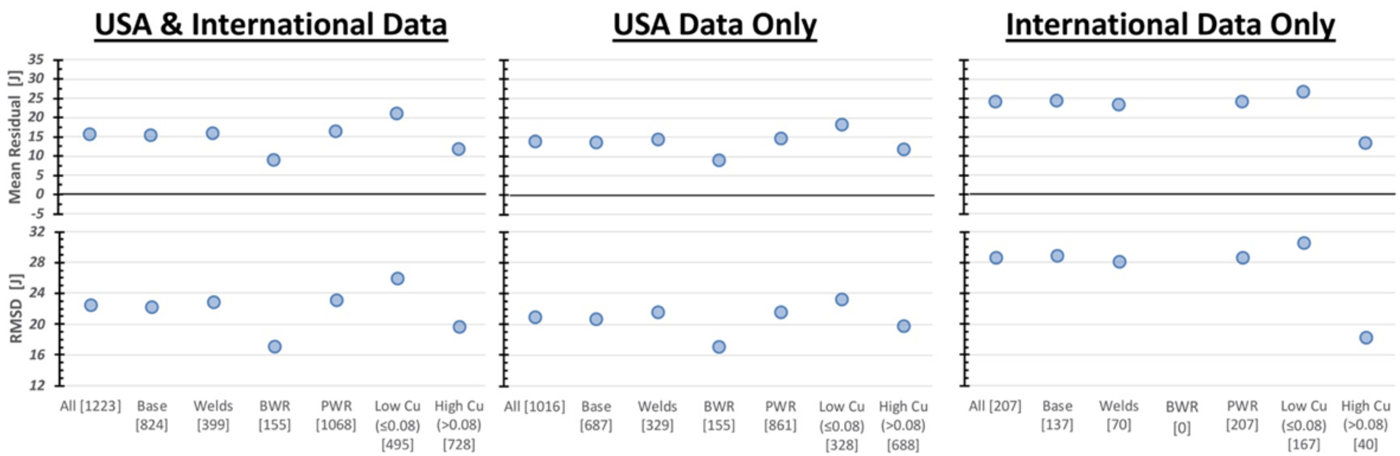
Assessment based on REAP dataset merged with properties from BASELINE. Dataset includes domestic and international power reactor data.

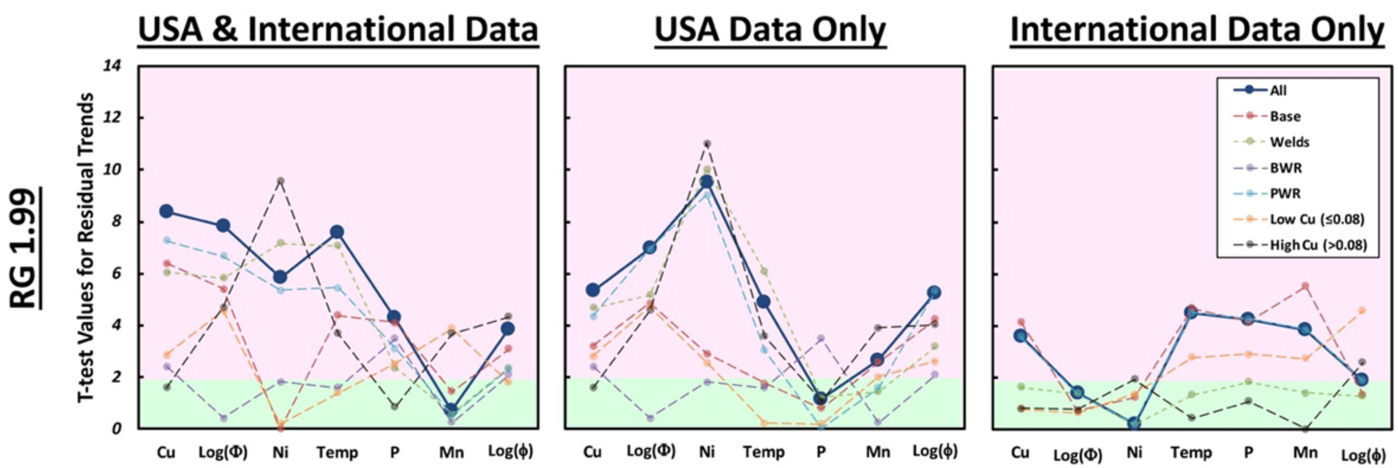
REAP includes data up to ~5-7 years ago.

ΔUSE Results



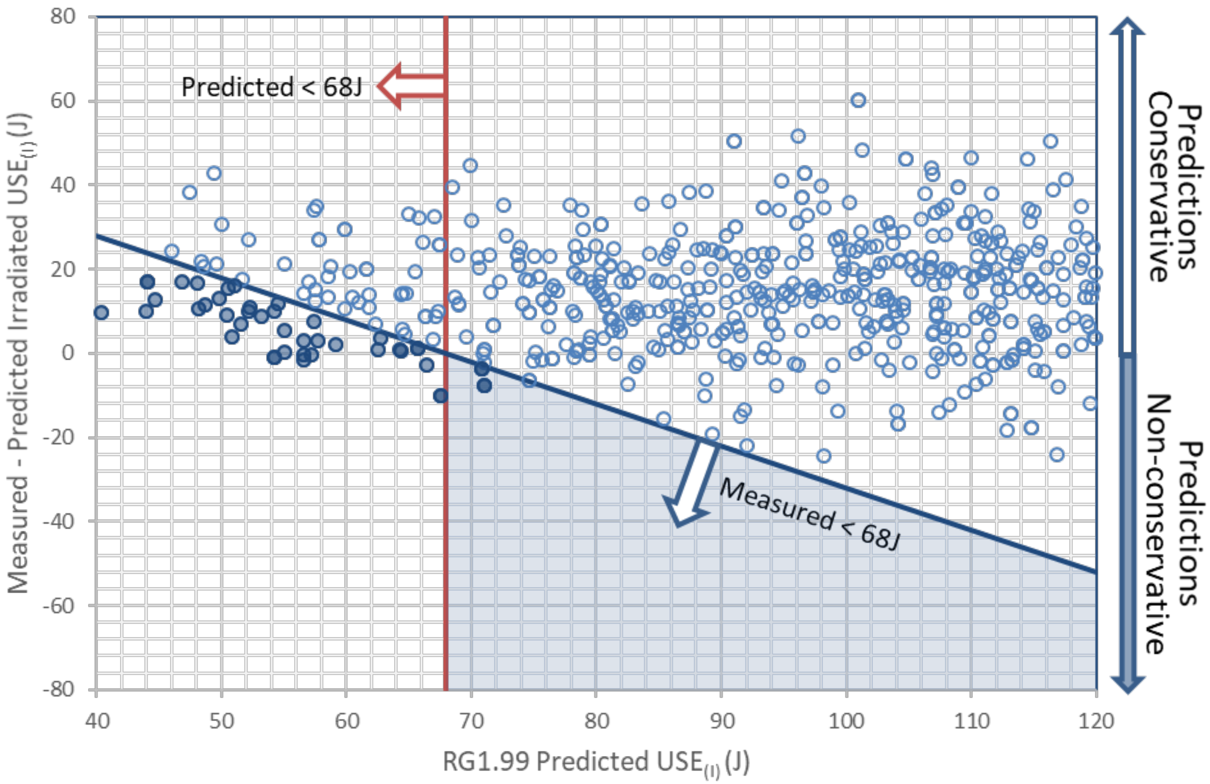
ΔUSE Results





RG1.99 USE estimate was designed to be bounding, hence positive mean residual and RMSD is to be expected.

ΔUSE Results



50 ft-lb = 68J

EMA – Equivalent margin analysis.
Limited number of materials are likely to be measured below 68J (50 ft-lbs) but not have been subject of an EMA.

ΔUSE Results

Primary deficiencies:

- Limited number of materials are misprojected to remain above 50 ft-lb and not trigger EMAs*
- ΔUSE predictions are not bounding as originally designed

Minimal impact – the safety criteria supported by USE estimation (50 ft-lb) is known to be extremely conservative.

To date no material has failed to be justified by EMA; including many well below 68J.

