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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

May 6, 2005

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UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

(ACRS)

522nd MEETING

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FRIDAY,

MAY 6, 2005

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ROCKVILLE, MARYLAND

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

COMMITTEE MEMBERS:

GRAHAM B. WALLIS, Chairman

WILLIAM J. SHACK, Vice Chairman

GEORGE E. APOSTOLAKIS, Member

MARIO V. BONACA, Member

RICHARD S. DENNING, Member

THOMAS S. KRESS, Member

DANA A. POWERS, Member

VICTOR H. RANSOM, Member

COMMITTEE MEMBERS: (cont.)

STEPHEN L. ROSEN, Member

JOHN D. SIEBER, Member

ACRS STAFF PRESENT:

JOHN T. LARKINS, Executive Director

ASHOK C. THADANI, Deputy Executive Director

THERON BROWN

SAM DURAISWAMY

JENNY M. GALLO

NOBLE GREEN, JR.

MICHAEL L. SCOTT

NRC STAFF PRESENT:

RICH BARRETT, RES

JAMES A. DAVIS, RES

WILLIAM E. KEMPER, RES

MICHAEL MAYFIELD, RES

MICHAEL E. WATERMAN, RES

A-G-E-N-D-A

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

9:10 a.m.

CHAIRMAN WALLIS: The meeting will now come to order. This is the second day of the 522nd meeting of the Advisory Committee on Reactor Safeguards. During today's meeting the Committee will consider the following, the Steam Generator Tube Integrity Program, Digital Instrumentation and Control Systems research plan, reconciliation of ACRS comments and recommendations, future ACRS activities, report of the Planning and Procedures Subcommittee, and the preparation of ACRS reports.

This meeting is being conducted in accordance with the provisions of the Federal Advisory Committee Act. Mr. Sam Duraiswamy is the designated Federal Official for the initial portion of the meeting.

We have received no written comment, nor request, for time to make oral statements from members of the public regarding today's sessions. A transcript of portions of the meeting is being kept, and it is requested that the speakers use one of the microphones, identify themselves, and speak with sufficient clarity and volume so that they can be readily heard.

I'll remind you that we are having our annual ethics training over lunch today. John Szabo will be here at 12:15, and you may have been told that it will be in the small room, but it will actually be held here.

Without more ado, I'd like to proceed with the meeting, and I'd ask my colleague Dana Powers to lead us through the first item.

MEMBER POWERS: Thank you, sir. We're going to discuss the Steam Generator Tube Integrity Program, most of which is, many aspects of which are being done at Argonne National Laboratory.

It's part of -- it's one of the topics that we're going to address in our ACRS quality research review. And so maybe we should look upon this as background for the presentation on that quality review.

We're going to try to do this over the course of an hour and 25 minutes, James, so we need to move right along.

MR. DAVIS: Okay.

MEMBER POWERS: I'll introduce James Davis from the Office of Nuclear Regulatory Research to at least get us started here. I don't -- I have no idea who the goat sitting next to him is. I'm sure you will introduce that.

MR. DAVIS: It's Bill Shack. He's a program manager for this program at Argonne National Lab.

MEMBER POWERS: Oh, he's just a manager. I thought he was a technical pursuance --

MR. DAVIS: Yes, but he also does a lot of the other. Okay. We're doing research in quite a few areas on steam generators. I've specifically been asked to cover Task 3, which is tube integrity.

The reason that we're doing this work in tube integrity is user needs from NRR are related to the in-service inspection capabilities, reliability of in-service inspection. And then models for rupture burst and leak of steam generator tubes.

And NRR plans to use this information to review licensee submittals. In addition to the work that we're doing for the user needs, we're also doing work on crevice chemistry, tube support plates.

ACRS told us that they didn't feel that we had a -- anybody has a good enough understanding of what causes degradation of steam generator tubes at the tube support plates.

So we're doing a pretty good study in

that area.

MEMBER POWERS: Is this destined to be an anachronism? I mean as people go through and change out steam generators, aren't they eliminating the crevices?

MR. DAVIS: No, they're not. They still have the tube support plates.

MEMBER POWERS: But I mean --

MR. DAVIS: They have a different design.

MEMBER POWERS: -- isn't that a broached hole kind of design so you don't have narrow crevices anymore?

MR. DAVIS: Well they still have crevices, and we feel it's very important that we understand what's going to happen with 690 over the long-term, and these crevices.

And that's what the real objective of that work is, is with these new stainless steel tube support plates and with the different design. We feel it's very important to know what's going to happen over the long-term.

MEMBER POWERS: What's the potential difference between the stainless steel and the 690?

MR. DAVIS: I'm not exactly sure. I

know I don't think it's very big because of the low conductivity of the solution, but we haven't physically measured it at this point.

We're working on that. What I'm going to present today, I'm going to emphasize Task 3, which is tube integrity and integrity and predictions. I'll give you the objective.

I'm going to go through some of the leak rate models. I'm also going to discuss pressurization rate testing because there are some questions about the effect of pressurization rate on testing when you actually pull tubes in the field.

I'm going to discuss the main steam line break, study what we did where you have a depressurization on the secondary side. We've done some very interesting work recently on constant pressure crack growth, and I'll get into that.

Okay. And then I'm going to tell you how we statistically treat the models and then I'll summarize the results. And I'll mention some of the future work that we have planned.

I'm not sure we're really going to have time to discuss Task 1, 2, and 3, which are assessment of inspection reliability, ISI technology and degradation modes, but I put it in the package just so -- just for reference material.

The objective of Task 3 is to evaluate and validate models for leak and rupture behavior, failure pressures, and leak rates for degraded tubes.

And this is under normal and accident conditions.

MEMBER POWERS: Can you give us, maybe not immediately but in the course of the presentation, can you give us an idea when you say you want to evaluate and validate these models, what kinds of levels of precision of accuracy you're looking for from these models?

Plus or minus one percent sort of things, or plus or minus factors of two?

MR. DAVIS: We're not to that point with real cracks yet because part of the problem is the assumption that we know exactly what the crack looks like and we don't always know that.

That's one of the problems. With the idealized cracks we do a very good job with the EDM notch -- notches and we just don't do quite as good a job with real cracks because --

MEMBER POWERS: Wait a minute. The question I'm driving at is you can take these notches that you prepared, that you know very well, and you can model those, and then you try to apply them to these cracks that have ligaments and whatnot running through them. How do you know when you're good enough?

MR. DAVIS: Good enough?

MEMBER POWERS: Yes. I mean you're never going to get it exactly because there's stochastic component and what the crack looks like, but there's a point where continued refinement of the model's not going to do you any good.

MR. DAVIS: Yes.

MEMBER POWERS: You're not going to get over that, so how good is good enough here?

MR. DAVIS: I don't know if I actually know the answer to that.

VICE CHAIRMAN SHACK: Well, you know, that's almost a question for NRR to answer. But our -- with essentially a well -- a good geometry, we're typically, you know, somewhere on the order of ten to 15 percent.

So when we know the geometry -- as Jim says, the difficulty with the real crack is that you don't know the geometry. You can be very conservative, you know.

The typical response now is to take a complex crack, shape, and bound it with a rectangular crack that's, you know, as long as the real crack, and as deep as the deepest portion of the real crack.

And that can be very conservative by factors of two. So you're looking for something to get you closer to the 15 percent or so.

MEMBER POWERS: I guess I'm still struggling. Okay. I mean what's important here, how fast you depressurize, how fast you put liquid out?

VICE CHAIRMAN SHACK: Well again, I think in many cases it's a question of whether you've met your -- you know, when you do your operational assessment, like most of these rules, you know, if you've made the limit you're golden and if you haven't made the limit --

MEMBER SIEBER: You're brown.

VICE CHAIRMAN SHACK: -- you have a problem. And so you'd like to avoid access conservatism, but you'd like to understand whether you really do have the margins that you intend to have.

You know, I can't give you a risk number for what happens if you don't meet the ASME margin on your condition assessment, but that is what the regulations require. So it is a compliance problem.

MEMBER DENNING: Now is it a question of plug-in criteria? Is that what it is? I mean it's how confident you want to be that you'll detect a crack and it'll be a certain size, and then you'll decide to plug? Is that what it comes down to?

VICE CHAIRMAN SHACK: Well, I mean certainly you want to be able to do that, but I think the bigger problems is when you're doing the operational assessment at the end of the cycle and the -- you know, you have to demonstrate that you have the required margins, that, you know, you know you're operating with cracks.

You know, in most of these alloy 600 steam generators there's not much question about that. The question is whether you've really got the required margins when you're done, and --

MEMBER POWERS: But doesn't that again come down to the question of plugging criteria and the degree of confidence you want to have that in the next cycle you're not going to --

VICE CHAIRMAN SHACK: No, it's -- I think -- you mean that's an important question, but the question that you're immediately answering is you've come to the end of the cycle and you're looking at all the cracks that are in the steam generator, making sure that you have enough margin, that is you know, you predicted that you would go through the cycle and always have tubes that met all the ASME requirements.

When you get to the end of the cycle you have to find out whether that prediction was in fact true. And if you haven't made that then you've essentially violated your condition, which is to always operate within the proper margins.

So you then look at your worst cracks and you try to determine whether you've had enough margin or not.

CHAIRMAN WALLIS: Now you inspect every tube?

VICE CHAIRMAN SHACK: That's a -- in many alloy 600, it's close -- it's basically 100 percent. You know, most of them have enough.

They meet all the expansion rules that you're ever going to have.

MEMBER KRESS: What purpose does it serve to find out after the fact that you violated your condition?

VICE CHAIRMAN SHACK: Well I think it --

you know, because you're going -- you're going to make an assessment now for the next cycle. You, you know, --

MEMBER KRESS: Then change your model, or --

VICE CHAIRMAN SHACK: Well, yes, you may add conservatism. I think, you know, that's, you know,

MEMBER KRESS: So it's for the next assessment?

VICE CHAIRMAN SHACK: I mean it's basically --

MEMBER KRESS: You want to know how good your model is, then?

VICE CHAIRMAN SHACK: It's a verification of your prediction method --

MEMBER KRESS: I see.

VICE CHAIRMAN SHACK: -- you know, for all the uncertainties that we have. And we, you know, we have uncertainties in crack sizing, uncertainties in growth rate, you know.

So you've made those predictions. You now find out whether your -- you've met all your requirements or you haven't. If you haven't, obviously you have to justify what you're going to be doing for the next cycle.

MEMBER KRESS: So you're going to change the model?

VICE CHAIRMAN SHACK: Which typically is to presumable assessment conservatism.

MEMBER DENNING: Now wait a second, I don't understand. But the safety concern or consideration is if in the next cycle you're going to have a tube rupture which has safety concerns associated with it, right?

So I mean there's all these questions about models, but isn't the real issue am I going to plug tubes or am I not going to plug tubes. Isn't that what it comes down to? I'm missing --

MEMBER APOSTOLAKIS: Or change the models.

MEMBER DENNING: No, no, no. I mean the -- you can change the model but that's secondary. The real question is are you going to burst the next time, and if you have to make more conservatism that means that you have to plug more tubes, right, or plug at a lower level?

VICE CHAIRMAN SHACK: Well I think the answer -- you certainly don't want to burst any tubes in the next cycle but you also don't want to run the tubes even with less margin that you intend to have.

I mean you're not only supposed to get through the cycle without bursting tubes, that's, you know, that's --

MEMBER DENNING: Sure, sure.

VICE CHAIRMAN SHACK: -- requirement number one.

MEMBER DENNING: No, no, no. I agree. I agree, but I think getting back to Dana's question, how accurate to we have to be, the question is what risk are we willing to take that we will not have a sufficiently conservative plugging criterion that you'll have a -- too large of a probability of another break.

MEMBER APOSTOLAKIS: Which is -- I mean in a broader sense, the question is at which point reducing the uncertainties doesn't change the decision. And that's where Rich is going.

What is the decision that they have to make, and you know, if I have uncertainty say that's only five percent, I reduce it from ten to 15 percent to five percent.

Would the decision change? If it doesn't change then I can tolerate it, right? I don't care about reducing it anymore. And that's where Rich is going.

I mean what decision is that, plugging the tubes or what?

MEMBER DENNING: And I think that the decision is do I plug or don't I plug.

MEMBER APOSTOLAKIS: Yes, yes.

MEMBER DENNING: Right? Am I simplifying it too much?

MR. KARWOSKI: This is Ken Karwoski from the NRR Staff. I think it's important to recognize what plant procedures are what type of safety factors are built in to all these plugging criteria and plant practices because, you know, one, it's important to know the uncertainty in predicting the burst pressure of the flaws, but lets look at a typical plant with mill anneal tubing who has cracking.

Most plants, unless they have an alternate repair criteria approved, plug all flaws on detection. And as Bill was pointing out, so when they find these flaws they want to make sure that they had the margins that they thought they did.

And so when you look at a given plant with mill anneal tubing, if you just look at pressure loading, they're trying to maintain a safety factor of 3 against burst during normal operation.

So the key consideration is are they meeting that. And so it's tolerable not to meet it. It's not something that the plant wants to exceed, but it is tolerable for the plant to have a reduced safety factor of let's just throw out 2.9, because the tubes still won't burst during normal operation, nor during accident conditions.

So there's a lot of margin built into the acceptance criteria for these inspections. In addition, when we're talking about probability of burst we're -- in assessing degradation, we're not using the mean value.

We tend to use like a 95 percent confidence value. So the real consideration is do we have enough confidence in the uncertainty associated with those burst pressure predictions.

And so it is tolerable to exceed this performance criteria. It's not something that we want plants to do, but when they do exceed, or if they do, because it doesn't occur that frequently, but if they do then they take prompt corrective action.

MEMBER DENNING: Well, you're --

MEMBER POWERS: We've probably spent enough on this question. But when you tell me that you're developing a model and validating it, I really feel like I need to have some sense if when you can say QED, and I don't have that sense here.

MEMBER ROSEN: On another point, I think you were correct when you said that most mill anneal 600 plants will inspect 100 percent but I don't think that's the picture that's really out there now.

I mean so many of those plants have replaced their steam generators. I don't know how many are left in operation, but the new 690 plants, after the first cycle where they do do 100 percent, the baseline -- I don't think they're doing a full 100 percent anymore.

MR. DAVIS: No, they don't.

MEMBER ROSEN: There's much -- the amount of inspection after the first baseline is much reduced. And that picture will continue to come into focus as more and more mill anneal 600 alloy plants go out of service.

So we're dealing really with a future that looks like less inspection typically.

MEMBER DENNING: Yes.

MEMBER ROSEN: Unless, you know, unless the 690 plants behave badly. I mean if you don't get into -- what is it (C)(1), you know, where you have more than one percent and have to go into one of these expansions, you're going to do a fairly limited inspection.

MR. DAVIS: That's right.

MR. KARWOSKI: This is Ken Karwoski from the NRR Staff. I just wanted to clarify all plants that replace their steam generator, the industry guidelines, and to my knowledge, all plants who currently replace, they do 100 percent inspection in the first outage after replacement to identify the condition of the tubes.

MR. DAVIS: Right.

MR. KARWOSKI: After that they may do less inspections, and that's frequently what we see, but --

MEMBER ROSEN: I'm aware of that. Now after that what is it typically?

MR. KARWOSKI: It varies from plant to plant. For the 600 thermally treated plants, they typically inspect two of their four steam generators, you know, in a four-loop plant, every other outage.

They'll inspect two steam generators one outage. The next outage they'll inspect the other two, and they'll go on. But those practices evolved with time, and it's difficult to --

CHAIRMAN WALLIS: How many tubes in those SGs?

MR. KARWOSKI: Five thousand.

MEMBER POWERS: We're really getting off the track here. I failed to see --

CHAIRMAN WALLIS: And how many do they test?

MEMBER POWERS: I mean one of the problems I'm running into here is I don't understand how these models relate to all of this regulatory inspection and things like that.

MEMBER ROSEN: Could I ask -- Graham asked the final question which we never quite got to, which was the ones they inspect, what's the percentage?

MR. KARWOSKI: It varies from plant to plant, but we can provide you tables of historic practices for like thermally treated 600, but plants, -- some plants do 100 percent when they look at those two steam generators, others do 50 percent.

MEMBER ROSEN: That much?

MR. KARWOSKI: Yes, yes.

MEMBER ROSEN: On a new steam generator?

VICE CHAIRMAN SHACK: It's a thermally treated 600. Six ninety would typically be --

MR. KARWOSKI: Be even less.

VICE CHAIRMAN SHACK: -- less.

MEMBER POWERS: You can go ahead.

MR. DAVIS: The steam generator tube materials are very ductile, and so in the models what we consider is that the failure under design basis conditions is by plastic instability.

Under severe accident conditions where you're at higher temperature it's more likely at creep or at plastic instability. Now the real cracks have complex shapes, and as Bill said, we use a rectangular -- equivalent rectangular crack method to give conservative results.

And we're developing methods to give more realistic predictions of the ligament rupture. An efforts ongoing to develop more realistic predictions for burst.

We don't do as well on bursts as we do on ligament rupture. The first model I'm going to discuss is for an axial flaw that's through wall and it's idealized.

And Erdogen came up with a model for predicting the rupture, and it's -- the critical pressure is sigma H, where H is the wall thickness over the mean radius, and factor M, which comes out of linear elastic fracture mechanics modeling.

MEMBER KRESS: What's a flow stress?

MR. DAVIS: Right.

MEMBER KRESS: What is a flow stress? I've never heard that term.

MR. DAVIS: Flow stress is the average of the yield in the tensile.

MEMBER KRESS: Why do you call it a flow stress?

MR. DAVIS: That's just what they call it in fracture mechanics.

VICE CHAIRMAN SHACK: It's a way of accounting for work hardening with an elastically perfectly plastic model. It's just a simplification. It turns out to work quite well for ductile materials.

But if you use the yield stress you're being extremely conservative because the materials can work hard in a great deal.

MEMBER KRESS: Right.

VICE CHAIRMAN SHACK: Use the ultimate stress, you're non-conservative, --

MEMBER KRESS: So it's a --

VICE CHAIRMAN SHACK: -- realistically.

MEMBER KRESS: -- somewhere in between those two?

VICE CHAIRMAN SHACK: It's the average of the two, and that turns out to be quite good for ductile and work hardening materials.

CHAIRMAN WALLIS: So you're misusing a word from thermal hydraulics to make it more respectable?

MEMBER KRESS: Yes, that must be it.

VICE CHAIRMAN SHACK: Well actually it comes from GI Taylor, so we know it's got to be right.

MEMBER KRESS: Oh, it has to be good then.

MR. DAVIS: Another case that we have a model for is where you have a ligament where you part-through crack. And here you come up with a -- instead of M an M sub-p.

And this is related to the crack size and the wall thickness and the M factor, which is the linear elastic fracture mechanics. Once you do rupture a ligament, now if the critical pressure is higher than the ligament pressure then you're not going to burst the tube you're just going to leak.

And what we found in our work at Argonne in that the -- this model works well for long cracks but it doesn't work so well for short, deep cracks. So Argonne modified this expression and included the term alpha, which is a geometric factor as well.

And it turns out that the modification that Argonne did gives us much better results on short, deep cracks.