Credibility Criteria

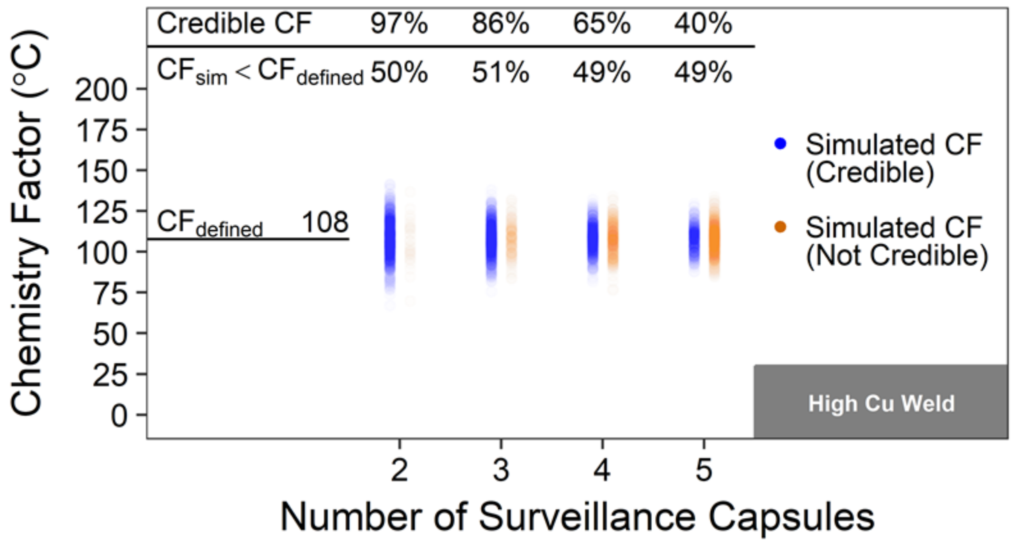
- Vague criteria open to interpretation.
- If data is not deemed credible, data is not considered.
- Criteria compare measured data to refit (chemistry factor) RG1.99 prediction results with a requirement of shape-function of RG1.99

Credibility Criteria

- Staff presentation, Wichman 1998, provided staff perspective on implementation of vague credibility criteria.
- This included that a single outlier does not invalidate a dataset.

Credibility Criteria

More data -> higher likelihood of being deemed non-credible.



* Simulated materials have material and statistical properties as described in RG1.99, Rev. 2. Simulation rejects data for single outlier.

Credibility Criteria

Critical consequence: benefit of fitting predictions to surveillance data is nullified by credibility criteria that reject data not conforming to the shape-function of RG1.99

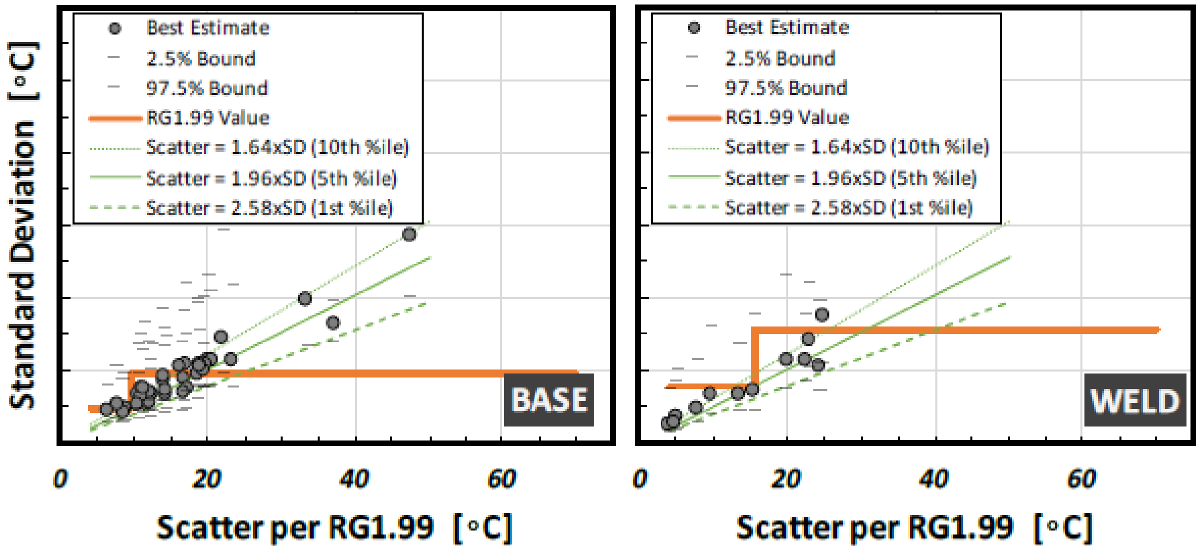
High fluence and low Cu data not expected to conform to shape function of RG1.99.

Credibility Criteria – Credible Data

If surveillance data is deemed credible, RG1.99 allows reduction in margin term.

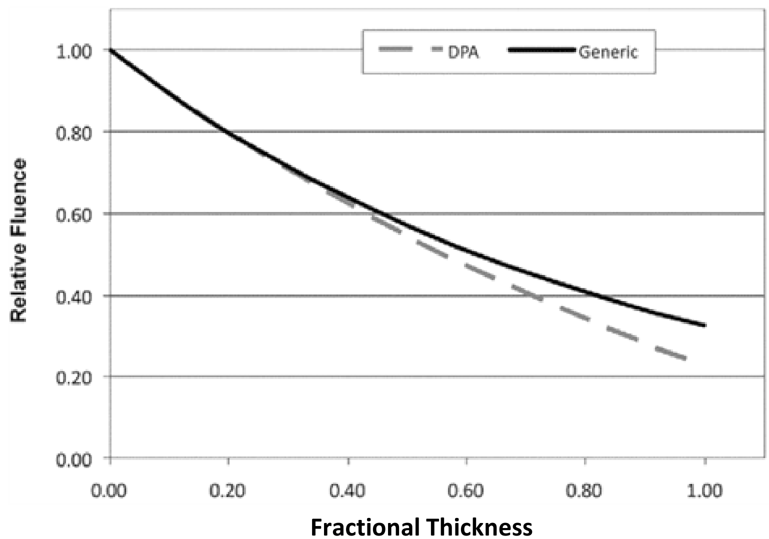
No apparent statistical basis.

Does appear to "work" with data.

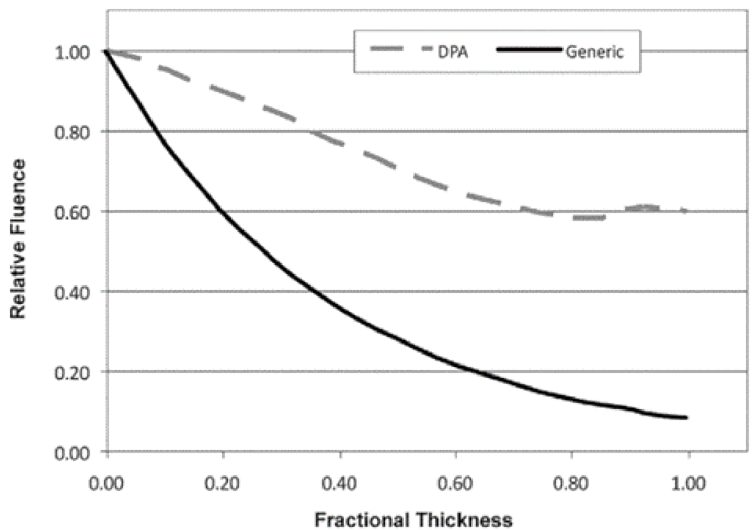


Attenuation Formula

Attenuation formula matches well to modern results. Formula *only works* for areas horizontally adjacent to the active fuel.



Geometric Beltline



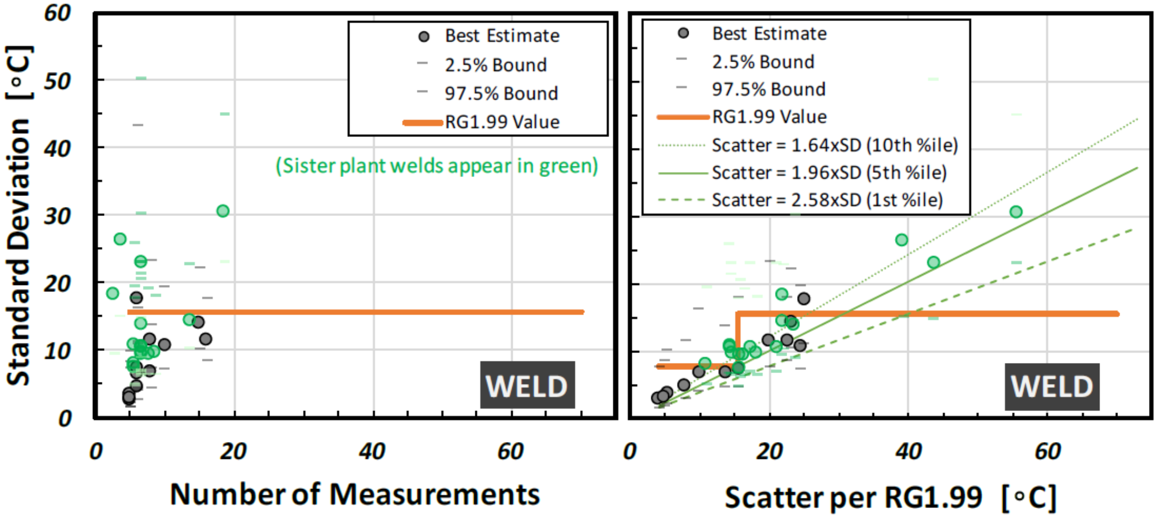
Above Core

Jones, E. N., "Comparison of Regulatory Guide 1.99 Fluence Attenuation Methods," Journal of ASTM International, Vol. 9, No. 4, 2012, pp. 1-7.