CHAIRMAN WALLIS: What do you mean by short, deep cracks?

MR. DAVIS: Like a quarter inch crack that's 80 percent through wall.

CHAIRMAN WALLIS: A quarter inch wide, or what's the --

CHAIRMAN WALLIS: Well then long and deep sound to me -- seem to be the same thing.

MR. DAVIS: It's -- a short, deep crack is like a quarter inch crack that's 80 percent through wall. A long crack is like maybe a half inch or an inch long and --

CHAIRMAN WALLIS: It's long this way and then it goes through the wall that way.

MR. DAVIS: Yes. But if it's --

CHAIRMAN WALLIS: Tangentially is length?

MR. DAVIS: If it's short and deep --

VICE CHAIRMAN SHACK: Length is axial or circumferential.

CHAIRMAN WALLIS: Well I would say wide and deep, not --

MR. DAVIS: No.

MEMBER POWERS: It matters not what you would say it only matters what they say.

CHAIRMAN WALLIS: Okay, but --

MR. DAVIS: What we've done with the actual stress corrosion cracks is we've -- or irregular cracks is we've come up with this rectangular crack method.

The problem that we run into with this model is that it -- sometimes we don't account for ligaments.

CHAIRMAN WALLIS: Now rectangular crack means that this shortness and this depth are sides of a rectangle?

MR. DAVIS: Yes.

CHAIRMAN WALLIS: Is that what you mean?

MR. DAVIS: Yes. And you take a rough

crack and you take the best rectangle that you can find.

CHAIRMAN WALLIS: And it has sharp corners, does it?

MR. DAVIS: Yes. It has sharp corners. For our model that's what you use.

CHAIRMAN WALLIS: Does it make the computation more difficult when there's sharp corners?

MR. DAVIS: No.

CHAIRMAN WALLIS: No?

MR. DAVIS: No. It simplifies it actually.

CHAIRMAN WALLIS: Okay, okay.

MR. DAVIS: But what we do is we take a series of these rectangular cracks and we calculate M sub-p and we take the one with the highest M sub-p for conservatism and use that in the model.

The problem that you have is if you have ligaments or you have a meandering crack, the -- you have an -- when you calculate it with the equivalent crack method you don't account for the entire length of the -- of what's going on.

And that's why you sometimes don't get very good results.

MEMBER ROSEN: Can you be a little more expressive when you talk about ligaments? I know what they are in my leg. What, exactly, what do you mean when you say ligament?

MR. DAVIS: So you have an inch long crack but it consists of a series of short cracks with metal in between them. And so to rupture that you have to rupture those ligaments.

It's not really an inch long crack it's a series --

MEMBER ROSEN: So you think of it as a --

MR. DAVIS: -- of short --

MEMBER ROSEN: Look at my hands and the two branches are cracks.

MR. DAVIS: Right.

MEMBER ROSEN: And the space in between is the ligament?

MR. DAVIS: That's a ligament and that's solid material.

CHAIRMAN WALLIS: The ligaments are still hanging on.

MR. DAVIS: They're still there and they're holding it together. And part of the problem is --

MEMBER ROSEN: It's quite strong.

MR. DAVIS: You're assuming you know what the length is using, say, eddy current to determine the length. But sometimes eddy current won't see the ligaments. And so --

MEMBER SIEBER: Volumetric.

MR. DAVIS: -- results will tell you that the crack's longer than it is. Or you'll assume it's longer than it really is and that's why you don't get really good results sometimes.

VICE CHAIRMAN SHACK: Ligaments just make life very -- they make it complicated for your inspection because they fool the eddy current. They provide a conductive path, and so --

MEMBER SIEBER: Right.

VICE CHAIRMAN SHACK: You know, it makes it difficult to detect because you're, you know, you want a high impedance for the detection so it makes it difficult to detect.

It screws up your burst calculation because although these ligaments are very narrow they add a surprising amount to the strength of the whole crack.

So you tend to be overly conservative with these bounding crack models. And you end up greatly over-predicting leak rates because again the crack turns out to be very, very sensitive to how wide the -- and this -- we use wide to say how much the crack opens up.

So it's long, wide, and deep. And so a ligament greatly reduces the width of the crack opening and greatly reduces the flow through the flaw, and so you're almost all the time -- our simplified crack type models over-predict the leak rate.

They essentially over-predict the burst pressure.

MEMBER ROSEN: So coming back to my hands model where my hands are the cracks, the material in between is still intact.

VICE CHAIRMAN SHACK: Yes, there's --

MEMBER ROSEN: And you're measuring this crack as being the width of to the back of my hands --

VICE CHAIRMAN SHACK: Your hand, right.

MEMBER ROSEN: -- whereas really it's got a lot other material in between those facing the cracks.

VICE CHAIRMAN SHACK: It doesn't take much material, you know. You have a half inch crack and you put a sort of a 32nd inch ligament in the middle of it and it makes a tremendous difference in the leak rate through that crack. A little ligament goes a long way.

MEMBER SIEBER: With enough ligaments you can actually be through wall and have it not burst.

VICE CHAIRMAN SHACK: Oh, yes. Now in the fact -- when we talk about ligament rupture that's the whole point, that we can predict when the crack goes through wall quite well even for a complex crack shape.

But the margin that you then have to actual bursts where you get an unstable tearing, you know, it's one thing to pot through and have a very small, tiny crack that's popped through in just a small portion of it.

It's another one to rip the whole length of the crack and to have an unstable burst that keeps on going. And again, we can predict the ligament rupture to go through wall quite accurately.

What we can't tell you is the margin you then have to the unstable burst.

CHAIRMAN WALLIS: The ligament must be

very material dependent, brittle material. I presume you don't have ligaments in certain materials. You have lots of ligaments because of the structure of the material.

VICE CHAIRMAN SHACK: In our gooey, rubbery alloy 600 we have lots of ligaments.

CHAIRMAN WALLIS: And so the flow is like a sticky stuff --

VICE CHAIRMAN SHACK: Right.

CHAIRMAN WALLIS: -- and pulls these bits of glue out.

VICE CHAIRMAN SHACK: And the stress corrosion cracks grow that way. They kind of meander through various grain boundaries rather than cleanly rupturing grains so that you get this complex --

MEMBER POWERS: Even in brittle ceramics they talk about ligaments.

VICE CHAIRMAN SHACK: But there it tends to be more a big bang kind of a failure.

MR. DAVIS: This is what Bill just covered, so -- we also have developed models for circumferential cracks. And there we didn't use the plastic instability as much as we used a fracture mechanics approach because it's a little more complicated to deal with.

CHAIRMAN WALLIS: I would think the ligaments would be subject to creep, that they would actually creep away because of the high stresses on them. Don't they?

VICE CHAIRMAN SHACK: Yes, we'll get to that.

CHAIRMAN WALLIS: Okay.

MR. DAVIS: We also develop models for severe accidents where you're at a higher temperature. At lower temperature you wouldn't expect a lot of creep, but at the higher temperature a creep rupture model has been developed.

And it -- and also it predicts a lot better than the flow stress model. To move on to the leak models, we developed a leak model based on simple orifice flow through a crack.

MEMBER KRESS: Is the area, the opening area -- you know, the crack has areas at front end and back end, a small area at the back end?

VICE CHAIRMAN SHACK: Yes, that also turns out to be an interesting question, but it's the smallest area which is typically at the OD.

MEMBER KRESS: At the OD?

VICE CHAIRMAN SHACK: Yes. And --

MEMBER KRESS: So the .6 is discharged from an orifice into a reservoir?

VICE CHAIRMAN SHACK: Right.

CHAIRMAN WALLIS: Sharp-edged orifice?

MEMBER KRESS: Sharp-edged orifice into a reservoir.

CHAIRMAN WALLIS: There's no friction or anything in all this crack?

VICE CHAIRMAN SHACK: Again --

CHAIRMAN WALLIS: If you're being conservative, you're saying.

VICE CHAIRMAN SHACK: Well, with leak rates it's hard to know when you're being conservative. If you're looking at -- if you want to do leak-before-break then every time you over-predict the leak you're being non-conservative.

If you're looking at how much fluid you're loosing from the reactor then it's conservative to over-predict the volume of leak. So conservative is a kind of a dangerous thing.

But what is surprising here is that everybody sort of thinks of this as clearly a two phase situation. The flow is going to go through.

MEMBER KRESS: Right.

VICE CHAIRMAN SHACK: You're going to have flashing, you know. You would expect these flows to always be choked. What was surprising to us was that many of the -- much of the time the crack acts as an orifice of a single phase fluid.

I mean this is just an orifice flow for a single phase fluid. You know, you really are looking at the time it takes to flash. And by the time it gets through the wall it hasn't flashed yet and so the fluid acts as though it's a single phase fluid.

And this becomes important under accident situations when you have the 2,500 and the crack opens fairly wide. So --

CHAIRMAN WALLIS: This is true of small dimensions, it takes a small time to go through.

VICE CHAIRMAN SHACK: A small time to go through.

CHAIRMAN WALLIS: If you go to Marviken everything is homogeneous because the length is so long.

VICE CHAIRMAN SHACK: And so for these kinds of accident flows the crack tends to be open and you get this single phase behavior, this orifice type behavior.

Now in the normal operation when, you know, the leak rate is 150 gallons per day and you're dealing with very tight cracks, then clearly you have very large fluid losses.

Frictional losses are very important. Getting the transition between when you have this orifice flow and when you have this much more restricted frictional flow is one of the things that we're still working on.

We have some explanations of when that happens and under the conditions in which you switch from one flow to the other.

MEMBER BONACA: I have a question. This is a response to a need from NRR, okay. Now the licensees must have similar models that they use to predict a fact from cycle to cycle, what's going to happen? Okay.

VICE CHAIRMAN SHACK: Yes. Well one of the differences is the licensee models up until now have always assumed that the flow has been choked.

MEMBER KRESS: Okay.

VICE CHAIRMAN SHACK: And that's not the case for these, you know. A crack that's larger than about five millimeters under a main steam line break condition that's not the case.

A crack that size, that open acts like a single phase fluid with no choking, and a simple orifice flow model.

MEMBER KRESS: So you're going to get a lot more flow?

MEMBER POWERS: Bill, --

VICE CHAIRMAN SHACK: You're going to get more flow.

MEMBER POWERS: Bill, in this equation, or this model -- or maybe Jim, I'm not sure who to ask on this. When they do a drill plate for an orifice flow meter, anything like that, I have to go calibrate it, okay, because this equation never exactly works.

Okay, what do you adjust, your discharge coefficient or the area?

VICE CHAIRMAN SHACK: The uncertainty is generally really with the area. You know, you're right, I mean there is a variability in the orifice coefficient.

MEMBER POWERS: Yes.

VICE CHAIRMAN SHACK: And if I was dealing with a drilled hole I would adjust the orifice coefficient. It turns out in dealing with a real crack, my difficulty is always in computing the crack opening area, because if I take, as I usually do, my sort of rectangular bounding crack, I'm going to over-predict the crack opening area.

So I have a very strong tendency over-predict leak rates. I sort of ignore ligaments. And again, I don't know whether Jim will have it come up here, you know, sooner or later when we do the fraction mechanics prediction you find that this area varies to about the fifth power of the length of the crack.

So if I put a ligament in the middle of that crack, I've suddenly changed the thing by a factor of about 30.

MEMBER POWERS: I mean the discharge coefficient used there is very simple.

VICE CHAIRMAN SHACK: Is very --

MEMBER POWERS: But it doesn't make any difference because all your problem is in the area.

VICE CHAIRMAN SHACK: All my problem is in the area.

MR. DAVIS: For an axial crack this is the expression that we use, and -- where V0 is a function of the Ce in the --

CHAIRMAN WALLIS: What shape is this area?

MR. DAVIS: It's a crack.

VICE CHAIRMAN SHACK: It's an ellipse.

CHAIRMAN WALLIS: It is?

VICE CHAIRMAN SHACK: Well, --

CHAIRMAN WALLIS: It's idealized to be an ellipse.

VICE CHAIRMAN SHACK: It's idealized to be an ellipse.

CHAIRMAN WALLIS: But really it isn't.

VICE CHAIRMAN SHACK: Well if you told me the shape of the crack I would tell you the shape of the opening.

CHAIRMAN WALLIS: That's part of the uncertainty.

VICE CHAIRMAN SHACK: That's part of the uncertainty. But when I bound everything with an equivalent rectangular crack it idealizes as an ellipse.

MR. DAVIS: I think we've discussed most of this, but the test show that due to short transit time across the steam generator tube wall leaks over a range of crack sizes can be described by a single phase orifice flow model with an opening based on the crack opening area.

The leak rate's a function of L over D,

where L is the length and D is two times the crack opening. Now we get a very good agreement, as Bill said, for slits, orifices, and open cracks.

CHAIRMAN WALLIS: Wait a minute, this crack is going in both directions. Doesn't that make a difference which way it's growing, whether it's growing wide-wise, or I mean --

VICE CHAIRMAN SHACK: Lengthwise?

CHAIRMAN WALLIS: Lengthwise or whatever the other thing you call it.

VICE CHAIRMAN SHACK: Oh, you mean axial or circumferential?

CHAIRMAN WALLIS: Right, it makes a difference which way it's growing.

VICE CHAIRMAN SHACK: Oh, yes. It's makes a very large difference.

MR. DAVIS: Very big difference.

CHAIRMAN WALLIS: Yes, so --

VICE CHAIRMAN SHACK: We're dealing with axial cracks here, not --

MR. DAVIS: Axials here.

VICE CHAIRMAN SHACK: We have equivalent models.

CHAIRMAN WALLIS: It's not growing any other way. It's already grown as much as it wants to the way and then it's just going that axial way, is that it?

VICE CHAIRMAN SHACK: Yes, the length of the crack increases either axially or circumferentially.

CHAIRMAN WALLIS: Right.

VICE CHAIRMAN SHACK: The width is not really a growth, it's --

CHAIRMAN WALLIS: No, no, no, that's right. The length --

VICE CHAIRMAN SHACK: That's an opening.

CHAIRMAN WALLIS: What do you call -- the other one is the depth? Length or the depth?

VICE CHAIRMAN SHACK: Yes, the length is how long the crack is either axially or circumferentially.

CHAIRMAN WALLIS: But is the length growing or is the depth growing or is just the length fixed and the depth is growing or what's happening here?

VICE CHAIRMAN SHACK: No, they're both growing.

CHAIRMAN WALLIS: They're both growing?

VICE CHAIRMAN SHACK: They're both growing. It's growing longer and it's growing deeper.

CHAIRMAN WALLIS: But it's still elliptical when it gets to the --

VICE CHAIRMAN SHACK: Well, --

CHAIRMAN WALLIS: -- other side?

VICE CHAIRMAN SHACK: The elliptical is the width if you're looking head on at the crack.

CHAIRMAN WALLIS: Yes.

VICE CHAIRMAN SHACK: You know, the mouth of the crack opens up into an elliptical shape.

MR. DAVIS: They'll be bigger on the side they initiate.

CHAIRMAN WALLIS: Right. That's from the theory, and it has this concentration into the ellipse, and --

VICE CHAIRMAN SHACK: By the time we get to the fish mouth the game is over.

CHAIRMAN WALLIS: Okay.

MR. DAVIS: As Bill mentioned with actual cracks, because of ligaments --

CHAIRMAN WALLIS: What if some of these things grew like a smile instead of an ellipse?

MEMBER POWERS: That's fish mouth and that's when the game is over. Please continue.

MR. DAVIS: But the ligaments do tend to cause us to overestimate the leak rates. Real stress corrosion cracks tend to undergo incremental ligament rupture with increasing pressure before the cracks become unstable.

And this causes the leakage to occur at lower pressures than predicted. The equivalent crack method has been generalized to predict incremental ligament rupture after initial ligament rupture.

CHAIRMAN WALLIS: Doesn't this incremental ligament rupture even occur at fixed pressure because of creeping of the ligament?

VICE CHAIRMAN SHACK: That --

MR. DAVIS: It appears that it does, yes.

VICE CHAIRMAN SHACK: We will be discussing that in more detail.

MR. DAVIS: What we found, one of the assumptions of course, you know, what the crack looks like. And we found that when you destructively examine the cracks that you get better, more accurate results than when you use eddy current, which is not surprising.

MEMBER BONACA: At some point though, I

would like to understand, these are models that you're using to predict.

MR. DAVIS: Yes.

MEMBER BONACA: Okay. Now a number of the inputs of the model is the size of the crack, the length, the depth, --

MR. DAVIS: Depth.

MEMBER BONACA: -- what you measure. How accurate are the measurements? You know, how accurately can you measure the length of the crack, the depth of the crack? Try to understand that, because you're using them as inputs to predict.

MR. DAVIS: Yes.

MEMBER BONACA: And depending on how well you can measure you can get different answers.

MR. DAVIS: That's something that we've looked at in a great deal of detail, and we developed this -- Argonne's expert system --

MEMBER BONACA: Okay.

MR. DAVIS: -- with the rotating pancake coil in order to try to get a better prediction than using a bobbin coil does.

MEMBER BONACA: Yes.

MR. DAVIS: And what we're found is that you do get much better results with the rotating pancake coil than you do with just a bobbin coil. But what we do is we verify it by doing destructive analysis and looking at the actual crack profile to see how well we predicted the shape.

And that's one of the biggest assumptions in this whole thing. And we spend a lot of effort on that.

MEMBER BONACA: If you want to verify what the licensee is telling you, or the predictions that he's making, --

MR. DAVIS: Right.

MEMBER BONACA: -- you will need to have from the licensee sentence predictions of well, measurements.

MR. DAVIS: Yes.

MEMBER BONACA: Okay.

MR. DAVIS: Okay. I'm going to describe briefly. We have two facilities that we use for doing this testing. You know, one's a room-temperature, high-pressure facility.

And this has a maximum pressure of 7,500 psi. We use a pump to provide the pressure, and we're limited to 12.8 gallons per minute in this facility.

We have it hooked up to a water supply

so we can test forever in this basically. We don't run out of water. We have a high-temperature and pressure leak rate test facility, also called a blowdown facility.

And there we have a maximum temperature of 650 F. We have a maximum pressure of 3,000 psi. And we thought the leak rate was going to be a little lower than it turned out to be, but we can actually have a leak rate of 400 gallons per minute.

But we have a storage tank that holds 200 gallons, so if we have a 400 gallon per minute leak rate we only have 30 seconds for testing. And so further limitations we have on the high-pressure facility, we've done a lot of our testing on the room temperature facility.

It's a lot easier to use and we think we're getting similar results. To verify things though, we do run test on the high-pressure, high-temperature facility.

MEMBER POWERS: Is there a reason for retaining the English set of units?

MR. DAVIS: Not really.

MEMBER POWERS: Just curious.

VICE CHAIRMAN SHACK: The reports are always written in scientific units, the discussion is always carried out in English units.

MR. DAVIS: Yes.

CHAIRMAN WALLIS: Gallons are horrible units because you never know what pressure --

MEMBER POWERS: These are godless creatures, or --

CHAIRMAN WALLIS: Mass glow should be mass flow, not gallons per minute. A gallon is an undefined quantity.

MR. DAVIS: We really do pounds per minute.

CHAIRMAN WALLIS: It's not dependent -- the mass depends upon the temperature and pressure and so on. A gallon in this sort of context is not defined until you add something to it, you see, gallons at room-temperature and pressure, or so on.

MR. DAVIS: That's right.

MEMBER POWERS: Well you have the same problem with mass.

CHAIRMAN WALLIS: No you don't. Mass is the same at room temperature as at other temperatures, I think.

MR. DAVIS: That's how we measure it for those.

MEMBER POWERS: It depends on which

planet you're on.

CHAIRMAN WALLIS: That's weight, that's not mass.

MR. DAVIS: We don't measure gallons per minute. We convert to gallons per minute.

MEMBER POWERS: Go ahead.

MR. DAVIS: Okay, the --

CHAIRMAN WALLIS: Why? Why convert to something bizarre when you've got the good unit already?

MEMBER POWERS: Because they like it.

CHAIRMAN WALLIS: Because the NRC likes it? Is that the NRC standard?

MEMBER POWERS: Mr. Chairman, if you continue to slow me down I will ask you to leave.

CHAIRMAN WALLIS: I'm sorry, I thought I was debating with you, but okay. Let's move on.

MR. DAVIS: Okay, the industry actually conducted some tests and what they found was they found an effect of pressurization rate on burst pressure.

And to NRR asked us to look into this and see if there was a pressurization rate effect on burst. When we looked into what the industry was doing it was actually -- Westinghouse did this testing.

And they used two different protocols for the slow and the fast test rates. And we thought that that could have a big effect on what they were saying looked like a pressurization rate effect.

And also, when we looked at their results we felt we could explain the differences in pressurization rate just by geometry of the specimens that they were testing.

And so we weren't convinced that there's a pressurization rate effect.

CHAIRMAN WALLIS: Does foil and bladder mean anything to anybody in this room?

MEMBER KRESS: Pardon?

CHAIRMAN WALLIS: Does foil and bladder mean anything to anybody in this room except the presenter?

MR. DAVIS: Okay. What happens is if you have a through wall crack and you try to burst it, somehow you have to keep the pressure in there. You have to be able to put the pressure in. So what you do is you put a foil in --

CHAIRMAN WALLIS: A bladder.

MR. DAVIS: -- and then a bladder, which

is like a piece of Tygon tubing, inside so that you're not loosing all you're --

VICE CHAIRMAN SHACK: Fluid.

MR. DAVIS: -- fluid and loosing your pressure so that you can actually burst the specimen. And if you have a large crack it's difficult to make it burst if you have a large leak rate. It depends on your --

VICE CHAIRMAN SHACK: The leak rate is limited to 12.8 gallons. Your through wall crack size that you can deal with is --

MEMBER SIEBER: It's the capacity.

VICE CHAIRMAN SHACK: -- pretty small.

MEMBER KRESS: Is there any reason theoretically to expect a rate effect such as give you time for work hardening if your doing it slow or having something to do with the time to reach its strain limit, or --

MR. DAVIS: Well, I think it's pretty common when you're mechanically testing materials that you have to control the pressurization rate. For like a stress-strain curve you do it at a certain rate --

MEMBER KRESS: At a certain rate.

MR. DAVIS: -- because if you change

your strain rate you're going to change -- you can change your yield strength.

MEMBER KRESS: These are not momentum effects, because --

VICE CHAIRMAN SHACK: No, no, no.

MEMBER KRESS: -- they're strictly something like work hardening or --

VICE CHAIRMAN SHACK: Yes, this -- you know, you could eventually get to something like a momentum effect but --

MEMBER KRESS: Yes.

VICE CHAIRMAN SHACK: -- that's with rates that are --

MEMBER KRESS: Really --

VICE CHAIRMAN SHACK: -- phenomenal here. But we are talking about changing things like work hardening.

MEMBER KRESS: You're actually changing properties of the material?

VICE CHAIRMAN SHACK: You're changing the properties of the material.

MR. DAVIS: What we did was we took different shaped flaws and we also had ligaments that we put in, which is shown at the bottom. You know, we had an axial ligament and a circumferential ligament.

And it's kind of hard to explain so I showed you the diagram. And what we did was we tested these at quasi-static, where you pressurize and then you increase the pressure in steps.

And then we did 1,000, 2,000, 6,000, and 10,000 psi per second pressurization rates. And what we found was there's no real pressurization effect up to 6,000 psi.

MEMBER KRESS: Now if you did this in steps, how would you see a pressurization rate effect?

MR. DAVIS: Okay, we did the first, the quasi-static in steps, but then --

MEMBER KRESS: Then you went back.

MR. DAVIS: And then we went and we went 1,000 psi per second, 2,000 psi per second.

MEMBER KRESS: Okay, I'm sorry. So you did two times, the test.

MR. DAVIS: And we didn't see any pressurization effect up to 6,000 psi per second. We talked to the industry and what they say is the maximum they ever use is 2,000 psi per second for their industry tests.

So we feel that under the actual field

testing condition there is no pressurization rate.

CHAIRMAN WALLIS: If you had a water hammer or something you'd get pressure rate rises which would be much more rapid than that.

MR. DAVIS: Right.

MEMBER SIEBER: You could, yes.

MEMBER KRESS: But if there is a pressurization rate it means you need higher pressure first.

MR. DAVIS: Right.

MEMBER KRESS: So by neglecting conditions like that you're probably being conservative, and once again you have this conservative word.

VICE CHAIRMAN SHACK: Right. And I don't think water hammer is generally a concern in the steam generator tube.

MR. DAVIS: We were concerned about -- or I think what NRR requested us was if they used different pressurization rates on their field samples are they getting good results. And that was a question we wanted to ask --

VICE CHAIRMAN SHACK: One-way to get your margin is to --

MEMBER POWERS: And then so you were

attributing the Westinghouse observation and to some differences in their protocols?

MR. DAVIS: Yes. It was two things. It was the different ways they tested and the shape of the actually curves that they were -- I mean the cracks that they were testing.

VICE CHAIRMAN SHACK: Actually in their test it was probably most the shape, because they were trying to deal with complex shapes and reproducing those complex shapes even when they were reproducing them as EDM notches.

You know, the geometry variations were essentially on the order of what you might expect from a rate effect.

MEMBER POWERS: I understand.

MR. DAVIS: Another study that we conducted was secondary side depressurization study. And what this was was to simulate a main steam line break where you have a larger -- you lose pressure on the secondary side.

And the typical analysis of depressurization events did not --

CHAIRMAN WALLIS: We heard about this six months ago or something.

MR. DAVIS: Yes, you did. You heard

this in detail. So the ACRS had raised some concerns several years ago about dynamic loads on the steam generator tubes.

So what we did, we calculated the dynamic loads using RELAP5 and benchmarked it against experiments. What we found was a large -- a main steam -- a large main steam line break creates a much greater pressure than a small steam line break or a feedwater line break.

And it was quite a big difference. And the pressure loading acting on the tube support plates is transferred to the tubes which are locked by corrosion products and deposits.

And we conducted a detailed finite element analysis and a fracture mechanics analysis for -- and we used the Model 51 Westinghouse steam generator, tube support plates, and tubes.

What we found out, the loads are primarily axial so then the dynamic loads have no effect, virtually no effect on axial cracks because the loads are axial.

Now if only one or two tubes are locked for circumferential cracks, the stress exceeds the ultimate tensile strength. But what you have to understand is it's very unlikely that only one or two tubes would be locked.

Also because the tubes are -- because the displacements are limited, unflawed tubes would not rupture, but the tolerance for circumferential cracks would be severely limited if you just had a few.

If greater than one and a half percent of the tubes are locked then the loads are very low, and cracks less than 180 degrees are stable. And these are through wall cracks.

So if you had cracks greater than 180 degrees through wall, you would -- they would be plugged and that would not be a problem.

MEMBER KRESS: What finite element analysis code do you use, ABACUS?

VICE CHAIRMAN SHACK: ABACUS.

MR. DAVIS: And then one of the more recent studies that we've done is constant pressure crack growth studies. A couple years ago we ran a limited number of specimens in the high-temperature facility and we noticed that we were getting some constant pressure crack growth.

So what -- the objective of this program was to determine the influence of flaw geometry on flaw tearing and the subsequent leak rate behavior.

And then determine the mechanism for flaw growth, and increase leak rates at constant pressure.

And since I made this slide up we've actually done a high-temperature verification of this, but most of the testing was conducted in the room-temperature facility.

We've run one test in the high-temperature facility. So as I said, the early work that we had done showed that there was some time dependence on the leak rate.

And we attributed this to ligament tearing and opening of the crack due to some type of limited time-dependent deformation. We had a number of theories on what was causing it.

What we found in some recent tests is that at room-temperature the crack grows at a fairly high rate. What we did was we took alloy 600. It was seven eighth inch diameter and it was 50 mil wall thickness.

We had trapezoidal cracks that were .2 inches on the OD and one inch on the ID. And then we had the reverse case where the ID was one inch and the -- I mean the OD was one inch and the ID was .2 inches.

And then we had, just to further look at it, we had rectangular cracks that were .2, .4, and .6 inches. We tested with and without a foil and bladder.

We tested them open to air. And then to simulate an actual steam generator what we did was we put shrouds around the cracks to see what effect that had, so like the adjacent tubes se tried to simulate.

The trapezoidal flaw design was just to -- is to show you what it looked like. And it's -- this is of course not to scale. It's 50 mils thick. It's a very thin ligament almost.

And one of the things we looked at was if you have a -- we thought if you have a jet that contributes. You know, you have large leakage in the jet, causes some of the problem.

So what we did was we tested jet-free to see what would happen, where we used a foil and a bladder. And then we have some pump oscillations when we test normally, and we thought that might be contributing.

So what we did was we pressurized with nitrogen. And we were wondering if there was some type of a corrosion effect. So we actually put moisture on the outside with the foil and bladder to see if that had any effect.

And what we saw was no crack growth with the -- using the pressurized nitrogen. When we tested with the pump on at the same pressure, this was at 1,300 psi, what we found was we get smaller, slight crack growth.

The pump gives you about a 30 psi oscillation just in the way the pump operates, and that's why we ran these tests. Then we started running tests with active jets.

And what happened was with an active leak the crack increased with -- from the original .2 inches to one inch in just a number of hours. It was like eight hours we went from the OD -- crack from .2 to one inch.

CHAIRMAN WALLIS: So does the crack growth rate change much when you have the flow rather than not having the flow?

MR. DAVIS: Yes, dramatically.

CHAIRMAN WALLIS: It does? So flow changes the crack growth rate?

MR. DAVIS: Right.

CHAIRMAN WALLIS: That's not in the fracture mechanics than is it?

MR. DAVIS: Well, we're looking into

that, but --

CHAIRMAN WALLIS: Some kind of fluid-structure interactions?

MR. DAVIS: There's some fluid-structure interaction, definitely.

VICE CHAIRMAN SHACK: I mean that's what we try to do with the bladder tests, you know.

CHAIRMAN WALLIS: Right.

VICE CHAIRMAN SHACK: We've sort of eliminated the possibility there was an environmental effect. We showed that any fatigue growth from the pump was very small.

So you're sort of left with the jet as being the mechanism --

CHAIRMAN WALLIS: There's a water-cutting phenomenon, is it?

VICE CHAIRMAN SHACK: No, it's -- Jim doesn't have a picture. You know, it's not as though it's cutting. I mean it really looks like a very tight fatigue crack so that the -- the thought is that it is a jet structure interaction leading to low amplitude, very high frequency fatigue crack growth.

So you get these very tight fatigue cracks coming out of the notch growing --

CHAIRMAN WALLIS: So the water is creating stresses rather than removing the --

VICE CHAIRMAN SHACK: The water is creating stresses. And the crack growth rates are, you know, two to three orders of magnitude higher than you would expect from stress corrosion.

MEMBER RANSOM: Well when you have a bladder don't you omit the forces that are being -- due to the pressure in the crack itself, tending to open the crack?

VICE CHAIRMAN SHACK: No, no. The bladder doesn't really reduce the stress on the crack tip. You know, the -- if you're thinking of the pressure acting on the crack face that's a very, very small part of the load acting on the crack, that when you have the bladder in -- you know, that's why we can do the burst tests with the bladder and it really doesn't make much effect.

In this particular case, that kept the load on the crack, but we -- what we missed of course was the -- you know, we had the static load was equivalent, but wed miss the whole dynamic load due to the jet action.

CHAIRMAN WALLIS: So I guess it's reasonable because, you know, the jet has the whole pressure imposed on it so the velocity is your square root of P over O.

That goes back into P if you stop the jet somewhere. So the jet is going around or has velocity fluctuations, pressure fluctuations could be comparable with the applied pressure.

So they're significant, they could be significant.

VICE CHAIRMAN SHACK: Yes. Measuring those is very difficult, and even detecting just what frequency range we're interested in is kind of a difficult question.

What we sort of settle on at the moment is that we can get very high crack growth rates. What was a little surprising to us, we did the first tests with a -- a kind of an eighteen inch confinement so that it was a truly free jet.

And we actually thought that well, when we muffled this jet if we sort of, you know, in a steam generator the tubes are only a quarter inch apart and so the jet isn't free, it's really much more muffled by the surrounding --

CHAIRMAN WALLIS: I think with ligaments I can see how the wake of the flow around the ligament could easily shake the ligament and break it.

MEMBER KRESS: Yes. But --

VICE CHAIRMAN SHACK: Vortex shedding, you know, simpleminded dynamic effects are --

MEMBER KRESS: Well can you back out. Looking at your fatigue -- assuming some fatigue rate growth, can you back out of frequency and pressure to give you that rate and then see if it corresponds to anything you might guess?

VICE CHAIRMAN SHACK: At the moment, what we do since we don't know the delta p or the frequency, what we have -- we select frequencies and then we compute the delta p that have to have in order to get the crack growth rate that we observe.

MEMBER KRESS: Okay, you do it --

VICE CHAIRMAN SHACK: But we don't know --

MEMBER KRESS: Both of those are variables.

VICE CHAIRMAN SHACK: We need to know one of those.

MEMBER KRESS: Yes.

VICE CHAIRMAN SHACK: And so the thought might be -- is that we can actually probably determine something about the frequency from accelerometers to so that when we do -- if we do -- when we do subsequent testing we will probably try to determine the frequency --

MEMBER KRESS: That's probably too small of an amplitude for an accelerometer to pick it up.

CHAIRMAN WALLIS: I don't know, microphone, I mean this thing could sing if it's really got that characteristic frequency.

MEMBER KRESS: Microphone might do it, yes.

VICE CHAIRMAN SHACK: Well --

CHAIRMAN WALLIS: You've got a musical instrument.

VICE CHAIRMAN SHACK: We don't think the frequencies, if they're audible, are high enough, that we -- it depends on how large you think the delta p has to be.

When we look at this we think the delta ps, to get the delta ps we think are reasonable we have to get the frequencies that are not in the audible range.

CHAIRMAN WALLIS: Not by you.

VICE CHAIRMAN SHACK: Well, coming back to my thing, when we put the surrounding tube on to essentially muffle the jet, of course the crack growth rate increased by a factor of three or four.

CHAIRMAN WALLIS: Well that's interesting too.

VICE CHAIRMAN SHACK: Then again, we did that with two kind of muffled jets, you know. And again the first tests were done with the jet off in air. And the thought was well if we put the jet into water that would dampen the vibrations in some sense.

CHAIRMAN WALLIS: It might make them worse.

VICE CHAIRMAN SHACK: Well it did.

MR. DAVIS: We tried looking with a scanning electron microscope at the fracture surface to see if we could see striations and we couldn't --

CHAIRMAN WALLIS: If a jet got into water it usually produces vortex rings around the jet.

MR. DAVIS: Here are the results graphically. What the muffled jet is is we just laid a plate over the crack and still allowed it to leak. But it was -- that was the slowest rate that we got other than the --

CHAIRMAN WALLIS: It's interesting that you cannot explain what's happening entirely by material's behavior.

MEMBER POWERS: The thermal-hydraulicists start to salivate. I am strictly reminded of the sage advice that came from Ivan Catton who pointed out that there was the big bang and everything else was thermal-hydraulics.

MR. DAVIS: Well we've sort of discussed this but the mechanisms that we're looking at are jet erosion of the crack faces, rapid lock erosion at room-temperature, which I think we can eliminate, jet-flaw structural dynamic interaction resulting in fatigue crack growth, which is what we think is the major contributor here, and then pressure oscillation from the pump causing crack growth.

And we think that's only a very minor part of this overall phenomenon.

CHAIRMAN WALLIS: Those are small fluctuations compared with the overall pressure.

MR. DAVIS: That's right. And we've actually hired a consultant to help us look into this.

VICE CHAIRMAN SHACK: And as Jim mentioned, you know, the next thought, the non-prototypical situation was we were dealing with a single phase fluid at room-temperature, would we still see this same phenomenon at high-temperature when we did have the two phase situation.

We ran the high-temperature test and we haven't finished the analysis but what it appears is that the crack growth rates, if not exactly the same, are really quite comparable to those we see in the room-temperature situation.

So the, you know, the flashing is not going to save your, you know, the -- locally it's still everything happens on a timescale for the flashing.

CHAIRMAN WALLIS: Is that true when you have a shroud around it as well?

VICE CHAIRMAN SHACK: We were shrouded -- I have to go back the look at the exact -- you know, we did -- we can't run the high-temperature test without a shroud because it --

CHAIRMAN WALLIS: It goes everywhere.

VICE CHAIRMAN SHACK: It's in a -- you know, it has to be in a confinement. And the confinement, you know -- so we -- it's probably the confinement we have is sort of equivalent to our medium size shroud in the room-temperature test.

And so that's the kind of baseline to compare against.

MR. DAVIS: The last area I'm going to discuss is the statistical treatment of our models. And what we've done -- Dominion Engineering developed CANTIA model which is a CANDU Tube Inspection Assessment model for the Canadian Nuclear Safety Commission.

And we obtained that code. What it does, it determines the probabilities of failure in leak rate from primary to secondary side during normal operation and during design basis accidents.

The models in the CANDU code are intended for the CANDU reactors -- the CANTIA code I mean, for integrity leak rate and degradation models. What Argonne did was they modified the CANTIA code maintaining the basic Monte Carlo structure but incorporating the Argonne models for predicting ligament rupture, unstable burst, and crack opening area, and leak rate for -- of flawed 600 tubes.

The source language was updated from Visual Basic 3.0 to Visual Basic 6.0, and the big advantage in doing that is that Visual Basic 3.0 limited you to 30,000 iterations for your simulation whereas the Visual Basic 6 has unlimited iterations.

MEMBER POWERS: The problem with it is

that your random number generator on the Monte Carlo system is flawed, and you add in the additional iterations. You're not doing any variance reduction.

VICE CHAIRMAN SHACK: We are at the moment using the built in Monte Carlo in Visual Basic.

MEMBER POWERS: Yes.

VICE CHAIRMAN SHACK: We sort of know there's a problem with that.

MEMBER POWERS: Yes, it only -- after about 32,000 you're just repeating the cycle again. It's a flawed random number generator in that code. You need to use something like a Mersenne Twister or something like that.