Common Addition – Sister Plant

Data from “sister plants” may be adjusted for temperature and used as plant-specific data.

Appears to increase SD relative to plant-specific data.



Using sister plant data is covered in Wichman presentation (ML110070570)

Conclusions

Primary Deficiencies:

- High fluence RT_{NDT} predictions
- Credibility criteria performance
- Embrittlement trend curve shape function

Additional Deficiencies:

- Gaps currently filled by Wichman 1998 presentation*
- Statistical treatment (standard deviation, etc.)

* Implementation of credibility criteria, degree-per-degree adjustment, etc.

Conclusions

- Deficiencies exist in every aspect of the RG.
- Deficiencies become concerning for high fluence PWRs beginning in the late 2020s.

Next Steps

Working group stood up to address:

- Licensing basis impacts
- Potential solutions

EPRI Review of TLR-RES/DE/CIB-2019-2, *Assessment of the Continued Adequacy of Revision 2 of Regulatory Guide 1.99*

Tim Hardin
Technical Executive

Meeting of the ACRS Subcommittee on Metallurgy & Reactor Fuels

August 22, 2019
Rockville, MD

www.epri.com

Contents

- Introduction
- Embrittlement Shift ΔT_{41J} ($\Delta T_{30\ ft\text{-}lb}$) Trend Curve
- Charpy Upper-Shelf Energy Decrease (ΔUSE) Trend Curve
- Credibility Criteria and Use of Credible Surveillance Data
- Neutron Fluence Attenuation
- Common Additions to RG1.99
- Comments about Implementation of Possible Future Revisions to RG1.99
- EPRI Comments on TLR's *Conclusions and Recommendations*

Introduction

- As requested by NRC, EPRI staff have reviewed TLR-RES/DE/CIB-2019-2 (hereafter, "TLR")
- The EPRI staff contributing to the review have extensive cumulative experience in:
  - Evaluation of the effects of neutron embrittlement and other degradation mechanisms on reactor pressure vessels (RPV) steels
  - Design and/or analysis of RPV material surveillance programs, and
  - Generation of pressure-temperature limits, pressurized thermal shock (PTS) evaluations, upper shelf energy (USE) evaluations and equivalent margins analyses (EMAs)
- This presentation offers the professional opinions of EPRI staff ***only*** and does <u>not</u> represent an Industry position of the US utilities

Embrittlement Shift ΔT_{41J} ($\Delta T_{30\ ft\text{-}lb}$) Trend Curve

EPRI Comments on ΔT_{41J} Trend Curve Analysis

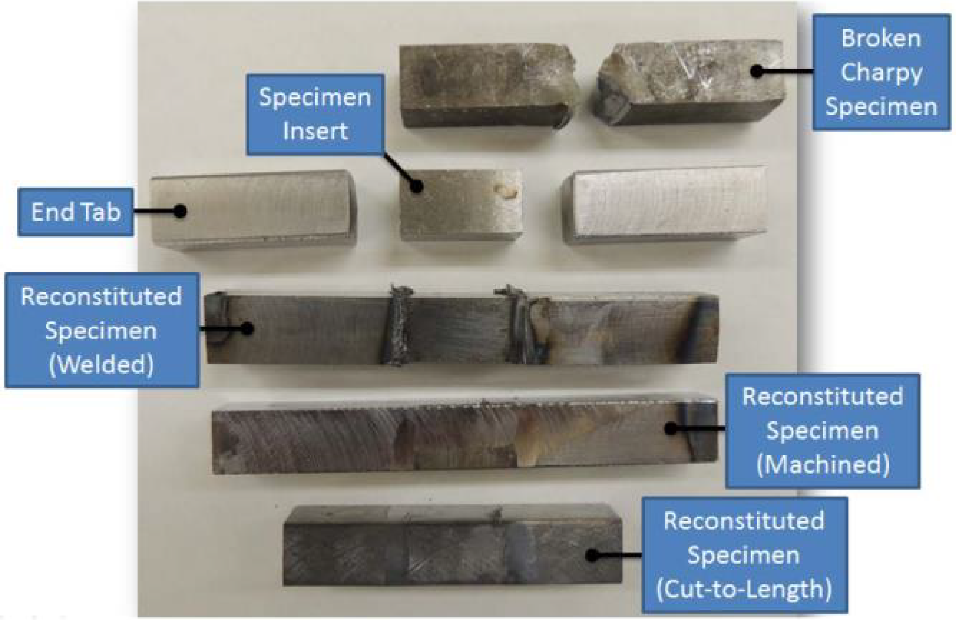
- Section 2.3 of the TLR assesses the residuals for RG1.99 ΔT_{41J} predictions relative to actual surveillance data
  - "Residual" = Predicted - Measured
- The information is largely consistent with evaluations performed by EPRI Materials Reliability Program (MRP) in ~2010-2013 to support development of industry programs to increase the amount of high-fluence surveillance data to inform future embrittlement trend correlations (ETCs)
- In the following slides, we will briefly describe the MRP programs and then discuss the evaluations of RG1.99R2 and other embrittlement trend correlations (ETCs) that were conducted as part of those programs

EPRI Comments on ΔT41J Trend Curve

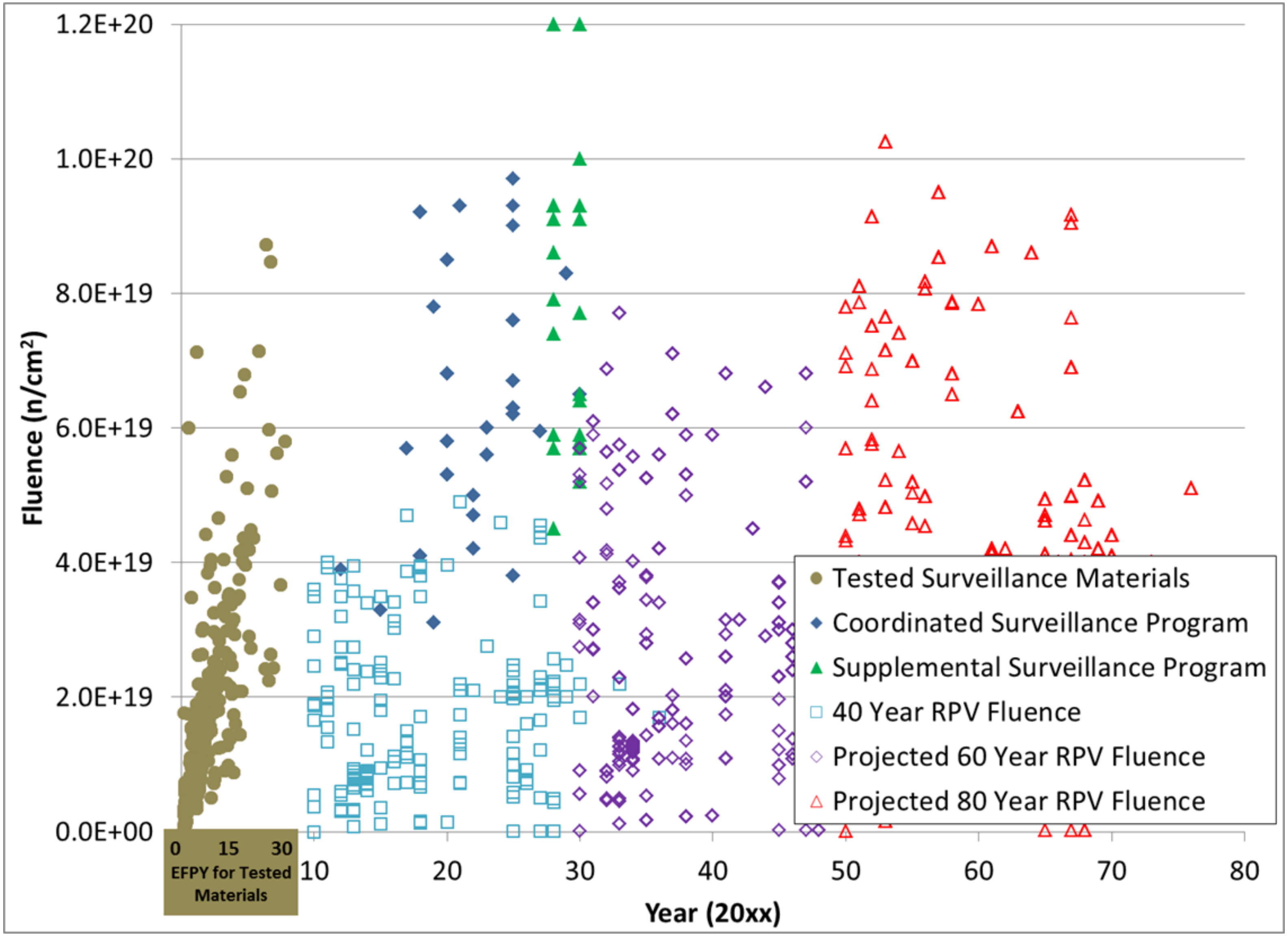
- The TLR cites two MRP programs that have been developed in the last 10 years to address a concern regarding the paucity of high-fluence PWR data sufficient to inform development of embrittlement prediction models applicable for 80 years:
  - Coordinated Reactor Vessel Surveillance Program (CRVSP) (MRP-326)
  - PWR Supplemental Surveillance Program (PSSP)
- The CRVSP was a program developed by MRP in 2011
  - All PWR surveillance capsules scheduled for future withdrawal were reviewed
  - For selected capsules, deferral of withdrawal was recommended in order to increase fluence while maintaining compliance with 10 CFR 50 Appendix H and E185-82
  - The program was successfully implemented; however, numerous high-fluence surveillance gaps were predicted to remain
  - To address the remaining gaps, MRP developed the PSSP