VICE CHAIRMAN SHACK: Yes. We're sort of aware that, you know, we're still worried about incorporating the models rather than actually exercising the Monte Carlo thing, so we're not --

MEMBER POWERS: Yes.

VICE CHAIRMAN SHACK: going to address that, but --

MEMBER POWERS: I agree with you but you've got an inherent flaw in that Monte Carlo mess there. I mean it's just not -- increasing the number of iterations is not going to do you any good at all.

CHAIRMAN WALLIS: If it's above your 32,000.

MEMBER POWERS: Yes, I think that's the cycle frequency on that particular random number generator. It's a linear congruential generator that's been floating around in the literature for dozens of years.

People write theses about how bad it is but it never goes away.

MR. DAVIS: The other change that we made is we went from a 1-D flaw model to a 2-D. And then we've added two crack growth rate models. One is the Scott model and the other is the Ford and Andresen model.

MEMBER POWERS: I think I don't get rid of that. We got rid of it.

MEMBER RANSOM: These models have uncertainties associated with them so when you do the Monte Carlo you're getting a distribution of -- I'm wondering why you don't only need like 69 iterations if you want a 95/95 result.

MEMBER POWERS: Well if you want to get the entire distribution with some precision you need to go up substantially beyond 69.

CHAIRMAN WALLIS: Sixty-nine is just for your one thing. If you want a distribution you need a tremendous amount more.

VICE CHAIRMAN SHACK: Gazillions.

MEMBER POWERS: Well, you don't need gazillions, but --

CHAIRMAN WALLIS: To find distribution you need an infinite amount of stuff.

MEMBER POWERS: You need -- I mean you need to know how precisely you want that distribution. If you just want to know a point value, yes. With 69 you know that you have samples about 90 percent of the distribution so you take you're highest value in that.

You can be reasonable confident that that's your 90th percentile value. But if you want to know the whole distribution with some accuracy -- the accuracy increases as only the square root of N so it takes a lot.

MEMBER RANSOM: When you say accuracy though, aren't the models themselves -- you know, have high degrees of uncertainty, presumably?

MEMBER POWERS: Yes, and what he's getting is a distribution of a result. And the problem is he's taking -- he's getting that distribution from finite sample, so the distribution itself is uncertain just because he's taking a finite number.

And to refine that distribution down, go slowly.

MR. DAVIS: Well, to summarize I presented models for plastic collapse of a tube with a through wall axial crack and a part-through wall axial crack.

And the -- also I presented the equivalent rectangular crack method. The original model underestimated ligament rupture pressures for short, deep cracks.

The Argonne modification provided much better results. The equivalent crack method was presented. It gives very good results for initial ligament rupture but not as good for subsequent tearing.

And then I presented the simple orifice model. It gets very good agreement for slits, orifices, and open cracks.

CHAIRMAN WALLIS: Now what's very good agreement? We've seen somebody's results of materials, research, and orders of magnitude here and there. Presumably you're not talking about that.

MR. DAVIS: No.

CHAIRMAN WALLIS: Five or ten percent agreement?

MR. DAVIS: Yes.

VICE CHAIRMAN SHACK: Give us 15.

CHAIRMAN WALLIS: You haven't shown us any data. If Peter Ford were here he'd say show me the data. Show me the data.

MEMBER POWERS: But we got rid of him.

VICE CHAIRMAN SHACK: We don't care about data now.

MR. DAVIS: I also presented the pressurization rate effects that we've discovered. And we're still not quite sure what the implications of that are, but it may be that the one industry is doing leak rate tests.

They may have to do them for a longer time. I presented the results of the results of the secondary side depressurization study, which you presented in much greater detail last February.

And basically what we've found is one and a half percent of the tubes are locked. Most likely they'll all be locked. It's very unlikely that only a couple would be locked.

CHAIRMAN WALLIS: When they're new they're not locked are they?

MR. DAVIS: They lock very quickly, the drilled hole.

CHAIRMAN WALLIS: But there must presumably be an instant when there's one locked if they're starting with none locked.

MR. DAVIS: You're absolutely right. And the thing that you have going for you in that case is that you don't have any degradation at that point.

So by the time you start getting degradation the tubes are locked.

CHAIRMAN WALLIS: Assuming you didn't put flaws in when you made the thing.

MR. DAVIS: You do a baseline and you hope that there's not --

CHAIRMAN WALLIS: Yes, you've inspected them all.

MR. DAVIS: And then --

CHAIRMAN WALLIS: And then putting the thing together you don't produce dents and --

MEMBER POWERS: You used to.

CHAIRMAN WALLIS: I bet they do.

MR. DAVIS: At Palo Verde the actually -- they drilled a hole in one of the tubes that was degrading that they put in.

CHAIRMAN WALLIS: Hammer it in because it didn't fit and things like that.

MR. DAVIS: Actually Westinghouse came to us and asked us about the orifice model for that case. And then I presented the constant pressure crack growth studies, and the active jets appear to be causing increased growth rate with time.

I think we have more work to do in that area. And then I presented the statistical treatment of the models that were presented. The future work that we're going to do is conduct tests on complex morphology cracks and develop predictive models for leak and rupture pressure.

CHAIRMAN WALLIS: There's no evidence of erosion of these walls? I mean there's pretty high velocity coming out there, isn't it? And water jets do erode nozzles pretty effectively.

You try to make a high pressure water jet, you've got to make it out of pretty hard and robust material otherwise it disappears after awhile.

MR. DAVIS: We did something similar

where we looked at the jets impacting adjacent tubes.

CHAIRMAN WALLIS: And it depends how clean the water is. If you have small particles in this water you can erode that -- the wall.

VICE CHAIRMAN SHACK: We see no signs of that in these jet tests. I mean when you look at the crack, you know, it's clearly a very fine type extension going out.

It's kind of a, you know, it's a low amplitude. You know, it's -- since you've eliminated stress corrosion as the mechanism you're really forced to conclude it's a low amplitude fatigue crack growth kind of thing that leaves you with very tight cracks, no evidence of any kind of the rounding that one would expect to see in an erosion type situation.

What, you know, what we haven't discussed here is okay, you get this jet driven crack growth. Obviously you don't get jet driven crack growth at 150 gallons per day.

That doesn't give you much of a jet. So the thresholds for this kind of behavior, you know, between the regulatory limits that you place on leakage and the kind of leaks that produce this jet drive crack growth are difficult to understand.

CHAIRMAN WALLIS: If you have a shape-edge orifice model for your flow, but shape-edge orifices are the ones that I'm familiar with that erode very -- that sharp edge doesn't last you very long.

VICE CHAIRMAN SHACK: You know, the long -- in the operation of equipment, you know, it may happen relatively rapidly. In the long that we're worried about, you know, we don't see any effect.

Now what we do need to understand, as Jim mentioned, you know, there's time-dependent leak growth in addition to this fatigue driven growth, that we really do see this notion that ligaments fail under creep or some kind of time-dependent deformation cracks open up, and to understand this whole scale over which we could go from a low leak rate to this, -- you know, once we get to this jet drive crack growth, you know, the jig is up.

You know, this all happens very quickly. But to understand the thresholds for that growth are sort of the problem we have at the moment. And you can't do that with an EDM notch because that's, you know, a three millimeter EDM notch gives you a far greater jet than a 3 millimeter crack would.

And so using our EDM notches is okay to demonstrate phenomena and to kind of sort things out, but it doesn't really give you quantitative results that you can use.

MEMBER ROSEN: So what I'm taking away from that discussion is that the typical operational behavior that you see of a crack is that it tends to -- the leak rate tends to increase gradually, and that you're saying that that is not erosion of the crack, it's typically crack growth that's causing that.

VICE CHAIRMAN SHACK: It could be a number of things. I mean it could be crack growth in the sense of stress corrosion crack growth, which proceeds, you know, at eight millimeters per year, you know.

That's that kind of a rate. It could them begin to open up and ligaments fail by creep which gives you increases in crack growth rate that take place over days.

And eventually that could lead to this jet driven crack growth which gives you crack growth rates on the order of a millimeter per hour.

MEMBER ROSEN: Well, yes. Plants don't monitor that. That's just the day it cracked.

VICE CHAIRMAN SHACK: Right, but it does sort of suggest that the margin we thought we had is smaller than it really was, that is you know, you're always computing well, you know, 150 gallons per day has to be a crack less than -- if it's going to grow to failure by stress corrosion, you know, it gives me essentially a year's worth of growth or more, you know.

But in fact I'm going to get to say, 6 millimeters, and you know, the game is going to be over. And I'm not sure that it's so inconsistent, you know, what always surprises me is how quickly steam generator tube ruptures develop in the field, that is that, you know, in theory -- I'm a leak-before-break kind of guy.

You should never get a rupture, you know. I should -- if I go from 150 gallons a day I should see impending leak rate increases that give me plenty of warning before I ever get to rupture. Well we get ruptures. And, you know --

CHAIRMAN WALLIS: Is this because of the liquid interaction with the --

VICE CHAIRMAN SHACK: Well, I'm not sure why.

CHAIRMAN WALLIS: It seems to be.

VICE CHAIRMAN SHACK: But things happen much more quickly -- now you can either argue that, you know, the growth and the degradation is occurring and you get a sudden pop-through.

But this to me provides another mechanism for how you go from relatively innocuous leak rates to rupture in timeframes that seem very short compared to our sort of classical leak-before-break arguments based on SCC crack growth rates.

So that, again, at 150 gallons per day it's not a problem, it's just that your margin between the 150 gallons and rupture, I don't think, is as large as you thought it was.

That's my takeaway from this situation. Now exactly how big that margin is we don't understand very well, but it's a lot smaller than you think it is if you're basing it on a kind of a stress corrosion crack growth picture.

CHAIRMAN WALLIS: You have flow, but you have rapid decrease in pressure near the hole, so you're actually imposing a stress gradient near that hole just because of the flow itself, no fluctuations at all.

That's in your -- that appears in your model too, does it?

VICE CHAIRMAN SHACK: No, it doesn't.

CHAIRMAN WALLIS: The fluid, if you've got a sharp orifice, is going from 3,000 psi to nothing in that tiny little length --

VICE CHAIRMAN SHACK: Yes, but --

CHAIRMAN WALLIS: -- which is imposed on the wall

VICE CHAIRMAN SHACK: But for fatigue, you know, I don't -- the 3,000 to nothing, you know, that doesn't grow anything by fatigue, you know. What I need --

CHAIRMAN WALLIS: No, no, no. But it's an imposed stress. It's a steady stress.

VICE CHAIRMAN SHACK: It's an imposed stress.

CHAIRMAN WALLIS: Yes, a steady stress field.

VICE CHAIRMAN SHACK: But you know, what I need to account for is the fact that this can fluctuate at a rapid rate at some unknown amplitude.

MEMBER POWERS: Bill, lithium niobate detectors won't do that for you?

VICE CHAIRMAN SHACK: Pardon me?

MEMBER POWERS: Lithium niobate kid of piezo electric detectors won't do that for you?

VICE CHAIRMAN SHACK: Oh, they probably will. We're sort of at this point, you know, we had a number of questions. One, was it fatigue drive, jet driven, you know.

And we think we settled that -- we settled that for the single phase room-temperature condition. Then the next question was is this an artifact of a room-temperature test or does it really exist under the more prototypical conditions.

We think our last test has settled that issue. Now it's time to go back and sort of think about --

MEMBER POWERS: Instrumenting --

VICE CHAIRMAN SHACK: Well, and we have to come up with tests that are more prototypical, that is we -- EDM notches won't tell you -- I mean we could do EDM notches to study frequency effects, but I think we really need to get, you know, if we're going to look at threshold crack sizes for which this takes over we need geometries that give us prototypical leak rates for lengths.

And EDM notches don't do that. They give us far too much leak rate for a given length.

MEMBER POWERS: I understand.

VICE CHAIRMAN SHACK: So they're very

conservative. And so we need to essentially do this with cracks, either fatigue cracks or growth stress corrosion cracks. And that's something that --

MR. DAVIS: That's something that we've been discussing a lot.

VICE CHAIRMAN SHACK: We're discussing at the moment.

MR. DAVIS: On how to produce the cracks.

MEMBER POWERS: I understand what the situation is.

MR. DAVIS: Yes, we talk about putting -- drilling a very small hole, and then use a 2 point or three point bending. But then you're got the hole there and that you don't really want.

So we're looking at other options. Maybe a surface scratch and then produce a fatigue crack. But we haven't decided yet. Or we could do the room-temperature stress corrosion cracks.

CHAIRMAN WALLIS: We have to speed up now.

MR. DAVIS: The other area we're working on is using other shapes than the rectangular crack method to model the cracks. And that might be like a trapezoidal crack or something like that.

And then we're -- as we develop and improve these models we're going to incorporate those into the CANTIA code as well. That's all I was planning on presenting.

CHAIRMAN WALLIS: That's what you're planning? I thought you were going to present the rest of it.

MR. DAVIS: I can present it if you'd like. Or --

MEMBER POWERS: We're only covering really Task 3.

MR. DAVIS: Task 3 is all you asked to cover.

CHAIRMAN WALLIS: You planned it very well, I'm sorry. I thought you were going to have another ten slides or so.

MR. DAVIS: Well I put those in --

CHAIRMAN WALLIS: Just in case.

MR. DAVIS: -- just in case there were no questions.

MEMBER POWERS: In the embarrassing case of no questions. Are there any other questions for the speaker?

MEMBER SIEBER: I'm curious about one thing. You know, they have a tech spec on it of 150 gallons a day, and it seems to me that if you had a single tube with a crack in it that was leaking 150 gallons a day is sort of a meaningless number as far as using it as a way to predict that that tube is going to fail.

You can measure down to a couple of gallons a day using radiological techniques, and I wonder why that number is so high. Is the presumption that you've got 50 tubes that are leaking?

You know, what is the assumptions behind that number?

VICE CHAIRMAN SHACK: Well I think if you look -- if you took the conservative assumption that it was all coming from a single crack --

MEMBER SIEBER: Yes.

VICE CHAIRMAN SHACK: -- but it was a stress corrosion crack, that would give you a large margin between -- I mean that's, you know -- the intent was to make it quite conservative.

And based on a single crack, which is a conservative assumption itself, and a stress corrosion crack growth rate, there is a quite large margin between that failure and burst.

CHAIRMAN WALLIS: That's with 150

gallons a day?

VICE CHAIRMAN SHACK: A hundred and 50 gallons a day.

MEMBER SIEBER: That's a lot of leakage from a single tube.

VICE CHAIRMAN SHACK: It's a small crack, you know.

MEMBER SIEBER: That's what I say.

VICE CHAIRMAN SHACK: If it's, you know, a few millimeters long and it takes you roughly a 25 millimeter crack to fail and it's growing by stress corrosion crack growth rates which are eight to ten millimeters per year, you nominally have, you know, a large margin to failure, which is you know, I think why that was selected as a --

CHAIRMAN WALLIS: Does fluid fluctuation effect this growth rate of these other cracks, these stress corrosion cracks? And once they get loaded with the fluid fluctuation --

VICE CHAIRMAN SHACK: Yes, some -- you know, this argument would tell you that at some point it's not going to grow from 3 millimeters to 25 millimeters by stress corrosion.

It's going to grow from 3 millimeters to X millimeters by stress corrosion. Then it's going to grow to 25 millimeters by --

CHAIRMAN WALLIS: By this fatigue.

VICE CHAIRMAN SHACK: -- this mechanism.

MEMBER SIEBER: Right.

VICE CHAIRMAN SHACK: And it's going to grow much faster. So if we knew what X was we'd know what your true margin was for the 150 gallons per day. At the moment all I would argue is that it's substantially smaller than you thought it was.

CHAIRMAN WALLIS: That's the thing that's striking to me is that if you were only doing materials analysis and you did it perfectly, you would miss an effect that you seem to have discovered experimentally, which is that the flow through the crack enhances the crack growth in a way which is quite --

MEMBER SIEBER: Dramatic.

CHAIRMAN WALLIS: And remarkable and --

VICE CHAIRMAN SHACK: And what Jim didn't tell you of course is that we didn't set out to study that problem.

CHAIRMAN WALLIS: You found it, you found it. I mean that's what happens.

VICE CHAIRMAN SHACK: We set up the test -- we were going to do a fracture mechanics tearing analysis where we would slowly grow this crack under increasing pressure.

CHAIRMAN WALLIS: Now let me ask you something.

VICE CHAIRMAN SHACK: It never got to a steady pressure.

CHAIRMAN WALLIS: You have discovered a mechanism for growing cracks more rapidly as a result of fluid structure interaction, which the experts who did the elicitation didn't know about perhaps when they were making their study of frequency of pipe break.

You've discovered a mechanism where by cracks can grow more rapidly than I think was known to most of those experts. Is that true?

VICE CHAIRMAN SHACK: You know, whether it's at all applicable to a pipe --

CHAIRMAN WALLIS: Well, the thing that concerns me is that, you know, if there's always this new mechanism that the experts didn't know about --

MR. MUSCARA: Joe Muscara with the Research staff. I think the thing we need to emphasize again is we found this phenomenon for a well developed jet that we get from a notch.

And we're trying to get more and more realistic in our testing. And then next step is to see what happens with cracks. We can have very long tight cracks that don't give the kinds of flows that we see with the EDM notch.

So it would still be a nice curiosity, but not really applying to real life.

CHAIRMAN WALLIS: We don't know.

MR. MUSCARA: We don't know.

CHAIRMAN WALLIS: It might be more important for a crack, a real crack.

MR. MUSCARA: No, I -- we've done work on real cracks and we have seen this magnitude of the phenomenon before. What we need to establish now is for a tight, long crack when do we get the kind of flow that leads through the fatigue crack route?

My personal view at this point is that's a pretty long through wall crack. But we need to see what happens in the testing.

MEMBER SIEBER: Well I think that you folks are sort of getting to my point. I think that when you use a number like 150 gallons a day you're already in the regime where you're into rapid crack growth rates now.

VICE CHAIRMAN SHACK: No, no, no.

MEMBER SIEBER: No, okay.

VICE CHAIRMAN SHACK: No, you know, we're seeing these rapid crack growths at two gallons per minute, but there is this whole problem of, as I say, there's a number of time-dependent phenomena that occur here that are not stress corrosion crack growth.

MEMBER SIEBER: Yes, right.

VICE CHAIRMAN SHACK: You know, the old models that we did never really considered the possibility of creep failure, and you know, failure of the ligaments increasing, you know.

So we get this increase in leak rate initially from other mechanisms that are probably more closely related to this ligament creep kind of behavior.

Then we get this jet driven thing. And I'll agree with Joe, you know, we don't -- all I would argue is that we get this jet driven thing long before we get to the 25 millimeter failure under static loading kind of condition.

So as I say, the growth from 3 millimeters to 25 millimeters by stress corrosion overestimates our margin. Now if it turns out that we don't see this until we get to ten millimeters you may well decide you still have enough margin and your, you know, your 150 gallons per day is fine.

All you want to do is just understand your margin, I think, at this point.

CHAIRMAN WALLIS: But it's in the direction of loosing margin.

VICE CHAIRMAN SHACK: You're clearly loosing margin.

CHAIRMAN WALLIS: It's something which I think you've discovered. It wasn't known before? So this is the sort of thing you have to guard against in asking experts when there are phenomena that they don't know about.

MEMBER SIEBER: Okay, thanks.

VICE CHAIRMAN SHACK: Well I mean we've looked increasing leak rates for quite awhile before we, -- you know, we were determined that it was due to time-dependent deformation and failure of ligaments because that was the model that we had in our head.

CHAIRMAN WALLIS: Right. And now you have another one in your head which might also be wrong. It's very interesting.

MEMBER SIEBER: Thank you.

MEMBER POWERS: Any other questions? Seeing none I turn it back to you, Mr. Chairman.

CHAIRMAN WALLIS: Being ten o'clock, we're always operating on time, we will have a 15 minute break until 10:15.

(Whereupon, the above-entitled matter went off the record at 10:01 a.m. and went back on the record at 10:17 a.m.)

VICE CHAIRMAN SHACK: Let's come back into session. Our next presentation is on Digital Instrumentation and Control Systems Research Plan. And Dr. Apostolakis will lead us through this discussion.

MEMBER APOSTOLAKIS: Thank you, Bill. The Office of Research has developed a plan, the NRC Digital System Research Plan for the fiscal years 2005 through 2009.

And this is the subject of today's meeting of the ACRS. But there is an unusual situation here. There are memos from NRR that -- well, there is a memo from Mr. Dyer, the Director of NRR, to Mr. Paperiello, the Director of the Office of Research which sends a mixed message there.

On the one hand he says we believe that the SRP presently is adequate to provide guidance to the Staff in performing safety reviews. But at the same time it says we generally support an active research program in this area.

But then there is a memorandum from the Electrical Instrumentation and Controls Branch of NRR that is very unusual. Essentially it looks at each project, almost all the projects that are in the research plan.

And there is a constant theme where they end by saying for example, there is no aspect of this project which will assist in risk assessment of digital systems and therefore is not justified on a risk basis.

There is no aspect of this project which will assist in risk assessment of digital systems and therefore is not justified on a risk basis. Constantly they dismiss all of them, except three which they feel may have some merit.

So here we have now the user organization saying we don't need it. And I don't know what to do. This is a briefing for information purposes today.

The idea was to select particular projects for more detailed review of the Subcommittee meeting which is coming up in June.

Obviously it seems to me we have to have somebody from that branch of NRR to explain to us their position.

And then we expect the stuff to come back to the full committee in July for a more formal review of the plan. So, with these --

MR. MAYFIELD: Dr. Apostolakis?

MEMBER APOSTOLAKIS: Yes?

MR. MAYFIELD: If I might. This is Mike Mayfield. I'm the Director of Division of Engineering at NRR. The memorandum from Mr. Dyer to Dr. Paperiello is a draft that had not yet been signed and had not as of this -- as of half an hour ago we were cleaning up some final issues.

The sentiments expressed in the non-concurrence memorandum from Mr. Calvo were those of Mr. Calvo. And while we, the Office, will be providing some recommendations and we believe constructive comments that address some of the technical issues raised in Mr. Calvo's memorandum, the Office has comments that will be provided.

It's my understanding the comments that will be provided in the formal memorandum for Mr. Dyer to Dr. Paperiello did not reach the same conclusion as the comments reflected in Mr. Calvo's memorandum.

The technical substance, much of that will be reflected in recommendations and suggestions to research for their consideration in the plan. But the sentiments that you were reading are not reflected in the comments that are being passed at the office level.

MEMBER APOSTOLAKIS: Okay.

CHAIRMAN WALLIS: Well, Mike, didn't NRR ask for this work in the first place?

MR. MAYFIELD: There have been variations on the user need memoranda and where those go. The notion that's in the Dyer, at least the draft Dyer to Paperiello memorandum, today we believe the standard review plan is adequate for the work that's in the plate today and in the relatively near term.

However, we do recognize that there's a lot of interest in new designs, some of this being somewhat into the future. And as a matter of policy we think that an active research program in this general area is useful.

There are, however, recommendations and some suggestions that we will be providing back, and it was just unfortunate we couldn't get the memorandum finally signed.

CHAIRMAN WALLIS: So this isn't in response to a user need memo, this plan that we see?

MR. MAYFIELD: Not the whole plan, no sir, which I am assuming that Research will explain how that fits. But I did since Dr. Apostolakis had this information.

MEMBER APOSTOLAKIS: So I was not supposed to --

MR. MAYFIELD: It's fine. I mean it's where it is. It's just the memorandum from Mr. Dyer to Dr. Paperiello has not been signed --

MEMBER APOSTOLAKIS: Okay.

MR. MAYFIELD: -- or hadn't been, simply just getting --

MEMBER APOSTOLAKIS: But it was much softer than the actual comments from --

MR. MAYFIELD: Yes.

MEMBER APOSTOLAKIS: -- that branch, which --

MR. MAYFIELD: Yes, sir.

MEMBER APOSTOLAKIS: -- were overboard, in my view. But there's one other thing here that, I don't know, it says in that memo from Mr. Calvo, it is recommended that in the future Research discuss these proposed research activities with individual NRR branches and sections prior to issuing their research plan.

I would expect that to happen. Doesn't it happen?

MR. MAYFIELD: We will be working as we go forward with -- and as we pass the comments from Mr. Dyer back to Dr. Paperiello, we will expect to have engaged with Research at the division branch and section levels as we need to, to make sure everyone understands the basis for the comments and the recommendations and how they may or may not be accommodated in the research plan.

And that's a dialog that we look forward to having.

MEMBER APOSTOLAKIS: Okay.

MR. MAYFIELD: Okay.

MEMBER APOSTOLAKIS: Rich?

MR. BARRETT: Yes.

MEMBER APOSTOLAKIS: I understand you will step up.

MR. BARRETT: Yes, just briefly. Mike already said a good bit of what I was hoping to say. But I do want to point out that the Instrumentation and Control Research Plan is a significant initiative for the Office of Research.

It's an area where we anticipate innovation in the future within the industry. And it's an area where safety and security challenges can be anticipated, especially as we go into follow-up licensing.

We have been discussing this plan with NRR for sometime, and also with NMSS and NSIR. And we look forward to getting feedback from all of the user offices on this end, and to interacting with them on an ongoing basis.

To support this effort, we in the past year have created a new section within the Engineering Research and Applications branch. And we've selected Bill Kemper to be the Section Chief who comes to us with considerable industry experience.

Bill is here today in spite of the fact that his daughter is graduating from college tonight in Florida, so if we run a little long this morning you're going to see go Bill get up and leave.

It's not -- please be aware he has good reason. We also note that the ACRS has -- now has an I&C Subcommittee. And that -- we think that's a very important step.

We look forward to interacting with you early and often, and we look forward to your input on this plan.

MEMBER APOSTOLAKIS: After I read that memo I thought maybe we had asked him to form a subcommittee. Nothing is needed. This is great.

MR. BARRETT: I think that the way we view it is that this is an area where we can anticipate a great deal of need. So with that brief introduction let me turn it over to Bill Kemper.

MR. KEMPER: Thank you, Rich. Again, I'm Bill Kemper.

MEMBER APOSTOLAKIS: Again, I don't know how I got this memo by the way, but what I do is I just go back to my computer and download and print it before I come here. So some --

MR. MAYFIELD: The memorandum isn't a great secret. It's part of an internal process.

MEMBER APOSTOLAKIS: Okay, all right.

MR. MAYFIELD: And --

MEMBER APOSTOLAKIS: I just didn't know -- and also of course when you get something on the computer I don't think the signature is on it.

MR. MAYFIELD: We see, you know, this is something where the office welcomes views, and that informs --

MEMBER APOSTOLAKIS: So it wasn't anything inappropriate?

MR. MAYFIELD: It was nothing inappropriate, and the information will inform Mr. Dyer, --

MEMBER APOSTOLAKIS: Okay.

MR. MAYFIELD: -- as he moves forward.

MEMBER APOSTOLAKIS: Thank you.

MR. MAYFIELD: Thank you.

MEMBER APOSTOLAKIS: Please

MR. KEMPER: Again, thank you.

MEMBER APOSTOLAKIS: Who me?

MR. KEMPER: Closer to me? Okay, can you hear now? Well again, I'm Bill Kemper. Thanks for having us and it's nice to meet you all. I am relatively new to the Agency, as Rich eluded to.

Most of my experience has been in the nuclear power industry. I have worked at three different utilities in three different power plants with a lot of experience in operations and also in instrumentation and control engineering from a commercial standpoint.

This committee has reviewed the previous research plan, I believe in 2001, and that covered from 2001 to 2004. We're here to present the draft Digital Safety -- Digital System Research Plan which covers the next five years basically, up through 2009.

Some of the projects we discuss are carryover items from the previous plan so you may be familiar with them. And I know that we've been before this committee on various occasions talking about selected projects, but there's also many new projects that we're going to discuss as well.

This briefing really is intended to provide the Committee with the information needed to determine what further interactions are needed from us with you all regarding individual programs and projects.

Also we have a lot of material to cover, you'll see when Mike gets into his presentation, and a relatively short time to do it, so we're going to try our very best to stay on schedule.

And so really with that, I'd like to introduce Mike Waterman. He's a Senior I&C Engineer in our section. He's going to provide the overview.

MR. WATERMAN: Good morning. My name is Mike Waterman. As Bill told you, I work for him in the instrumentation and control section. I started to work for the NRC in 1990, and for the first 14 years I was in what is now the Instrumentation and Control Section of the Electrical and Instrumentation Controls branch in NRR.

During that period of time I reviewed quite a few safety systems. Approximately 20 of those have been digital safety systems ranging in complexity from systems as such simple as aux feedwater systems, load sequencers, up through all of the oscillation power range monitoring systems used in BWRs today.

I also reviewed the Teleperm XS, so -- I came to the Office of Research with kind of a regulator perspective on the things that I thought I needed to get my job done as a regulator.

For the past ten years I've been on two working groups, IEEE working groups, the IEEE 10-12 Verification and Validation working group, and the IEEE 7-432 working group.

I was secretary on that group. In addition to that, in the past year by invitation I served as a member of the management board of the IEEE Software and Systems Engineering Standards Committee.

That management board oversees the

development of all software and systems engineering standards for IEEE. So with no further ado, that's just some of my background, I'd like to get into the presentation first with an overview that the research plan as we wrote it provides a flexible, adaptable framework for identifying NRR, NMSS, and NSIR research initiatives.

The original research plan, the 2001 to 2004 plan simply addressed the NRR research initiatives. We felt that for safety related systems we should write a plan that also supported the other offices.

The research plan is oriented toward providing a more consistent process for regulating nuclear applications. My perspective as a regulator was that I was getting a lot of technical guidance but sometimes I wasn't getting a lot of regulatory based acceptance criteria.

So when our -- so in the process of writing this plan we decided that what we would do is expand the plan's responsibilities such that in addition to regulatory guidance we would also develop a regulatory based acceptance criteria that we're objective, that a person can say either yes or no on the acceptance criteria.

Additionally, sometimes we needed assessment tools and methodologies that I did not have available to me as a regulator. I felt that including, acquiring if at all possible instead of developing assessment tolls to help the regulator evaluate the licensee submittals against the regulatory based acceptance criteria consistent with the technical guidance.

CHAIRMAN WALLIS: Can I ask, are these -- are objective acceptance criteria and assessment tools that things that the author of this memo thinks are not needed?

MR. WATERMAN: Yes, I suspect --

CHAIRMAN WALLIS: It seems to me they're very desirable things to have.

MEMBER APOSTOLAKIS: No, but the point is that maybe it's also a matter of language. I mean when you say more consistent processes, you're implying the current processes are not consistent.

And the guy who's implementing them may get offended by that. You're saying that you're going to have more objective acceptance criteria and the guy who's doing it now thinks that his criteria are objective.

So is it a matter of communication,

really?

MR. WATERMAN: Well, as I --

MEMBER APOSTOLAKIS: You're cutting them off?

MR. WATERMAN: Well, sir, as I recall the phrase was that the standard review plan had acceptance criteria.

MEMBER APOSTOLAKIS: Yes.

MR. WATERMAN: It doesn't mean it's all objective. Some of the acceptance criteria could be subjective. For example, take Branch Technical Position HICB-14 on software quality assurance.

I went through that Branch technical position, identified something like 183 different attributes with associated acceptance criteria. About half of those acceptance criteria for those attributes were subjective.

For example, I just happened to have the report here on style. Where you're supposed to check the style you're supposed to check the style against this NUREG-6463 which is review guidelines for software languages in nuclear power plant safety systems.

That's one acceptance criteria, right? Make sure that the style is in conformance with this but there was no way to really assess that. It's fairly subjective, do you use the book, what parts of the book do you use, etcetera.

I consider that to be kind of a subjective acceptance criteria about what parts of the book would go into particular review. And part of that is the way it's structures right now in my experience was that depending upon the impressions of the person doing the review you could come out with different results of the review simply because some of the acceptance criteria were not objective enough.

And it seemed to me that when a licensee has somebody show up at the site, it shouldn't really matter which regulator shows up at the site, or which regulator reviews their products, the results should always be the same.

The licensee should be able to expect a consistent review process. And what I found was that even with one person doing all of the reviews, the process wasn't always consistent because a lot of times I just didn't have assessment tools or detailed enough methodologies to keep myself consistent, especially when you think that over 20 -- over 14 years I reviewed only 20 projects, so it wasn't like I was going from project to project to project doing reviews.

I had other duties in between so consequently sometimes I lose the focus a little bit. You know, come into the next review and I'd have new anecdotal evidence to think about reviewing.

So I was sort of frustrated as a regulator by the fact that I did not have all of the objective acceptance criteria I thought I needed to be either justified putting my thumb down or putting my thumb up and saying this system is safe enough.

I reviewed a lot of systems. I approved those systems on the basis of the information I had available to me at the time, which was mainly I reviewed for quality.

And if the quality was high, and I did a couple thread audits to look at a couple safety functions and if those were okay, then I inferred the safety of the system from the quality of the development process.

Well it seems to me that I need something more than just quality to acceptance criteria when I do that. So that's where I'm coming from as formal regulator.

And I came over to research with the intent, really, of trying to improve that regulatory process to make it easier for the next regulator to come along to do his job.

Additionally, we don't have any formal training right now for bringing along new staff. When I was asked to train a new staff person my training involved taking that person with me on a software review at a licensee site and giving him on the job training while I was trying to do reviews.

It seemed to me that on the job training is really not the way we want to go. We want a systematic training process where when we bring in new staff they're actually trained in a consistent -- to review things in a consistent manner.

So I'm on a soap box now and I'm getting way off of the review right here. I think we really need to move on. I would like to say that in addition to their assessment tools and methodologies, I think we need to develop review procedures, and in some cases inspection procedures, so that we can codify exactly how a review is to be conducted.

And then also in the play you'll notice that we say we should develop curricula for each one of these projects, not a onetime training shot, but an actual training program so that when people come in as a regulator they can go through that training program and understand the technical guidance, understand what the objective acceptance criteria mean, and know how to use the tools.

So with that in mind I just want to say the plan is in draft mode right now. I expect it to change. There's things in there I can't believe I wrote to tell you the truth.

And those things will come out. And I really look forward to addressing all of the comments, whether they be on a non-concurrence or whatever to make this plan a better plan.

And obviously you're an important part of that.

MEMBER ROSEN: It seems to me your training program should be based on a task analysis, what you expect the person to do, just as we do task analysis for operators or engineers in the industry.

It seems like you have the same, start by figuring out what it is you want them to do, and then proceed from there to a program design.

MR. WATERMAN: Yes, sir. That's a good point. I've got a note here. I'll be sure to incorporate that.

MEMBER APOSTOLAKIS: All right, let's move on to three.

MR. WATERMAN: So what's the current situation? The issues facing NRC is that licensees are replacing, I've got up here analog systems with digital systems.

Well hey, we must be in the second generation because they're now starting to replace digital systems with digital systems. Take the core protection calculators at Palo Verde that's just gone in.

And licensing these digital systems presents some challenges to the NRC because of the increased complexity and the increasing complexity because we're seeing larger systems coming down the pipe.

There are rapid changes in the digital technology, and these may introduce new failure modes. So we believe that the licensing processes, while they've been serving their function, they ought to be kept current.

The standard review plan, latest revision 1997. A lot of things have changed since 1997. So we believe that we need to keep updating that standard review plan for the new issues.

We want to go to a risk-informed, performance-based safety assessment process for licensing digital systems, 1997 we weren't talking risk informed, I believe.

MEMBER APOSTOLAKIS: Now this is an important slide, I think, which in my mind should be expanded. And in general, this committee in the past when we were reviewing research plans, most notably the Human Performance Research Plan, we asked two questions.

What is the current situation? Where are we now? You're addressing some of it here, but maybe we should have a little bit more detail maybe at the Subcommittee meeting.

And were to we want to be say three, five years from now? I think that would be a good guidance, and also a nice framework within each of the projects can be evaluated.

And, you know, there may be specific issues, and say, you know, the SRP now has this deficiency, it was developed at some other time, and now we have new information, you know, and this is what we want to do.

And I, myself, am also all for expanding our state of knowledge and thinking about things. I mean we don't have to have a specific tool in mind, but we should not meet that this particular project will seek to, you know, broaden our horizons or whatever.

I think this is very important for -- we found it very important in the past for research programs. So I would encourage you, maybe by the Subcommittee time to think a little more about this and expand it a little bit. And then we'll take it from there.

MR. KEMPER: We do have a specific section in here we're going to talk about in some detail about the risk aspect of this, so hopefully we can answer some of that --

MEMBER APOSTOLAKIS: Yes

MR. KEMPER: -- as we go through.

MEMBER APOSTOLAKIS: Now another thing I want to say, and the last one, risk-informed performance-based should be developed. I would say that your research really should explore whether it can be developed because there are situations right now where we are not sure, like safety culture is one.

But this can be in a PRA in the

foreseeable future. And maybe this thing, the digital I&C, I don't know, fundamentally it's requirements are specification errors, right, which are really in the broader class of design errors.

And nobody knows how to bring these things into a PRA. Design errors in hardware are not in the PRA, yes or no. The answer is no.

CHAIRMAN WALLIS: Well, I was just wondering, I have no idea how reliable digital stuff is going to be compared with pipes and pumps.

MEMBER APOSTOLAKIS: That's true, that's true. But we should --

CHAIRMAN WALLIS: Or people.

MEMBER APOSTOLAKIS: I mean I think the --

MEMBER POWERS: I know relative to people.

CHAIRMAN WALLIS: All right.

MEMBER APOSTOLAKIS: The last one is stronger really than the current state of the art allows -- I mean you can't really claim I will spend, you know, five million dollars and two years from now I'll have digital I&C in the PRA because there are fundamental questions there that need to be addressed.

I'm not saying don't to it, I'm just saying change the words.

MEMBER BONACA: One question I have. I would like to just, you know, I always here about increased complexity. Do you view the complexity as necessary or it just as an offspring of the capability of the digital system to give you a lot of more information so you can use it for everything?