PWR Supplemental Surveillance Program (PSSP)

- The PSSP is a research project to design, fabricate and further irradiate two supplemental surveillance capsules containing previously-irradiated PWR materials
  - Previously-irradiated and tested Charpy V-notch specimen halves were reconstituted (per ASTM E1253-13)
  - These specimens are being re-irradiated for ~10 years, adding ~3.5 E+19 n/cm^2) to each material's previous fluence
  - The PSSP will obtain high fluence toughness data on 27 unique RPV materials
  - The capsules were inserted in Farley 1 (2016) and Shearon Harris (2018) and will be withdrawn and tested in 2027/2028
    - Use of 2 plants permits data collection at 2 irradiation temperatures



Future Availability of High-Fluence Surveillance Data Relative to RPV Material Predicted Fluence in Time



Updated figure by J. Brian Hall, WEC

Material Selection Process for the PSSP

- To select specific materials for the PSSP capsules:
  - All U.S. RPV surveillance materials were grouped according to product form: plates, forgings, and welds. Those groups were then further sub-divided according to chemistry (e.g., high-Cu, Low-Cu, high-Ni, low-Ni, etc.)
  - Each material group was then evaluated to determine whether materials from that group should be included in the PSSP
    - One metric was how well various ETCs predicted the embrittlement of the data for each group
    - Poorly-predicted groups were given higher priority for inclusion of those materials in the PSSP
  - The results are documented in MRP-364 (not publicly available) and PVP2013-97039 (available)

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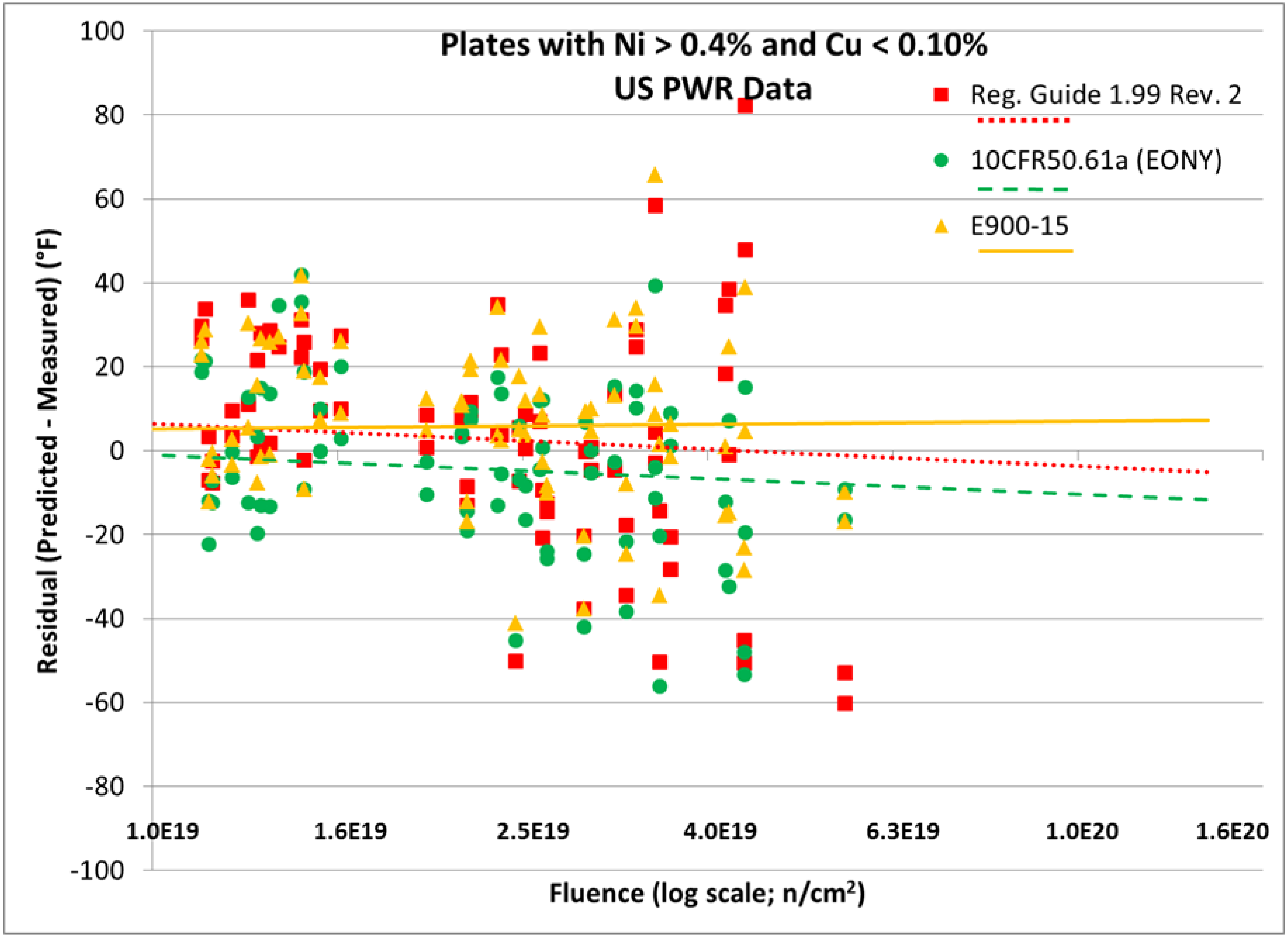
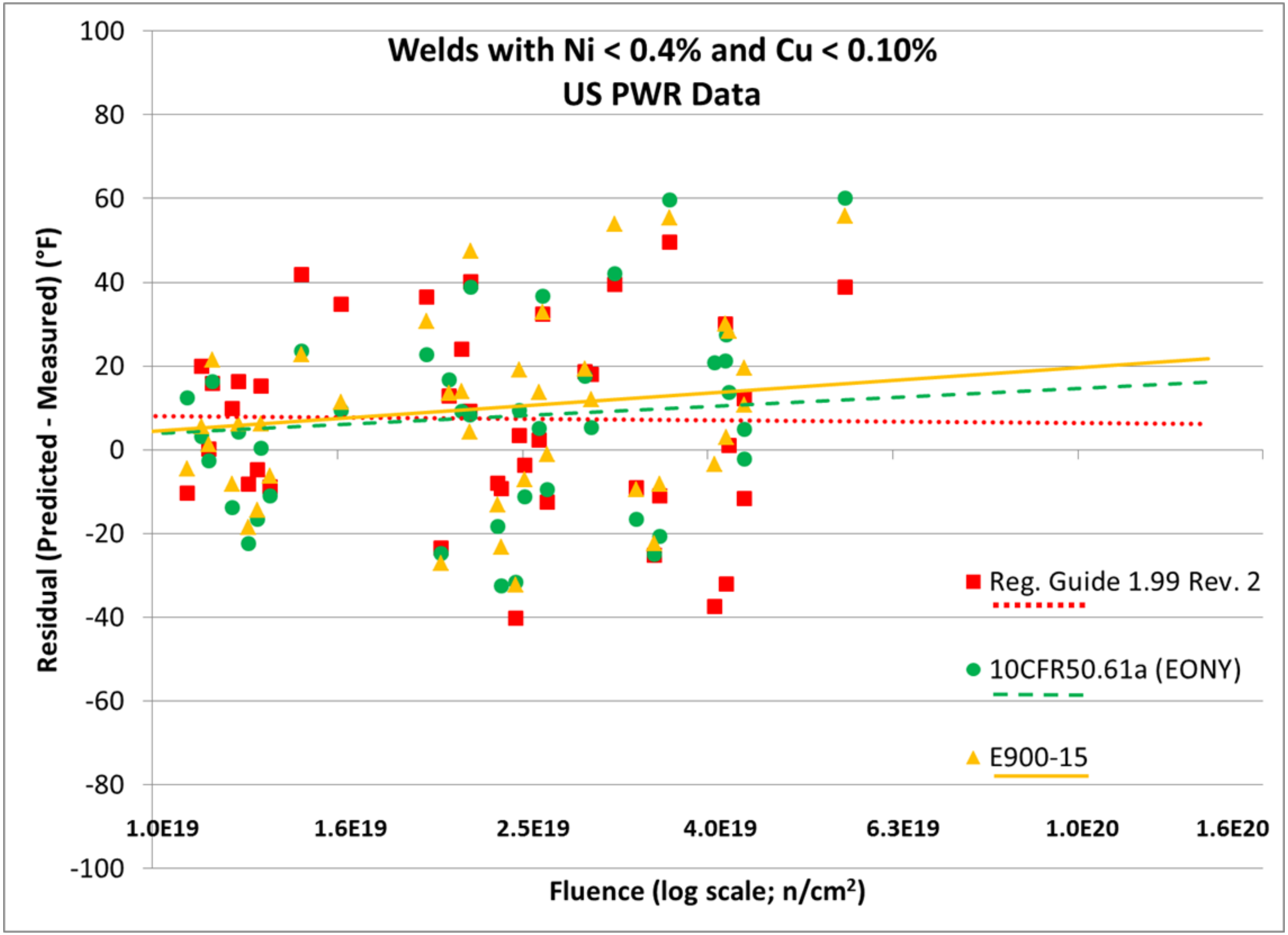
Existing U.S. Power Reactor Surveillance Data

- U.S. PWR surveillance database (as of ~2012) was compared with common prediction models
  - Regulatory Guide 1.99, Rev. 2 [177 surveillance data values were used to develop this 1980s model]
  - EONY [based on approximately 750 power reactor surveillance data values from about fourteen years ago] – as used in Alternate PTS Rule (10 CFR 50.61a)
  - WR-C(5), Rev. 1 – see Kirk, ASTM STP-1547 (2013)
  - More recently, ASTM E900-15 [which is based on an extensive world-wide power reactor database] was assessed for a few material groups, after its adoption
- Selected plots are shown in the following slides as examples
  - The data used here only includes US PWR irradiations
  - No model alloys
  - No Standard Reference Materials (SRMs)
  - Only 41J (30 ft-lb) index temperature shift measurements

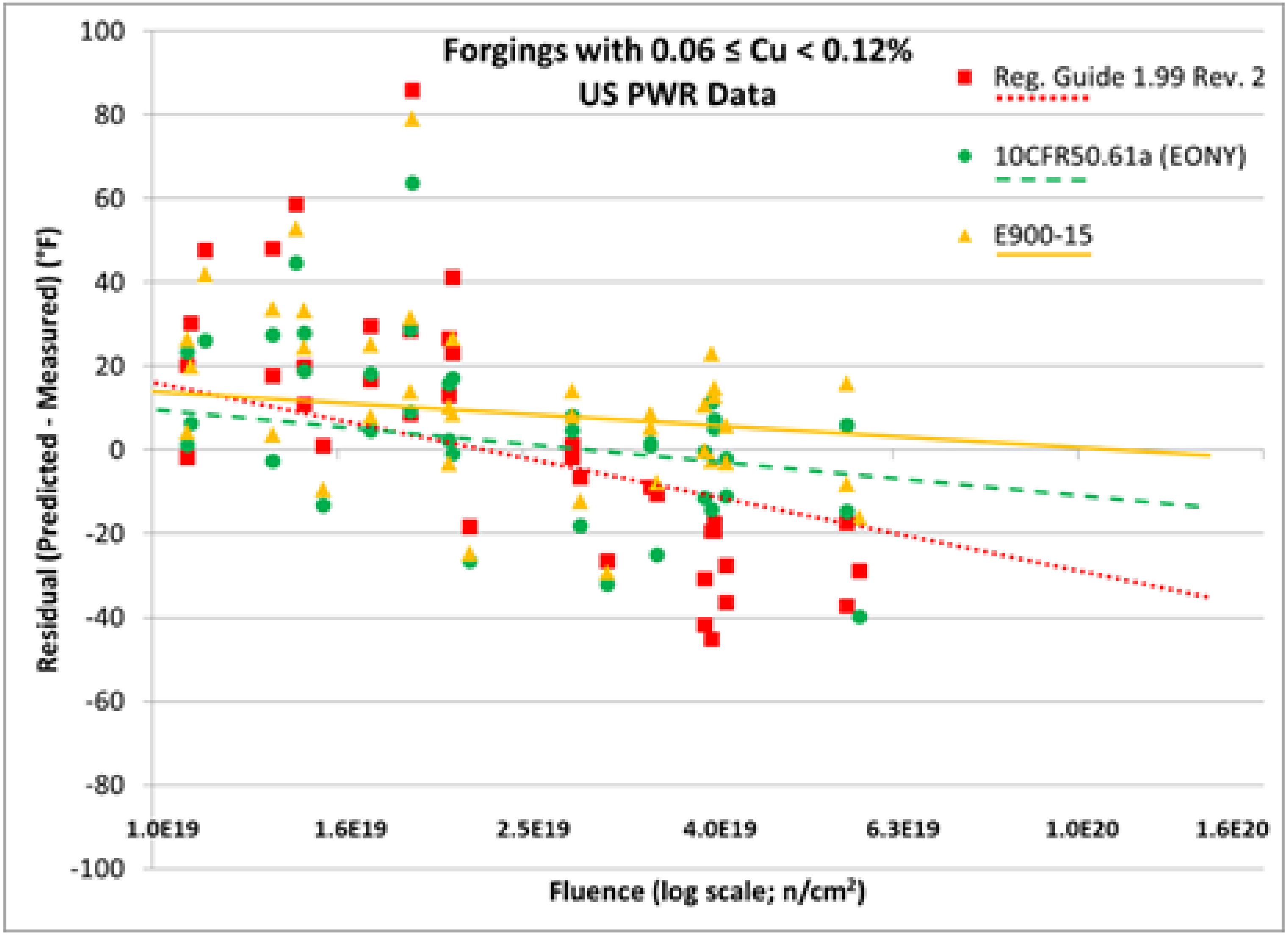
Example – Comparison of ETCs for Low Cu / Ni-added Plates