I mean we have seen what's happening in the automotive industry where there are some cars with such complex digital systems, not necessarily important to run the car, just simply they give you so many options, and then they don't run.

They are even, you know, the -- taking them back. Is it a similar situation, or is the complexity necessary?

MR. WATERMAN: Well, yes, I think it's a little bit of both, Dr. Bonaca. First, the systems are getting bigger. I think Oconee has come in, Paul Loeser is back there.

He's lead reviewer on the Oconee system. That's a full reactor protection system, engineered safety feature system changeout. Much more complexity involved in that system.

From the other perspective, part of the reason digital systems are being used is because they do provide additional capabilities, such as self-testing, allowing you to monitor processes more closely, voting logic and things like that.

So it's a little bit of both really. You know, it's just something we're going to have to face in the near future here. With regard to your comment, Dr. Apostolakis, my original draft which my boss would not allow me to bring in here -- slides, it had 122 slide in them so they wouldn't allow me to bring that in here, so now we're down to 29. So we do have a lot more detail --

MEMBER APOSTOLAKIS: At the Subcommittee you can bring 200 slides.

MR. WATERMAN: Thank you.

MEMBER POWERS: You'll only use 25 of them but you can bring 200.

MEMBER APOSTOLAKIS: One other thing that is of general interest and just occurred to me, because we were discussing it yesterday I think it was, it seems to me -- and in fact yesterday in that context we said that belongs to the digital I&C subcommittee.

What is the increasing use of digital

I&C doing to operator performance? Okay, somehow this has to be addressed by somebody. Okay. Are they bored to death or are they doing something else?

You know, because -- okay that's enough, let's move on.

MR. WATERMAN: The research focus in the plan is structured to develop better methods and to understand new technologies. First we know we need to consider going to risk-informed.

For example, by looking at risk assessment capabilities we want it to be more performance based. And for that we'd like to take a look at some methodologies for doing dependability assessments.

And we want it to be objective and repeatable, which is sort of my area.

CHAIRMAN WALLIS: It's not just dependability, it's whatever the measures of performance need to be.

MR. WATERMAN: Yes, sir. And we want it to be objective and repeatable, for example, measuring the software quality with some for of a methodology.

The focus is broad based, and it focuses on improving traditional review methods, not replacing. All we're trying to do is augment the traditional methods because there are certain necessary functions that have to be carried out in our traditional reviews now.

We do that, for looking at new applications, advanced applications, and looking at new issues and regulatory requirements. And we've had some new issues coming up since 9-11, haven't we?

The research plan is broken down into six basic programs shown here on this slide here. And I'll discuss each of these programs as we go. I'm just going to give you a high-level view of the various projects in these programs or the programs themselves.

MEMBER APOSTOLAKIS: So if I look at this figure now, which boxes are of immediately interest to NRR?

MR. WATERMAN: Well, system aspects of digital technology deals with a lot of things that are going on right now, for example, in the environmental stressors.

So obviously ongoing projects are immediately concern, right? Now the risk assessment of digital systems, we've been doing that research for some time, so that's fairly high priority because it's ongoing and we're trying to get to an answer on that.

MEMBER APOSTOLAKIS: But is NRR interested? Probably not. I mean right now they don't have a need for that. They have to -- I mean they have to understand the system aspects.

They have to say something about the quality of the software, but rather it contributes to risk probably is of no interest to them. That doesn't mean

MR. WATERMAN: Well --

MEMBER APOSTOLAKIS: -- it's not important.

MR. WATERMAN: Well --

MEMBER APOSTOLAKIS: I'm just trying to understand where they're coming from.

MR. WATERMAN: Well the PRA branch in NRR may have a different perspective on it.

MEMBER APOSTOLAKIS: The PRA branch may have a dir perspective. That's very true.

MR. KEMPER: We really have not had a chance to talk with NRR about this at all, so I apologize, I just -- we really can't answer any questions about NRR's perspective, if you will, in terms of that memo that you read there, so --

MEMBER APOSTOLAKIS: Okay.

MR. KEMPER: But as Mike said, we are talking with various portions of NRR, and the risk branch, particularly. Cliff Dowd, we've been in communication with him, is interested in participating with us on this risk aspect of this project.

MEMBER APOSTOLAKIS: Well maybe I should have put it in a different way. Not which boxes are of interest to them, which boxes are relevant to regulatory decisions that are being made now.

That's a different way, but it's more accurate.

MR. WATERMAN: Well I think when we get into the projects area, you know, we'll be able to --

MEMBER APOSTOLAKIS: Okay.

MR. WATERMAN: -- you know, maybe touch on that in a little bit more detail.

MEMBER APOSTOLAKIS: But in the future maybe we should have an answer at this level as well.

MR. WATERMAN: For example, our advanced

nuclear power plant --

MR. KEMPER: I think they all do.

MR. WATERMAN: -- digital systems project we're kind of on hold right now. Plans that have been submitted have been differed for further review.

Other designs are potentially being submitted, so let's get into the system aspects of digital technology, and we'll start right in. This seven projects in this particular program -- and let me talk about what we've done in environmental stressors.

The environmental stressor stuff is pretty much wrapping up now. We actually had three subprojects in environmental stressors that dealt with EMI/RFI.

There's one particular area on fast transient response that we needed to address. And we've updated Regulatory Guide 1.180 that endorses a couple of different standards on that.

CHAIRMAN WALLIS: Isn't this a moving target though, digital systems? As you get smaller and smaller spacings in the memories and so on --

MR. WATERMAN: Your IC circuit density.

CHAIRMAN WALLIS: -- and the Moore's law

and all that, then the breakdown that comes easier from lightning strikes and so on.

MR. WATERMAN: Yes, sir.

CHAIRMAN WALLIS: What you may have okay today may be no good at all next year because if you update, upgrade your electronics it's more susceptible to something just shorting out from lightning.

MR. KEMPER: Well, I think what --

CHAIRMAN WALLIS: It's going to be performance-based then.

MR. KEMPER: Sure. But as vendors seek to qualify these platforms, they know they have to comply with the standards and guides that we have now.

CHAIRMAN WALLIS: So you have to have some standard tests or criteria or something.

MR. KEMPER: Exactly. So as they see the need to upgrade those they'll invoke changes in industry standards, you know, I triple E standards, and therefore we'll follow that with regulatory guidance.

MR. WATERMAN: Additionally part of this guidance there is on how to harden the installation more so maybe than hardening the chips is what do you do for shielding, things like that.

For example, in the lightning we really haven't had any comprehensive guidance on lightning. We've got a draft guide out there now for public comment DOING-1137 that looks at several standards.

And most of that is addressed not toward so much, you know, how do you keep a micro electronics safe when lightning strikes it, but how you make the station absorb the lightning strike without it effecting your microelectronic.

In the area of environmental qualification we have a draft guide that's still in house on DG1077 that endorses a couple of new standards. IEEE 232 (2003), I think the last version of that was 1983, 2003, and then there's an IEC standard 60780 I think, something like that.

And Christine Antonesca can talk to that in more detail. So we're circulating that EQ draft guide right now through NRR and we've been working back and forth with them to come to some resolution on it.

I believe the Committee here has addressed the IEEE standard 323 endorsement in the past. I've only been in research for a year so I haven't really been involved in that project.

With regard to systems communications, the trend in digital safety systems, as you know, it toward networked intrasystem architectures using dedicated communication.

MEMBER APOSTOLAKIS: Is that also in the nuclear industry?

MR. WATERMAN: Yes, sir. If you take a look at the Teleperm XS the safety systems they're anticipating developing out of that are all, you know, internally networked, not networked to the outside word, but it's a network where you have two by four voters in every channel sharing information between channels.

You have micro processors that are dedicated to communicating data back and forth.

MEMBER APOSTOLAKIS: Now when you say intrasystem, what do you mean?

MR. WATERMAN: Now within -- our philosophy with digital safety systems is if there is a network that network cannot be interfaced with non-safety networks in such a way that a non-safety network could adversely affect the safety network.

MEMBER APOSTOLAKIS: But all the safety related systems will belong to the network?

MR. KEMPER: Well, you know, I don't

know.

MEMBER APOSTOLAKIS: Is there separation between the safety systems?

MR. WATERMAN: I beg your pardon?

MEMBER APOSTOLAKIS: The digital.

MR. KEMPER: There a common data acquisition, you know, if you will, protocol between the information busses, if you will. Many of the safety systems draw information from the same sensors out in the plant, for example.

So that's the type of what we're talking about as far as the intrasystem architecture so it's important that we understand these things and make sure that the communication protocols are established correctly so that, you know, problems won't result inadvertently.

MR. WATERMAN: And I use the word intrasystem because the NRC is very sensitive to having safety related networks connected to non-safety related networks.

MEMBER APOSTOLAKIS: That's a no-no, I understand.

MR. WATERMAN: Absolutely.

MEMBER APOSTOLAKIS: That's fine.

MR. WATERMAN: But within the network

itself it's all safety related. There are certain issues that need to be addressed. For example, what are the safety related aspects of proprietary communication protocol?

What things should a protocol do that are safe and what things ought a protocol not do that could adversely affect safety? To tell you the truth, we really don't review protocol right now.

MEMBER APOSTOLAKIS: Wait, if it's proprietary, you mean to the company that developed it, right?

MR. WATERMAN: It may be to the company that developed it. I believe that Siemens Teleperm XS, that's the one I have most experience with, developed their own communication protocols.

So while they're proprietary to the outside world, we can still for the most part get in and review the protocols.

MEMBER APOSTOLAKIS: Yes.

MR. WATERMAN: But you have to ask what's the acceptance criteria for a good protocol. I don't know. To tell you the truth I really don't know.

I guess I'm not smart enough to know that. So we need to provide the Staff with some guidance so that when they're reviewing a communication system that's safety related they understand what they have to look at when they're looking at a protocol.

MEMBER ROSEN: Let me pursue this separation idea for a -- if you have a process parameter in the plant that's used for both safety related purposes and non-safety related purposes, can you use the same sensor or must you have two separate sensors?

MR. WATERMAN: You can use the same sensor, but you have to isolate the non-safety component of that signal from the safety component. So generally what you do, you have sensor that comes down.

The sensor transmits off to the plant computer, which is a non-safety system, right? And that transmission link from the sensor to the plant computer is an isolated link.

Perhaps it's fiber optic, or photo isolator or something like that. And another connection goes to your safety system such that you're non-safety system can't feed back in and corrupt your safety system.

But you can use the same processor. And

I think that's fairly common.

MR. KEMPER: Commonly done, right? TF control, rod control systems, they are often the same temperature indications, for example, as the RPS does.

MR. WATERMAN: Where we were really concerned with isolation on safety systems is -- I know the plant computer is non-safety and it's receiving a lot of inputs.

And if you don't have one-way communication to that plant computer -- that there's a potential that some -- by some means the plant computer could corrupt your safety system.

Obviously we have two-way communication with safety systems with sort of non-safety systems with you put up a maintenance and test panel to go in and do an update to your safety system.

And then the maintenance and test panel is disconnected. And that's -- those are some security concerns there we're also going to address.

MEMBER APOSTOLAKIS: Okay.

MR. WATERMAN: With regard to COTS digital safety systems, we have already in house a ton, if you will, of guidance on how to review COTS safety systems.

The way the industry dedicates a piece of commercial off-the-shelf equipment is they use one or more of a combination of four basic processes. They do test and special inspections, source verification, supplier surveys, or use historical data.

But the historical data has to be used in combination with one of those other processes. Two of those processes are fairly qualitative when you think about it, the source verification where you go out and watch your equipment being made, and a supplier verification which is sort of like an Appendix B auditing process that a licensee or a vendor would use on somebody who's not an Appendix B programmer.

What we do when we review the COTS equipment is we use the qualitative process to review a qualitative result. It seems to me that maybe we need some independent way of assessing, you know, how well a COTS dedication was done.

For example, maybe by using the fault injection method that's been developed for estimating digital system dependability in COTS, and when I say system I don't mean -- you know, when I think of system I think of the hardware integrated with the software, the hardware and the software.

So you got three components that make up a system. And that -- whenever I say system just try to keep that in mind. It's hardware, it's software, and it's the integration of hardware and software.

MEMBER RANSOM: I guess you include the communication system or the

MR. WATERMAN: Well, whatever system it is --

MEMBER RANSOM: fiber optic or hardwire --

MR. WATERMAN: -- if it's digital it has they're major components that you have to evaluate, hardware alone, software alone, and how those two integrate together.

Sometimes the integration is where all the problems are.

MEMBER RANSOM: Yes.

MR. WATERMAN: Without what we're looking at is a way of refining our methods for reviewing COTS equipment such that we may have an independent process, which I believe is -- what we're supposed to be is reviewing things independently, independent from what the licensee of the vendor did.

MEMBER APOSTOLAKIS: How are we doing it now?

MR. WATERMAN: Well, the way we do it now is we go to the licensee or the vendor and we take a look at their COTS dedication, we review what criteria characteristics they felt that they had to match up with the manufacturing process.

We take a look at the documentation that shows what process they went through and is that process consistent with an Appendix B process. Take a look at the results of their special tests and inspections, for example, or look at their source verification and look at the scope of that and come to a conclusion about whether or not they followed a good process in dedicating that equipment.

EPRI has done a pretty good job of addressing COTS. This goes back to the, as you recall, the early '90s counterfeit parts issue. And we've reviewed that COTS -- or that EPRI COTS technical report and have endorsed it with a safety evaluation report.

I believe Paul Loeser had a lot to do with that. And that provides some pretty good guidance, but right now what we're doing is reviewing what the licensee wrote down.

And there's -- we haven't had a lot -- a lot more independence than that. And sometimes that kind of made me nervous because a lot of times the licensee writes down what he wants you to see.

So with regard to electrical power distribution systems interactions, this is actually an internal research project. We're anticipating supporting our division of safety analysis and regulatory effectiveness.

What they have found is that there's been a lot of nuclear power plant digital-controlled power equipment that has reflected sensitivities and changes to grid voltage.

Grid stability goes down, your voltages fluctuate, and normally we would say well that's not a big deal because we have uninterruptible power supplies.

We can address that. What they have found is that sometimes the uninterruptible power supplies haven't responded as expected. At other times the plant has been requested to try to make up for the power and couldn't do it because it's voltage regulators weren't set correctly.

At other times the voltage would

fluctuate enough to drop down to the 80 percent threshold level, which you know, most of you know nuclear power plants.

Eighty percent drop in voltage is a reason to trip your reactor coolant pumps. It challenges your safety system. So there's been like over 100 licensee event reports that have been identified of grid fluctuations, of challenging nuclear power plant safety systems.

And so we've been requested by the Office of Research to go ahead and assist them in the evaluation of this, and kind of come up with some way of determining the effects of grid voltage fluctuations on electronic equipment.

Now let's take a look at our voltage. Our voltage and power characteristics, or voltage and current characteristics inside the plant, which is taking a look at the total harmonic distortion, which is all the harmonics in a typical sine wave, all the extra harmonics divided by the characteristic wave.

And they usually represent that some percentage of total harmonic distortion. Now when you talk to most people they'll, you know, say well what's your sources of total harmonic distortion.

And the obvious answer is well, power supplies, motor control centers.

But actually any non-linear load will introduce additional harmonic distortion into your power and into your current and into your voltage. And what's one of your big non-linear loads that are coming in?

Digital equipment. Microelectronics are all non-linear loads. Right now we've got fairly simple systems with a few microprocessors involved in them.

Well they all contribute to total harmonic distortion, but the contribution isn't very much right now. What happens when we bring in a full-blown reactor protection system engineered safety features actuation system where you may have a couple hundred microprocessors and all the supporting chips.

What is that going to do to your total harmonic distortion? IEEE stated in IEEE Standard 519 that you ought not to get your total harmonic distortion above about five percent because if you do your electronics can start having adverse effects.

You know, back to Dr. Sieber's comment

about the chips are getting smaller and bigger, right, smaller distances between your adjacent circuits.

And they're also getting lower voltage requirements for changing memory states. It used to be what, five volts was the threshold voltage for changing and memory state.

It's down to like three or three and a half volts now. What happens when total harmonic distortion starts playing around with that? You can start losing memory states, perhaps with an over-voltage or an over-current.

You start getting migration between adjacent circuits and things like that. So we feel that that's something that's worthy of a little bit more investigation with regard to safety systems.

MEMBER SIEBER: But that's covered by the standards, right?

MR. WATERMAN: Well, it's covered by the standards, but how it's implemented, you know, the devil is in the details, you know.

MEMBER SIEBER: Well the specification is in the standards. The question is how do you test to assure yourself that the specifications are being met?

For example, things like opening and closing the circuit breakers, particularly opening of them --

MR. WATERMAN: Yes,

MEMBER SIEBER: -- which impulses on the RFI and all kinds of things on your power supplies that go right to the CPUs. And you can end up resetting or restarting CPUs where it looses scads of data during the interval when it's down, even though it will recover and restore itself.

It can really mess up the way things are being sequenced.

MR. WATERMAN: It certainly can. And one of the areas is, you know, the conception is that well if I have great power supplies I don't have to worry about THD because they'll clean the power up.

This is all stuff downstream of the power supply. You got good power coming in and you got your microelectronics screwing everything up. So how much does it mess up?

What can we do to prevent that? Those issues, I think, need to be addressed.

MEMBER SIEBER: How to you deal with questions like system overloads? You know, if you get into a fast moving plant transient where you're exercising a lot of actuators and signals are changing, that puts large additional computational loads on the computing system which could cause it to fall behind. How do you test for that?

MR. WATERMAN: Well I think most of the computing systems anymore assume that you have a certain amount of time to respond and they just cyclically calculate and pick up the conditions as when they come around to their next cycle to calculate.

So it's not like an interrupt driven type system that looks for something to happen and then responds. It simply continues to calculate should I trip, wait 50 milliseconds, should I trip, wait 50 milliseconds, should I.

MEMBER SIEBER: So what you're saying --

MR. WATERMAN: That type of sequence there. So when a lot of things are happening in the plant your design basis will tell you how fast systems have to respond, and then you just do your -- the system just continues to run. And instead of calculating zero for don't trip it calculates a one for trip, so it's --

MEMBER SIEBER: So what you're saying --

MR. WATERMAN: I think that's pretty similar.

MEMBER SIEBER: -- is the computational load really doesn't change.

MR. WATERMAN: So, not in safety systems. That's been my experience with the systems I reviewed is they pretty well addressed that one because of that very concern.

You just can't interrupt processes and try to jump on something right away. Just take things slow and steady. You got plenty of time, as you know.

In a control room when you get a trip you got plenty of time to address it. Let's not get in a hurry here, let's just do things right. That's the way the systems are being developed now.

MEMBER SIEBER: Okay, thank you.

MEMBER POWERS: Could I understand something philosophical a little bit in your approach to defining a research program here? You posed the question what's the effect of total harmonic distortion on digital system components, for instance, okay.

Isn't that enough? Can't you say you, applicant, please answer this question?

MR. WATERMAN: Well, yes. We can but after the answer to the question how do we evaluate it if we don't have some kind of guidance to say well is that a good answer.