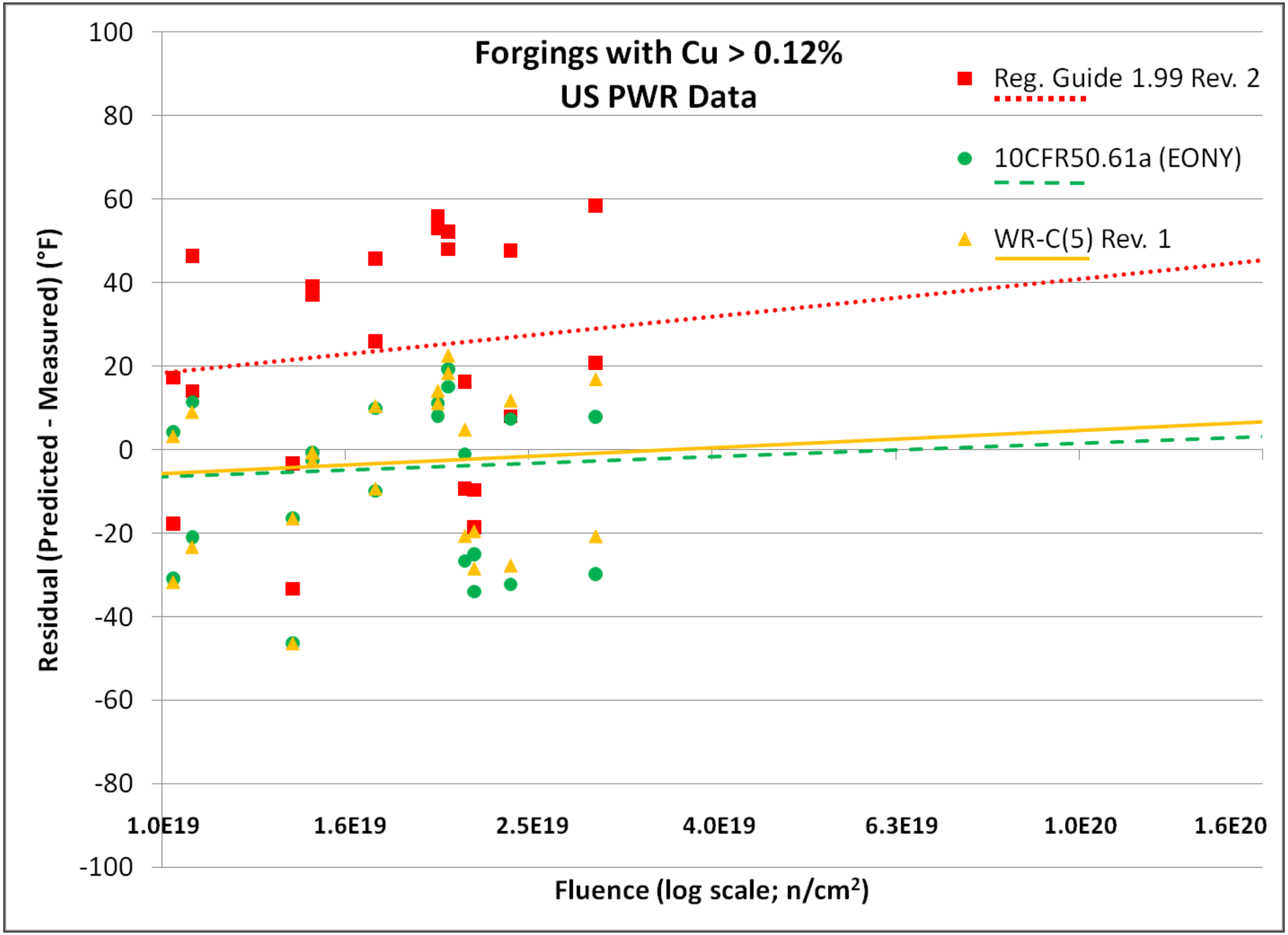
Example – Comparison of ETCs for Low-Cu, Low-Ni Welds



Example – Comparison of ETCs for Medium Cu Forgings



Example – Comparison of ETCs for High Cu Forgings



Summary of MRP Analyses of Surveillance Data vs. ETCs

- In 2013, MRP assessed the residuals for U.S. PWR surveillance data compared to several ETCs
- The objective was to inform selection of materials for inclusion in the PSSP capsules
- The mean trends vary significantly as a function of product form and chemistry
- Overall, scatter in the RG1.99R2 residuals increases significantly with increasing fluence

Form/Ni Division	Cu Group	RG 1.99, Rev. 2 Fit	EONY Fit
Plates SA-302BM, SA-533B1	< 0.10	O/U	–
	0.10–0.17	– /U	–
	> 0.17	–	U
Plates SA-302B	All	–	–
Forgings SA-508	< 0.06	–/U	–/U
	0.06–0.12	O/U	–
	> 0.12	O	–
Welds Ni > 0.4%	< 0.10	O	O
	0.10–0.23	–	–
	>0.23	O	–
Welds Ni < 0.4%	< 0.10	–	–
	0.10–0.23	O/–	O
	>0.23	O	–

O = Overpredicts; U = Under-predicts;
"–" = Reasonable prediction (>1E19 n/cm^2)
"/" indicates a difference <3E19 n/cm^2 versus >3E19 n/cm^2

Comments on TLR Section 2 (1 of 2)

- Section 2.5 of the TLR states, "Not all plants use the RG1.99 ΔT_{41J} trend curve directly as many supplement it with surveillance data or other adjustments such as degree-per-degree. For these plants, deficiencies in the trend curve are not expected to correlate directly to potential deficiencies in licensing bases."
- EPRI Comment #1:
  - This statement understates use of RG1.99R2 in the fleet. **All plants use RG1.99 directly for** any materials where surveillance data does not exist – which, for any given RPV, are ***most of the RPV materials***

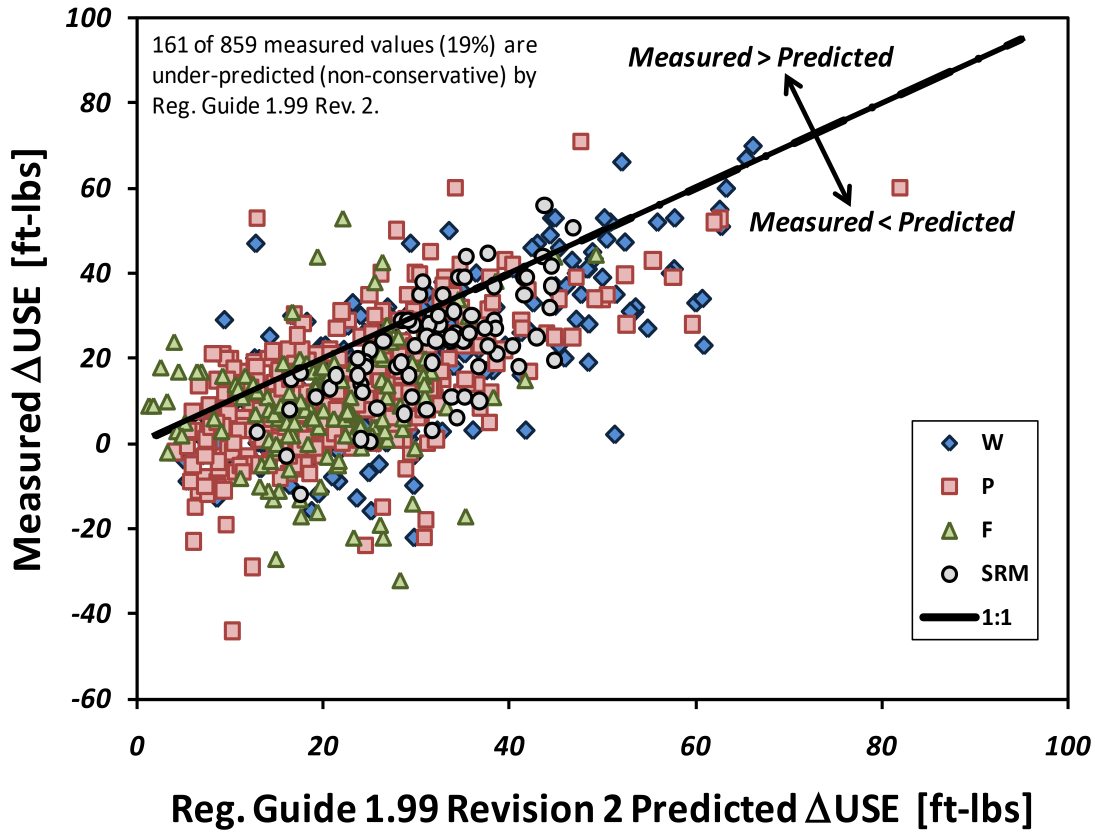
Comments on TLR Section 2 (2 of 2)

- EPRI Comment #2: Currently, to apply weld surveillance data for evaluation of vessel welds (matching heats) when the chemistry of the surveillance and vessel welds differ, the Chemistry Factor (CF) from RG1.99R2 Table 1 is used in a ratio procedure. If a new approach is adopted that no longer defines/uses a Chemistry Factor (CF), it will be necessary to develop alternate guidance for adjusting shift (ΔT_{41J}) to account for chemistry differences
- EPRI Comment #3: The TLR references the Wickman-Hiser-Mitchell slides (1998) but does not mention that the same guidance (in summary form) is also documented in NUREG-1511, Supplement 2, Section 2.3

Charpy Upper-Shelf Energy Decrease (ΔUSE) Trend Curve

NRC Research USE Prediction Method

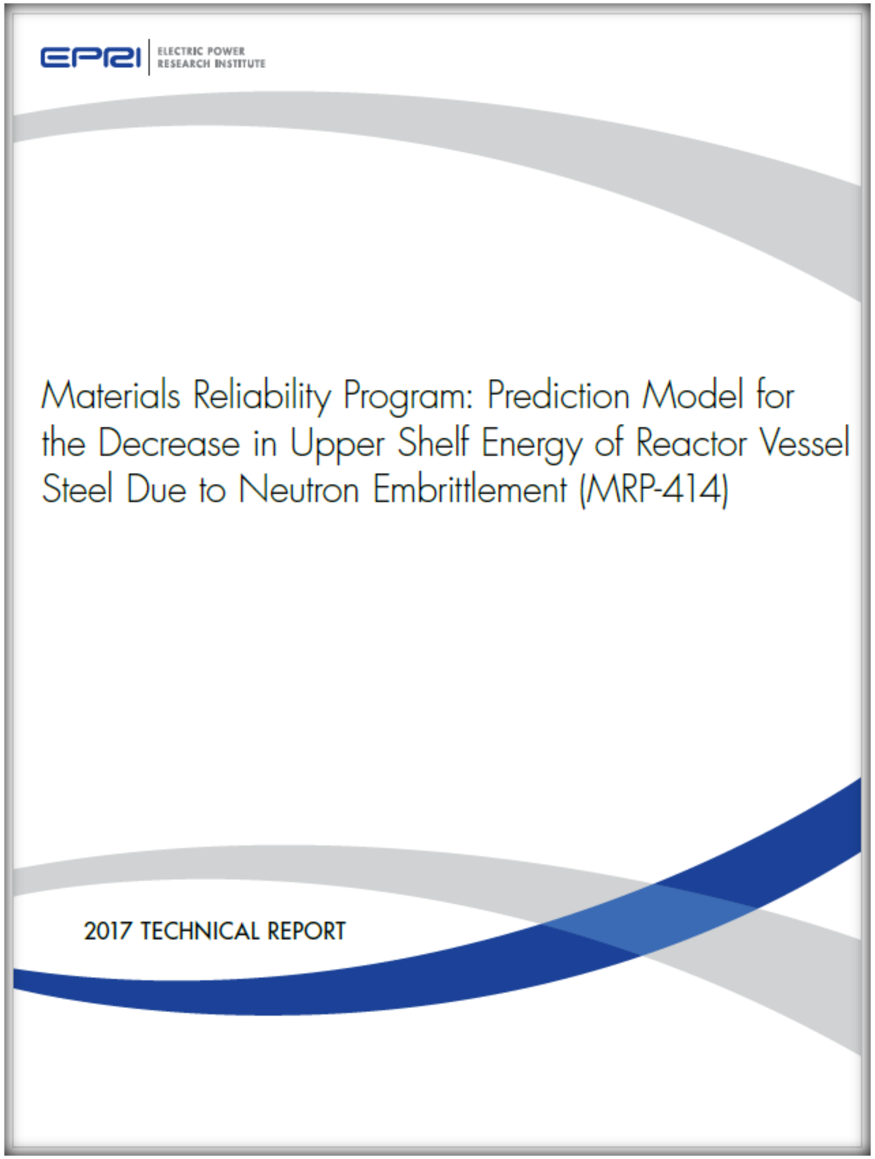
- According to NRC analysis of surveillance data, 19% of data are under-predicted by current RG1.99R2 prediction method for USE decrease
  - Only a 1.3σ bound
- NRC Research developed a new prediction method "UNM-6" to achieve 2σ bound [Kirk 2010, referenced in the TLR]
- MRP was concerned that the new method [Kirk 2010] may unfairly penalize non-Linde 80 weld materials and cause significantly more materials to fall below a USE of 68J (50 ft-lbs)



Source of figure: Kirk, USNRC

MRP Project for USE

- In 2016, MRP conducted a research project to develop an updated prediction method for USE decrease
- Final report was published in July 2017:
  - *Materials Reliability Program: Prediction Model for the Decrease in Upper Shelf Energy of Reactor Vessel Steel Due to Neutron Embrittlement (MRP-414).* EPRI, Palo Alto, CA: 2017. 3002010330.
    - Not yet publicly available
  - Also presented in PVP2017-65317 (publicly available)


EPRI ELECTRIC POWER RESEARCH INSTITUTE

Materials Reliability Program: Prediction Model for the Decrease in Upper Shelf Energy of Reactor Vessel Steel Due to Neutron Embrittlement (MRP-414)

2017 TECHNICAL REPORT

Overview of MRP USE Prediction Model Project

- An extensive USE database was assembled
  - >1500 irradiated material USE change measurements (LWR surveillance data only) from US, Korea, Germany, Brazil, Spain, Mexico, Sweden, France
    - After screening, 1,177 data used for modeling
- Two types of best-estimate fit models were investigated
  - One using transition temperature shift (TTS – e.g., ΔT_{41J}) predicted by ASTM E900-15 as the primary input parameter
  - One type not using TTS
- To reduce complexity, MRP-414 recommended the model that did not use the E900-15 TTS as a primary input parameter

Results from MRP-414 USE Prediction Model

- MRP assessed the impact of the model recommended in MRP-414 on the operating PWR fleet
  - USE at the end-of-license for 60 & 80 years operation was estimated for 65 PWR plants
  - The impact on the number of operating US PWRs which have a decrease in USE below 50 ft-lbs (30 PWRs, 92 material heats) is similar to RG1.99R2 (30 PWRs, 82 material heats) and less than the UNM-6 model previously published by NRC Research
- MRP-414 provides an USE prediction model that bounds 2σ of the data but has negligible increase on the total number of plants that will need to perform an EMA (as compared to RG1.99R2)
- EPRI Comment #4: If NRC pursues revision of the RG1.99R2 USE decrease prediction model, we recommend NRC consider the work that was performed in MRP-414 / PVP2017-65317

Additional Comments on Section 3 of the TLR (1 of 2)

- Section 3.5 states: "The RG1.99 predictions of ΔUSE contain conservative bias, significant uncertainty, and significant residuals relative to input variables. The impact on the operating fleet and new reactors that may be constructed is unclear as two acceptance paths exist (i.e., maintaining USE greater than 68J [50 ft-lbs] during licensed operation, or conducting an EMA). Further work is needed to evaluate the regulatory significance of the current 68J criteria and to determine if it should be retained, modified, or eliminated."
- EPRI Comment #5: Generally agree, but we note that the requirement for minimum USE is established in 10CFR50 Appendix G, not RG1.99R2. Therefore, the last two options ("modified, or eliminated") imply a recommendation for rulemaking for revision of 10 CFR 50 Appendix G
  - We request clarification regarding NRC intent for revision of Appendix G

Additional Comments on Section 3 of the TLR (2 of 2)

- In Section 3.4 “Fleet Impact” [of USE trend curve evaluation], the TLR states:
  - “For this assessment, a preliminary estimate of the number of reactors that may fail the 68J (50 ft-lbs) criterion if measured but are not predicted to do so was conducted. Seven reactors were identified [using a modern trend curve, “Kirk2010”] (a further four reactors identified plan to cease operation imminently as of 2019). Of these, three had implemented equivalent margins analyses. The remaining four all had approved USE calculations from license renewal applications with staff verifying their calculations. These plants warrant further review.” [*emphasis added*]
- EPRI Comment #6: This statement/conclusion should be clarified or revised. It implies an inadequacy in the existing USE calculations and could be interpreted as a regulatory challenge questioning plant licensing bases
  - As acknowledged in the TLR, the USE calculations for those plants are based on current regulations and existing NRC guidance for the evaluation of USE
  - Therefore, until NRC revises its guidance, the TLR lacks a technical justification for questioning the licensing basis or recommending “further review” of plants that have approved USE calculations – especially when verified by NRC staff

Credibility Criteria and Use of Credible Surveillance Data

Credibility Criteria and Use of Credible Surveillance Data

- TLR Section 4.1 (page 21) states the following:
  - "Should the data be deemed non-credible, the user is directed to discard the chemistry factor refit losing what may be a superior data-based fit of the RG1.99 trend curve."
- EPRI Comment #7: While this statement is consistent with the RG as written, it is not consistent with how NRC has *implemented* the guidance
  - If a fitted CF has been calculated from the non-credible surveillance data and it is ***higher*** than the table-based CF from the RG, the NRC has required the higher CF to be used for calculation of Adjusted Reference Temperature (ART) or RT_{PTS}. Furthermore, in that case the NRC has required the ***full*** margin term to be used
  - This is specifically documented as Case 3 of the Wickman-Hiser-Mitchell slides (e.g., "*Noncredible surveillance data from the plant to be evaluated and Table CF is nonconservative*")

Neutron Fluence Attenuation

Attenuation of Neutron Embrittlement in Cylindrical Shell

- MRP has sponsored testing on the subject of attenuation:
  - *Materials Reliability Program: Static Tensile Testing of a Pressure Vessel Steel Irradiated to Assess Through-Wall Attenuation of Radiation Embrittlement (MRP-333).* EPRI, Palo Alto, CA: 2012. 1024798. (publicly available)
  - Also: MRP-203, MRP-243, and MRP-277 (publicly available)
  - The paper referenced in the TLR ("Server 2010") is a summary based on the MRP reports listed above
- This research supported the conclusions of the TLR regarding attenuation