MR. KEMPER: Yes, we feel as though it's important in some of these areas to have our own independent confirmatory research to validate some of these issues.

MEMBER POWERS: So you want to be able to go in and say okay, he's told me this is a great system and it will do just fine, but I want to now use my tool which I suspect is different from his, and of course one of the natural evolutions is that the applicant will quickly evolve to using your tool, okay. Is that okay? I mean in --

MR. KEMPER: Well as long as it's a viable process and it satisfies our regulatory concerns and criteria. I mean what we do, we're public utility. So you know, if they choose to follow our path, if you will, I don't see any way to --

MEMBER POWERS: But it seems to me that it puts a different spin on the way you design your research program. If I'm doing -- if I have an individual tool here that nobody knows about except me, and I go through and I look at the system that's supposed to be great and I say yes, it's great.

I mean it's better than any system I've ever seen before. And you just accept the licensee's assessment, and the SER gets written with his assessment in there.

If you come back and you say gee, it's just not quite right. I've got some questions here. You pose those questions. The licensee satisfactorily answers them and you write the SER, okay?

So you don't have to -- your tool doesn't have to be the state of the art or anything like that. I mean it just has to be adequate for you to pose questions and assess the answers when they come back.

Now if a licensee is designing his system using your tool, then you suddenly have an obligation to say, yes, this is as good as I possibly want to be.

I mean it has to be maybe not next to the industry state of the art, but it has to be my state of the art, okay, because I've got no independent way to check it because he's designed based with my tool.

It seems to me you design your research programs a little differently in those two cases, don't you?

MR. KEMPER: Yes, I agree with that, but let's take, for example, fault injection. You know, we're putting effort into fault injection testing as a way of providing --

MEMBER POWERS: Yes, sure. It's a great example, yes.

MR. KEMPER: -- reliability, right? Well there's a number of ways to do that. We're going to pick one or two. It would be nice, in my personal opinion, if we successful at this the vendors pick up on this and they start doing their own fault injection testing so therefore when they make the submittals to us, now that issue has already been addressed, if you will.

Now we may come back with our own tool and independently validate that to a certain extent, but this can only help promote a safer and more reliable process controls industry in nuclear industry by sharing this information and methodology.

But that's kind of where I'm coming from, I guess.

MEMBER POWERS: Sure, sure. I mean it's just a question of philosophy and approach. Now let me ask you just a little more on philosophy. There are lots of people in this world that have the same problem you do.

They want to see digital systems used in nuclear power plants. I mean they're going to see them. It's not a question they may see them, they will see them.

What else is going on in the world in this same area? I mean how does your plan compare to what else is going on in the rest of the world?

MR. KEMPER: Well we are on selected projects. We're trying to interface with NASA. The train, the rail system in some cases, you know, some of the testing builds off some of that work.

Military, so we are looking at other agencies and other interests.

MEMBER APOSTOLAKIS: How about international activities?

MEMBER POWERS: What I see in the agenda for the next American Nuclear Society meeting, simply because I just happen to look at it, is there must be 20 papers from the Koreans --

MEMBER APOSTOLAKIS: Yes.

MEMBER POWERS: -- dealing with some aspect of digital systems. And they look like they're universally assessment types of things. I mean they come in and they do something on this digital system and they get a characteristic out of it.

I don't see anything that comes in and says okay this is the characteristic and I know that's good because. I mean they're just deriving a number.

But like I say, it must be 20 papers on that of some sort.

MR. KEMPER: Hopefully we've got some more projects we're going to get into here.

MEMBER APOSTOLAKIS: But you are -- you are abreast of what's happening internationally?

MR. KEMPER: Yes.

MEMBER APOSTOLAKIS: You are keeping up?

MR. KEMPER: Yes, we are. Yes, we attend international conferences.

MEMBER APOSTOLAKIS: Okay.

MR. KEMPER: We --

MEMBER APOSTOLAKIS: Let me tell you this back to the fault injection thing. I know that in other industries -- I mean you have to be careful when you say I'm going to look at what other people are doing because other people don't always have the perspective of a nuclear regulatory agency.

And we had in fact a presentation here last time by a very well known professor who has been practicing this for awhile. But you know, coming from the nuclear perspective, you know, and looking at this fault injection method and, you know, they're injecting faults and this and that, but they when they start using Markov models and transition rates to estimate reliability from that they lose me because I want to understand what the failure rates mean.

And apparently that's not important to these people, okay. So this is where you come in and say yes, we're going to look at this from the nuclear power perspective, and we tend to question things like that.

When somebody says the transition rate lambda from state five to state eight is this, you have to ask him where did you get that from, and how do you know there is a constant rate of transition.

This seems to me to be a very significant assumption on their part. And then of course, you have a nice formula in terms of those failure rates, which excites people.

They say well now I got the reliability. I don't think so. So this is where you come in and evaluate these methods and question them because there's a lot of stuff out there, you know.

Just because something has been published doesn't mean that --

MEMBER POWERS: Oh, my goodness. A professor's saying something published is not sainted.

MEMBER APOSTOLAKIS: Unless it's my journal.

MEMBER POWERS: Oh, yes, that's right. I'd forgotten that.

MR. WATERMAN: Moving right along now. With regard to operating systems --

MEMBER APOSTOLAKIS: Well, by the way the Koreans are publishing a lot. I get lots of papers on digital --

MR. WATERMAN: Oh, yes, I mean it's --

MEMBER APOSTOLAKIS: They are really doing a lot.

MR. WATERMAN: It's a bunch of stuff.

MEMBER APOSTOLAKIS: The Korean Advanced Institute for Science and Technology. Okay, great.

So we are what, three quarters of the time?

MEMBER POWERS: Yes.

MEMBER APOSTOLAKIS: And we are only at one third done with the presentation? So now you appreciate why your management reduce your number of slides from 120 to 29.

MR. WATERMAN: Hell, if I had 193 slides I'd be on slide 12, wouldn't I?

MR. KEMPER: Well we've talked about many of these issues, quite honestly, that are on subsequent slides.

MR. WATERMAN: That would just broaden it.

MR. KEMPER: So if you will we'll move on through them quickly.

MEMBER APOSTOLAKIS: Yes, you can actually accelerate the process.

MR. KEMPER: Okay, thank you.

MR. WATERMAN: In the past we really haven't been able to assess proprietary operating -- COTS operating system characteristics mainly because we couldn't get into the code.

But there is another class of operating systems where we have been able to review. And that's typically on the platforms where the vendor of the platform, the developer of the platform has developed his own, if you will, 64K kernel operating system, the stripped down operating system that handles just specific processes.

We, you know, I have difficulty reviewing those systems because they're usually written in machine language and I haven't had any guidance that actually told me the operating system ought to do these functions and ought not to do theses functions.

So some time ago research initiated a study to look at operating system characteristics, and that study was sort of inconclusive and so it was dropped.

And so was the user need requesting it. But what we found it I believe we need further research to identify safety critical design aspects of operating systems. I think we're seeing more and more kernel type operating systems coming along that we can actually get into.

And we need to develop processes for performing safety assessments of those operating systems. Right now, even though we have a lot of acceptance criteria in the standard review plan, when it comes to operating systems it's just -- wow, it's -- sometimes it's hard to apply.

Now with regard to diversity and defense-in-depth, as you know, we already have Branch Technical Position 19. I helped Matt write that technical position back in the mid '90s.

And we have -- that's sort of a deterministic approach to looking at diversity and defense-in-depth. Now the nuclear power industry conversely has proposed using risk insights from PRAs, for example, using their leak-before-break analysis to justify not putting in a diverse system, or arguing that a PRA shows the probability of a common mode failure is low enough that you don't need to consider it in severe accidents.

So what we propose to do with this project is actually several things. First, we want to verify deterministically that existing guidance --

CHAIRMAN WALLIS: You mean leak-before-break, you mean they show some symptom that things aren't right before they completely go wrong? Is that what you mean?

MR. WATERMAN: Well as you recall in the early to mid '80s plants were required to put in jet impingement barriers and pipe whip restraints on their plant unless they could analyze their way out of it.

The way they did that was they analyzed that a small leak would grow into a large break over time. The operator would have enough time to respond.

And therefore they really didn't need to put in the pipe whip restraints. So what they've tried to do is to shoestring into this position off of that analysis of leak-before-break.

And I think that was Oconee's original approach. And I don't know what they're doing now. Paul Loeser can speak to that. What we want to do it determine whether or not the criteria in the Branch Technical Position are realistically conservative.

I mean you can have things that are really conservative that nobody can live up to. We want to determine whether that's realistically conservative.

MEMBER APOSTOLAKIS: We don't have a realistic --

CHAIRMAN WALLIS: We don't have a definition of realistically conservative.

MEMBER APOSTOLAKIS: It's something that

Agency is using now.

MR. WATERMAN: Right.

CHAIRMAN WALLIS: It's an invocation, isn't it?

VICE CHAIRMAN SHACK: Yes.

MEMBER SIEBER: A chant.

MR. WATERMAN: Back in the mid '90s we contract, I believe, Lawrence Livermore to develop a NUREG/CR on how to implement diverse systems. And they identified something like seven different characteristics that have to be diverse.

And each one of those had a whole bunch of bullets under them that ranked various diversity aspects. For example, software languages was not considered as diverse as some of the other features in that category.

What we'd like to do -- and those were called coping strategies. What we'd like to do is take a look and see if there's on optimal mix of coping strategies that licensees can actually live up to.

Bill in his experience in the industry, they've tried to apply it and said it's a fairly onerous process. And it doesn't appear to be anything that's really applicable.

And what we'd like to do is figure out a way to make that more reasonable.

MEMBER APOSTOLAKIS: I'm listening to you and I think it's fine what you're saying. I'm just wondering though, how did you come up with this? Obviously NRR did not request this, I mean judging from the memo I read.

So did you have a group of people sitting around a table and saying this sounds like a good idea, or how did you decide that this is something that's worth supporting as a research project?

MR. KEMPER: Well, it seems to be a -- it's a major industry initiative right now. Basically, you know, the proliferation of digital processes in the American industry is far behind the foreign -- many of our foreign or international countries.

Complying with diversity and defense-in-depth is one of the key issues here that is the big struggle, quite honestly. So based on that, since it is such a difficult issue between the industry and the Agency, it seemed prudent to do this research in an anticipatory basis, quite frankly.

MEMBER APOSTOLAKIS: So has there been a

situation where the industry and the Agency disagreed on some defense-in-depth measures, or --

MR. KEMPER: I believe that the --

MEMBER APOSTOLAKIS: Apparently there is an NUREG/CR already.

MR. KEMPER: Right.

MEMBER APOSTOLAKIS: So somebody must have decided that the guidance there is not good enough.

MR. KEMPER: Yes. Applications have been submitted to the Agency for review and then withdrawn based on, you know, their strategy that they prescribed for complying with this versus our push-back to them.

So it's not to say that our process is wrong or bad or anything, we're just -- we just feel as though it bears some resources to look closer at this to see if there is some optimum conservatism that should be applied using this process.

MEMBER DENNING: But I think -- weren't you asking a process question? That's a little bit different from that specific answer for this particular thing.

And that is in putting together this research program, how do you actually decide which of these activities are the ones to undertake? Was that something that your group just got together and did?

MR. KEMPER: Yes, for the most part, that's right.

MEMBER DENNING: That the way you did? And so you came up with a list them and you prioritized them --

MR. KEMPER: That's right.

MEMBER DENNING: -- within their groups.

MR. KEMPER: Right. And out intent was --

MEMBER APOSTOLAKIS: But you --

MR. KEMPER: And our intent was to engage out clients, you know, NRR, NSIR, and NMSS.

MEMBER APOSTOLAKIS: But you have not done this yet.

MEMBER DENNING: But you haven't done that yes.

MR. KEMPER: Well we have with some.

MEMBER APOSTOLAKIS: With some.

MR. KEMPER: NSIR and NMSS. We did not engage anybody else.

MR. WATERMAN: But part of that engagement is writing a draft research plan for them to review. I guess we did.

MEMBER APOSTOLAKIS: I would expect, though, that you would interact with them before you wrote anything.

MEMBER DENNING: Well, particularly NRR.

MEMBER APOSTOLAKIS: Particularly NRR, yes. Then you wouldn't get this kind of reaction. Anyway, oh there is -- I'm sorry.

MR. CHIRAMAL: I'm Matt Chiramal from NRR. And --

MEMBER APOSTOLAKIS: The infamous branch?

MR. CHIRAMAL: Yes.

MEMBER APOSTOLAKIS: Okay.

MR. CHIRAMAL: The subject we were just talking about is something that was reviewed by the National Academy of Sciences and it was determined that you had in defense-in-depth is okay.

MEMBER APOSTOLAKIS: You need what? I'm sorry?

MR. CHIRAMAL: That defense-in-depth and diversity is a requirement that will apply to nuclear plants is a good idea.

MEMBER APOSTOLAKIS: No, but I'm not questioning the value of defense-in-depth, I'm asking why this particular project. I know that the Agency has been implementing defense-in-depth and diversity for awhile.

MR. CHIRAMAL: That's correct.

MEMBER APOSTOLAKIS: So -- but what it is that this particular project -- I mean is there something wrong with the way we're doing it, or is it something that sounds like a good idea to some people based on their experience, which is fine?

I mean we've been making decisions like that for a long time.

MR. CHIRAMAL: That's correct.

MEMBER APOSTOLAKIS: There's nothing wrong with that. I just want to understand.

MR. CHIRAMAL: Yes. And the other point is that --

MEMBER APOSTOLAKIS: Do you agree with me?

MR. CHIRAMAL: The SRP Chapter 7 is based upon IEEE 7.4-3.2, and the new version of this, 2003, came out. And mike worked on it and it adapted all the requirements that we had in the SRP into the standard.

And that's up to date already and none of these subjects that you're looking at -- they're all covered by that communications qualification, and all the requirements that the research is doing is already covered by the new standard, which is being endorsed by -- a researcher's going to be putting out pretty soon.

And it includes the requirements for security added to it.

MEMBER APOSTOLAKIS: So what you're saying is that the objectives of these projects have already been met by a standard that is about to be approved?

MR. CHIRAMAL: Yes, and that's something we'll discuss with research when we -- this is something we'll discussed with research when we get together on this project.

MEMBER APOSTOLAKIS: I assume you would. Okay.

MR. CHIRAMAL: I'm trying to digest all this, but --

MEMBER APOSTOLAKIS: Yes, please, go ahead.

MR. SHAFFER: Can I just say something?

MEMBER APOSTOLAKIS: I'm sorry.

CHAIRMAN WALLIS: Are we going to be asked to referee this contest?

MEMBER APOSTOLAKIS: I don't know.

MR. SHAFFER: I'm Roman Shaffer, I'm on I&C section.

MEMBER APOSTOLAKIS: From which?

MR. SHAFFER: Roman Shaffer, I'm in Bills section.

MEMBER APOSTOLAKIS: Okay.

MR. SHAFFER: I was involved in the early stages of revising the research plan. I get the impression here that maybe the Committee thinks that we just sat in a room and operated in a vacuum and came up with these activities.

We actually continued some of the projects from the previous plan, and through interactions with licensees and the vendors and other colleagues within the Agency we same up with these activities.

These are areas of research we think we need to continue or start based on the state of the industry as well as where we see them going. And defense-in-depth project is one we think is particularly important.

I mean we don't operate in a vacuum, we engage various people in groups. So I just wanted to make that clear.

MEMBER APOSTOLAKIS: I understand what you're saying, but I mean this memo that we've been discussing, and maybe we shouldn't, but it says -- it actually preaches here, it says it is recommended that in the future research discuss these proposed research activities with individual NRR branches in sections prior to answering the research plan to gain a better understanding of actual regulatory needs and practices?

Wow, that's pretty strong. And one would expect that this, you know, would have happened already. But anyway that's why the issues are coming up today, not -- even stronger statements in other places.

Let's go on, though. I think we have exhausted this particular aspect.

MR. WATERMAN: With regard to software quality assurance we have three projects identified. That's assessment of software quality, digital system dependability, and self-testing methods.

And if I can get through those fairly quickly here we can still get Bill down to Florida. On the assessment software project quality, NRC evaluates digital systems development processes manually.

And that doesn't sound too bad until you sit in a conference room with a vendor site and you ask him to bring in all the documentation for his system and realize that you've got about a week to do thread audits across about 10,000 pages of documentation, which is about what it is.

I usually don't call it pages I call it feet, because you look at it and say it's about three feet of documentation. That's about right.

CHAIRMAN WALLIS: We're used to that experience too.

MR. WATERMAN: So what we're looking for in this research project here is to develop a more effective and through supporting process. You still have to go through the documentation, believe it or not, because there are interfaces in those phases that only the human eye can pick up the errors on.

But we need some way of supporting that process to come up with some more objective assessments of the quality of the development process.

And what really kind of perked up my ears, to tell you the truth, was the University of Maryland project, which is using metrics to assess software quality.

That looks to me like a tool that we can adapt to be a verification tool, or a testing tool to see the quality of the verification development process.

So I look at that tool as the tool that you would use to assess everything from the concepts phase through the implementation phase. How well did the vendor put that product together?

He used a tool so that their assessments come out consistent. And then you also do the manual reviews to pick up the little interface problems that I don't think any tool --

MEMBER APOSTOLAKIS: But again, before you jump into any of these methods you would scrutinize the assumptions, right -- and behind them?

MR. KEMPER: Yes, you would, of course.

MR. WATERMAN: And that tool complements the fault injection test assessment methodology already developed for digital system dependability testing.

I look at the -- and I'll talk about that in another minute here. Additionally we're taking a look at what Halden Reactor Program is doing on evaluating software engineering practices used by other countries.

We're paying the money already so why shouldn't we use some of that data and see if it can be useful.

MEMBER APOSTOLAKIS: I wonder if -- well Dr. Powers is not here, but is there such a thing as Swedish operators working on Finnish computers? That's an inside joke.

MEMBER SIEBER: AS long as it's Microsoft you're okay.

MEMBER APOSTOLAKIS: What?

MEMBER SIEBER: As long as it's Microsoft and Windows-based, you're okay.

MR. WATERMAN: With regard to digital system dependability, not all safety significant errors in digital systems may be detected by V and V processes.

That goes without saying. And so I think we need an independent method of evaluating licensee's and vendor's digital systems. And the fault injection methodology shows some promise in allowing us to do that.

And it's already been developed and they use it to assess dependability. It's been -- this particular fault injection tool was used on the Los

Angeles Green Line metro system.

And they did the equivalent of ten billion tests on the system. They found three safety-significant errors, and I'll get into that on the next project.

So what this project will do is produce a process for using the tool to determine the dependability safety systems. I look at this tool as a validation tool.

What do you do after implementation? You've integrated it into your system. How can you test the system? So that's the validation part. The toll, this tool by itself isn't going to tell you everything you know about the system any more than the University of Maryland tool, or some tool like that they use in metrics, could tell you everything you needed to know about the system.

But the two tools working together can give you a better feeling for the quality of the system, which is really important in the out years, right, when you have to maintain it, and how well the system works right now.

So I look at those two tools as a possible adjunct to help the regulators regulate the systems appropriately.