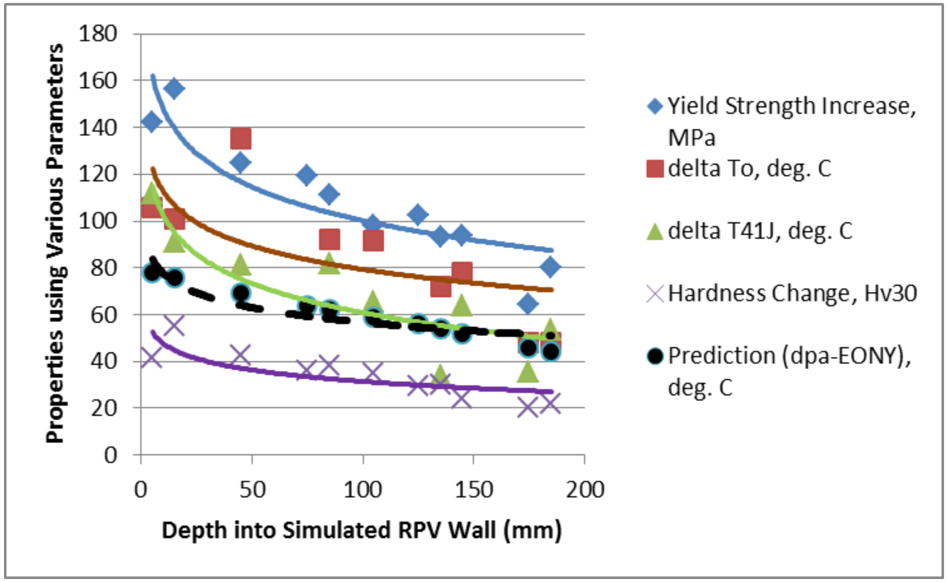
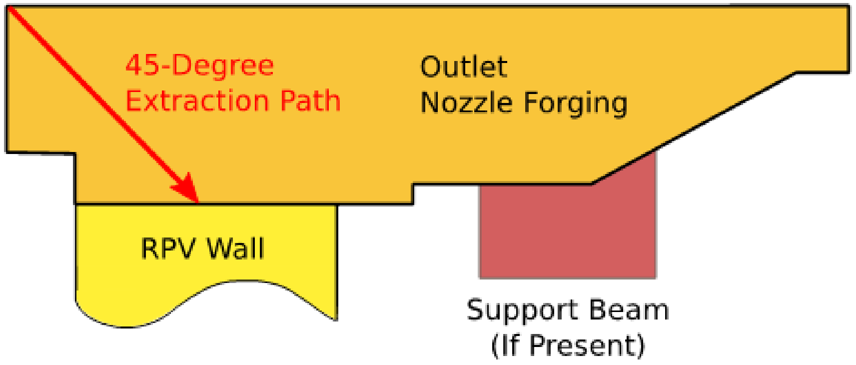
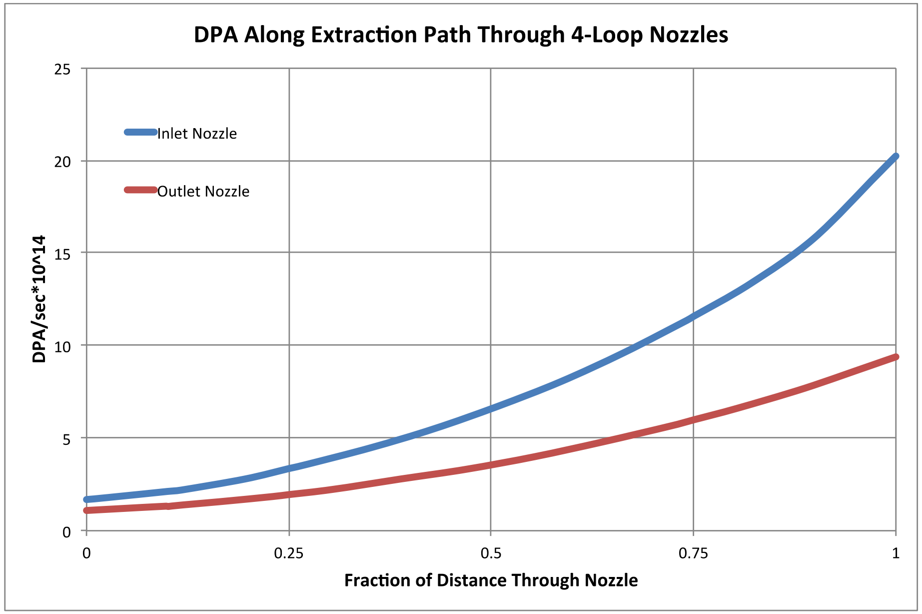


Figure 6-1 from MRP-333. Comparison of Various Mechanical Property Changes Attenuated through the RPV Wall Including the Predicted Charpy Transition Temperature Shift using dpa-adjusted Fluence and EONY Correlation.

Attenuation of Neutron Embrittlement in Nozzles

- MRP also conducted analysis of neutron attenuation in PWR nozzles:
  - *Materials Reliability Program: Fluence Attenuation Profile in the PWR Nozzle Shell Course (Inlet/Outlet Nozzles) (MRP-345).* EPRI, Palo Alto, CA: 2012. 1025157. (publicly available)
- This research also supports the conclusions of the TLR that the RG attenuation formula is not applicable in the extended beltline/nozzle region because the peak dpa rate occurs on the outer surface of the nozzle forging, in the cavity region





New, On-going Research on Neutron Attenuation

- Experiments on fluence attenuation in the cylindrical shell are continuing as part of the current DOE LWRSP testing program on the decommissioned Zion-1 RPV beltline
  - [Sokolov et al., PVP2019-93801, "Preliminary Characterization of RPV Materials Harvested from the Decommissioned Zion Unit 1 Nuclear Power Plant," Technical Presentation only]
- EPRI Comment #8: The results of through-thickness toughness measurements from decommissioned Zion RPV material may have implications for treatment of neutron attenuation effects
  - The results from the testing of the through-thickness properties of the Zion RPV wall should be finalized, understood, and appropriately considered in development of future guidance on accounting for the effects of neutron attenuation

Common Additions to RG1.99

Common Additions to RG1.99

- The TLR discusses and analyzes the use of sister plant data.
  - EPRI Comment #9: "Sister plant data" is, to some extent, a misnomer and a concept not well defined. In practice, it is "matching heat number data." The reality is that data from surveillance materials with heat numbers that match vessel material heat numbers are considered when evaluating vessel materials – whether or not the data originate from a "sister plant"
- The TLR states that "Consequently, the addition of sister plant data increases the likelihood that plant-specific data will be rejected." and… "…Consequently, the inclusion of sister plant data will increase the likelihood that a data-set will be deemed non-credible."
  - EPRI Comment #10: It should be noted that in a few high profile instances it has been very helpful to have sister plant data. In many cases, the data has benefited more than not, especially for critical materials

Comments about Implementation of Possible Future Revisions to RG1.99

Implementation of Future RG Revisions

- The adoption of new guidance regarding prediction of the effects of embrittlement will have significant impact on all operating plants (and international plants that use RG1.99)
  - P-T curves, Low Temperature Overpressure (LTOP) setpoints, etc.
- The last update of RG1.99 (1988) was introduced with onerous requirements for quick impact assessment and adoption (Generic Letter 88-10)
- While that may have been justified due to perceived safety concerns in 1988 (due to a general lack of surveillance data and the planned adoption of the new embrittlement correlation into the PTS Rule), the data presented in the TLR show that few plants will approach the fluences at which the potential nonconservatisms of RG1.99R2 is a concern (e.g., 6E+19) before 2028
- <u>EPRI Comment #11</u>: The data support a ***phased implementation*** of the next revision to RG1.99, to enable plants to adopt the guidance during normal updates of operating limits and minimize unnecessary burden

EPRI Comments on TLR's *Conclusions and Recommendations*

Conclusions and Recommendations

- The conclusions of the TLR are succinct and their technical bases are thoroughly documented
  - Exception: The comment that 4 plants need further USE review
- The recommendations of the TLR are reasonably supported by the analyses presented and are generally consistent with EPRI research
- EPRI research on USE prediction models is available for consideration should NRC revise the RG USE decrease model
- A new, high-fluence dataset will become available from the PSSP in 2028-30 that could be used in a future validation of a revised RG and to inform development of future ETCs
- The data and analyses support a *phased* implementation of any revision to RG1.99R2 to **minimize unnecessary burden on the operating fleet**

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