MEMBER APOSTOLAKIS: When you say evaluate dependability, are you going to get the number, or is it something that is a concept, you know, that now I feel better about?

MR. WATERMAN: Well, to tell you the truth, if I was using this tool I wouldn't care about -- if the dependability number came out. I don't want the tool to tell me whether or not after ten billion tests it found any errors in the system.

MEMBER APOSTOLAKIS: So it's not the number?

MR. WATERMAN: Well, it produces a dependability number and Steve Arndt can talk more to this project than I can, Dr. Apostolakis.

MR. KEMPER: Yes, they can be used in both ways.

MR. WATERMAN: And I'm looking at a validation methodology.

MEMBER APOSTOLAKIS: If he comes to number and I see these Markov results again, I'm telling you I'm not going to be friendly. I don't think people have really scrutinized the assumptions behind those things.

Although if you tell me that you did it ten billion times and you found three faults, I think that's great.

MR. WATERMAN: Can we tunnel down into this?

MEMBER APOSTOLAKIS: That really adds to my confidence, but when people jump into those Markov models I have a problem with that.

MEMBER SIEBER: How confident are you that the University of Maryland metrics method of evaluating software really tells you important things, characteristics about the quality of the software?

MR. WATERMAN: Well, I haven't really had a chance to look at the whole tool yet. I've been sort of a strong advocate for metrics. And it looks like right now it's a stripped down metrics tool as opposed to using a lot of metrics.

So I've seen all of their integrals and all that other stuff, but what I'd really like to see is how the whole thing pans out. But if we don't do the research we'll never know that answer.

MEMBER SIEBER: Yes, I was surprised at the accuracy that they claim to have in that. But the link between those metrics and the actual quality of the product to me -- somehow escapes me a little bit.

MR. WATERMAN: It's sort of like us linking the quality of a product with safety, isn't it?

MEMBER SIEBER: That's right.

MR. KEMPER: Well it's still a work in progress, clearly. You know, this is the first crack now. As we speak they're in the middle of trying a sophisticated reaction protection system type of a platform in software.

MEMBER SIEBER: Well if they hadn't achieved remarkable accuracy I would probably comment that you ought to look as to whether you ought to finish or not.

But some of that work was impressive in my opinion.

MEMBER APOSTOLAKIS: Do you have any criteria? I mean a lot of this is exploratory, right?

MR. WATERMAN: Yes.

MEMBER APOSTOLAKIS: Do you have any criteria that you would use, objective criteria that -- yes, we've done enough and this is going to lead us anywhere.

MR. WATERMAN: Well, obviously we need to shake these projects out, right?

MEMBER APOSTOLAKIS: Because not all of these projects will actually produce --

MEMBER SIEBER: Something.

MEMBER APOSTOLAKIS: But they're claiming they will produce because, you know, a lot of it is exploratory.

MR. WATERMAN: That's true, but you know, the only way we'll know that answer is to go ahead and do the work, it seems to me. And so, you know --

MEMBER APOSTOLAKIS: What does --

MR. WATERMAN: We've just got to go down that road until we get what we want.

MEMBER APOSTOLAKIS: What does the work mean? I mean there could be a phase approach where you're exploring first the feasibility of something and you get encouraging results you say okay, I'll go to the next phase, or something like that.

MR. KEMPER: Well that's precisely -- well I don't know how we got on that project. We're kind of ahead of ourselves. But at any rate, that's precisely what the metrics project is doing, right?

It's a three phase process. The first two phases really were proof of concept. We've gone far enough. We believe that to be true. We believe it's a viable concept so now we're trying to invoke that process on a STAR module system.

I think it's -- we got it from Oconee, right Steve? For a safety related system and application software. So that really will be the proof in the pudding, as we say.

We can get meaningful results from that test.

CHAIRMAN WALLIS: Well I think this applies to the whole plan.

MEMBER APOSTOLAKIS: Yes.

CHAIRMAN WALLIS: I mean the problem I have with the whole plan was you've laid out all these things which you want to get done but there's no indication for me about the likelihood of success in getting these things done.

MEMBER SIEBER: Or even to know when you're successful.

CHAIRMAN WALLIS: Or the competence of the people or whatever, or the methods you need to have some phasing or something with all of these projects.

MEMBER APOSTOLAKIS: Yes, that would be useful because a lot of this stuff is really still in its infancy.

CHAIRMAN WALLIS: So it's a hope?

MEMBER APOSTOLAKIS: Well not the plan, I mean the state of the art out there. And the other thing that is amazing, I mean I guess it happens in all field when they're new -- it reminds me of the '70s and risk benefit analysis, which was new at the time. People publish something, they issue a report or a paper or present a paper and so on that is not really scrutinized by experts because thee are no experts in the field.

Or if there are they're biased and so on, so a lot of the stuff that's out there not, I'm not sure how applicable it would be, or it would -- to what extent it would survive a scrutiny from the nuclear regulatory respect. So we always have to be --

CHAIRMAN WALLIS: But then how do you get something new started, George? It's --

MEMBER APOSTOLAKIS: No, I mean all these things are elements here that the decision makers need to take into account. Now we're still on 17 and we're going project after project.

I mean do we really need to continue doing this? We got an idea.

MR. KEMPER: We skim over two or three

of those projects.

MEMBER APOSTOLAKIS: Are there any projects that you really feel you ought to talk about? Like this data on 19 for example, I think that's an interesting -- unless you disagree.

MR. WATERMAN: Okay. Well with regard to self-testing why are we looking at self-testing?

MEMBER APOSTOLAKIS: No, no, no.

MR. WATERMAN: It's been my experience that errors that fail systems are self-testing errors.

MEMBER APOSTOLAKIS: I'm not questioning why you're doing this. I'm just saying that since we're running out of time there may be --

MR. WATERMAN: Ten minutes.

MEMBER APOSTOLAKIS: -- a few that you want the to point out.

MR. WATERMAN: Well, we're continuing our work on risk assessment digital systems, obviously.

MEMBER APOSTOLAKIS: Okay.

MR. WATERMAN: And since we've already had several meetings with you all I don't know that we really need to get into great details on that. We're continuing to move down that road.

MEMBER APOSTOLAKIS: We'll probably review this during the Subcommittee meeting, so --

MR. WATERMAN: Exactly. So into security aspects of digital systems. We've attended different conferences and different universities and things like that to get input on what aspects of secure systems we probably ought to address.

And we identified four projects, cyber vulnerabilities, electromagnetic attack vulnerabilities, wireless network security, and firewall security.

Cyber security, as you know, it's always been a concern of ours. If you look in standard review plan back in '97 we were talking about cyber security.

Now ever since 9-11 it's kind of become a heightened issue.

MEMBER APOSTOLAKIS: But what can they do? I mean I don't understand that. I mean what can they do?

MR. KEMPER: It depends on the connectivity of your system.

CHAIRMAN WALLIS: There was one plant which had a worm in it wasn't there?

MR. WATERMAN: Davis-Besse got his with

the Slammer worm

MR. KEMPER: We just took a trip out to one of the labs and they gave us a demonstration on some of their cyber attack capabilities and it was phenomenal.

I mean though the system that they had set up they were able to just through an e-mail, if you will, they simulated you acknowledge, you answer your e-mail, and as soon as that happens they take control of your PC, and because of it's connectivity they actually get into the control system and the process controls the whole application they had, so --

MR. WATERMAN: But that's not the only security concern we have to concern ourselves with. It's not just the safety system that we have to worry about.

We're talking about security of our country and our critical infrastructure. So you know, if you take a look at the grayouts in California last year, can you imagine what would have happened if somebody had attacked the switch yard?

It's way outside the protected area. You cause the plant the trip. You don't have to destroy a plant for critical infrastructure. All you got to do is make the thing shutdown.

You don't even have to shut it down permanently. If you're in a grayout situation you've already got a blackout on your hands. Now how many people are going to die from that?

And remember one of our missions in the NRC, besides protecting the health and safety of the public, protecting the environment, is to ensure national security.

MEMBER APOSTOLAKIS: In the nuclear arena.

MR. WATERMAN: From a security perspective we have to consider, you know, what are we doing --

MEMBER APOSTOLAKIS: Wait, wait, wait.

MR. WATERMAN: -- for critical infrastructure.

MEMBER APOSTOLAKIS: The common defense and security, I think, refers to nuclear matters.

MR. WATERMAN: Well --

MEMBER APOSTOLAKIS: We're not going to stop protecting infrastructures are we?

MR. WATERMAN: Critical infrastructure is a concern for the Department of Homeland

Security.

MEMBER APOSTOLAKIS: Yes, and they should pay for this, not us.

MR. WATERMAN: And nuclear power plants are part of that critical infrastructure.

MR. KEMPER: Well I guess more specifically to us, these cyber attacks have the ability to challenge --

MEMBER APOSTOLAKIS: Yes, I understand that, and I agree with that.

MR. KEMPER: So that's the real -- that's where it really comes home.

MEMBER APOSTOLAKIS: But we should limit ourselves to the nuclear part of it.

MR. KEMPER: But at any rate we worked pretty intensely --

MEMBER APOSTOLAKIS: And this will be classified?

MR. KEMPER: Some of the results of this may very well be classified, or at least SGI.

MEMBER SIEBER: I think there's one thing for sure. The people who write malicious software are working just as hard or harder than the ones who write defenses and firewalls against it.

MR. WATERMAN: As a matter of fact it's

not just the garage hacker either.

MEMBER SIEBER: No.

MR. WATERMAN: It's hostile nation states like -- well I won't name any countries right now, but we have hostile nation states who essentially have an unlimited budget and who are attacking our critical infrastructure on a daily basis.

MEMBER APOSTOLAKIS: There is a lone forming over there.

MR. MORRIS: Hi, I'm Scott Morris. I'm the Chief of the Reactor Security Section in NSIR. And Bill and I have worked together on various aspects of cyber security.

In fact we've met with the industry and we could go -- I could go on fro quite a bit, but suffice it say that we have interacted. My staff's interacted with Mike and Roman and even NRR, Matt Chiramal, and --

MEMBER APOSTOLAKIS: Even them.

MR. MORRIS: Even OIC, even OIS, the Agencies own IT security people. There's no question this Agency needs, in my view and I think in the collective view of the Staff, a more comprehensive cyber security policy, because we really don't have one to be quite frank.

We all have a common interest in cyber security. We know it's a big issue. We know the threats out there. We haven't quantified the threat.

It's certainly not part of out design basis, threat document to any great degree. So we're wrestling with these issues right now, and I think some of the projects that Bill and his staff have proposed are valid.

Or -- I shouldn't say some, they all have some validity. But they all have a varying degree of validity to us right now. We have some urgent needs.

We as a staff have generated some documents to help the existing fleet of reactors understand the cyber threat, or the cyber vulnerability of their sites.

We've provided them a tool that they can use to systematically assess the digital system security. But they're under -- there's no compulsory means -- they're under no obligation to employ it right now.

So again, we are working on that as a policy. And I think that some of the projects that

Bill has laid out, some are, you know, some are more forward looking.

They're trying to examine, you know, some of the newer systems that are coming out that aren't necessarily in place now. My immediately focus, quite frankly, from a user needs standpoint, is to examine what's out there right now.

Let's understand the vulnerability of those systems right now to the existing threat as we have defined it. And again, the cyber threat isn't very well defined.

So -- but suffice it to say that there has been a sufficient level of interoffice interaction on the projects that Bill is proposing. I understand the issues about switchyards and SCADA systems and wireless controls, and they're all very relevant and important.

And the industry is very concerned that they not get more than -- they don't want to be overregulated and multiply regulated by DHS now, and FERN and NRC all on relatively the same sorts of control systems.

There's a lot of very difficult issues. We're interacting closely with the North American Electrical Liability Council and development of their cyber security standards.

So like I said, as I said, I could go on for a long time, but there has been quite a bit of interaction between my staff, Bill's staff, and even NRR and OIS on this.

And to a limited degree we support what they're proposing here.

MEMBER APOSTOLAKIS: I wish you hadn't said to a limited degree, but --

MR. MORRIS: Well it's a matter of what's more important right now.

MEMBER APOSTOLAKIS: And we'll probably review these things at another meeting but --

MR. KEMPER: Yes, I hope so.

MEMBER APOSTOLAKIS: Yes. Okay, so we are convinced that this is important. Next.

MR. WATERMAN: Emerging digital technology and applications. It's the things that we've been doing all along. It think most of you -- we're wrapping up the wireless technologies.

We've got a long term project to look at new technologies that are coming along to give the Staff a heads up on those technologies. On the advanced nuclear power plant digital systems we broke it down into advanced instrumentation, advanced control, and --

MEMBER APOSTOLAKIS: So who's going to worry about the operators here? I mean advances nuclear power plants, advanced instrumentation. Is somebody else worried about it, or you will worry about it, or it will be joint project?

MR. KEMPER: Well it's lead by primarily Human Factors but we will support that as needed.

MEMBER APOSTOLAKIS: Okay, so you're supporting them?

MR. WATERMAN: Yes, sir. We're just -- this is -- yes, somebody wants us to take a look at something, maybe the robotics on the refueling -- on the fueling machine bracers, okay we'll take a look at it.

We don't have any research in place right now, we're just -- this is a placeholder. Remember it's a flexible, adaptable program. As things come down the road we'll go ahead and take a look at them.

MEMBER APOSTOLAKIS: Fuzzy logic controls. All right.

MR. WATERMAN: Seimens trip systems.

MR. KEMPER: That wraps us up. I apologize for --

MEMBER APOSTOLAKIS: No problem, no problem.

MR. KEMPER: -- going over, but it was lots of very good energetic discussion.

MEMBER APOSTOLAKIS: So I'd like to -- first of all do the members have any questions of these two gentlemen? Anybody else with to say anything? Yes, sir, please come to the microphone and identify yourself.

MR. CALVO: Yes, my name is Jose Calvo. I'm the author of the memo that you're all reading. I hope you enjoy it. But let me tell you something about myself.

I was hired by the NRC years ago because I was a computer systems specialist, okay. I had -- as a matter of fact my first system, I went around the country doing applications of computer and nuclear processes.

As a matter of fact the first computer is in the Smithsonian as the one as it was used. But I did work for Westinghouse, and I did work with the -- facility.

And what I was to do, I just analyze these systems and try to make recommendations what to do with it, okay. I'm the Plant Chief now. I've been Plant Chief for about five years in the area of computer systems.

We had to review a lot of systems. WE had to review the Siemens. We reviewed the Techtronics, and the Common Q. Let me tell you something. I was the one who reviewed those systems, because some kind of way I've still got a hang-up that I want to get involved with those systems, all right.

So I feel that the emphasis here today it was talking about tools. When I first analyze these systems I used to go inside the system and find out how the system will make it work.

So when I became the Plant Chief, I asked everybody else how do you review with the system, how to you know. They say we'll you're following a process.

What do you mean you're following a process? Do you know if the system that you -- what kind of a system do you have? They say well we don't have the talent, we don't have the expertise.

It takes too long. So then they show me the standard review plan. It follows a process. They're looking about the life cycle. And then I say how do you know that you have some problems in there?

They say well, we're following a process. If the process is done correctly then the -- and we verify what the vendors has done, then we got some reasonable assurance everything is going to be fine.

Tools, I said why do you want the tools. I couldn't convince Mike and I couldn't convince the other much. They want to have a tool, okay. All right, so let's buy a tool.

So we buy a tool. It costs about 50,000 dollars, all right. Well given that they have to review one of the systems it takes something like 800 to 1,000 hours.

When that tool comes in we almost double that number because we spend all the time trying to figure out what the tool does. So we have to throw the tool away, all right.

Say I knew that was going to fail because I had used tools, I have developed tools before, and you spend all your time with the tool. And the question is if you've got a tool with Siemens, Siemens might say no, my tool is better than you're tool, okay.

What your tool does, what their tool

does is do different things. So the tool is a nice thing to have, but you got to perfect it, you got to make it accommodate.

And you keep in mind the technology is moving so fast these days that in three years all those tools are going to be obsolete as well as the computers being obsolete.

Look, the computer systems that we have, all the platform has been done. All we do, we're trying to implement the plain and specific. I need research help in this area.

I want to look at what we have done today, and tell me today if we have done the right kind of a thing because that's what we need. I don't want what we do 20 years from now.

That's fine. I won't be here 20 years from now. But just I want to know the Agency, we're marching along this area and the appropriate manner. So that's what we do, that's the purpose of the memo, tell you that all the things that are being asked in this are looking to the future.

I want to know what we can do today. And let me tell you something else. We value the ACRS. You provide a good forum for us to discuss these things and seek some advice so we know how to proceed.

Because some kind of way, you can see, we don't get together.

MEMBER APOSTOLAKIS: Are you willing to come to the meeting? We will invite you to come to our Subcommittee meeting.

MR. CALVO: Yes. As a matter of fact I was going to make that request. I like to be here next time so you hear the other side of the story, and maybe together the four of us, we can do something here to help the Agency to move forward.

MEMBER APOSTOLAKIS: Mr. Calvo, I just say that some of the statements you wrote down were pretty strong. Were you upset at the time?

MR. CALVO: Well, my staff was upset.

MEMBER APOSTOLAKIS: Or --

MR. CALVO: In some kind of way, yes, they was strong.

MEMBER APOSTOLAKIS: Your staff was upset?

MR. CALVO: Keep in mind that we've been making those statements for five years. For five years we keep saying please don't proceed this way. Help us with this one.

But again, I know you got some new

people working the research. For the last five years we were not successful in getting anybody else to help us out.

I'm concerned that we're moving ahead with 103 plans, we're going to be implementing these platforms, and we don't have the kind of support that I needed to find out that we did it the right way, okay.

And again, I don't have the talent either. And neither does research has the talent either. Mike is there because I sent him there. He used to work for me.

And they needed some regulatory flavor, so I say Mike go and help research, and he did. And that's almost less than a year. So what we got to do is get together and talk.

And we need you guys as the forum so we can add these things up in here in front of you.

MEMBER APOSTOLAKIS: Yes, this is a kind of an unusual role that you're asking us to play.

MR. CALVO: Well --

MEMBER APOSTOLAKIS: But we'll be happy to have a subcommittee meeting and listen to both sides. And fundamentally do you have anything else to add?

MR. CALVO: Well, keep in mind the UFM work the same way. We use you as a forum. It was very soothing. It helped the Staff to get together.

MEMBER APOSTOLAKIS: What was soothing?

MR. CALVO: The UFM, the ultrasonic flow meter. That was another one that we had some problems. This one can be solved the same way. We need to bring the third party to play a role of facilitating while he's advising.

CHAIRMAN WALLIS: The Agency has no mechanism apart from the ACRS to do this?

MR. CALVO: Well, anyway that's all I have to say. I think that we need to communicate in a selected communication situation.

MEMBER APOSTOLAKIS: Thank you very much, and I do appreciate your willingness to come in June.

MR. CALVO: We'll be happy. June we'll be here.

MEMBER APOSTOLAKIS: Thank you very much.

MR. BARRETT: I'd like to answer that there are a lot of things on the table right now, but I'd like to start by answering the Chairman's question.

We do have a process for deciding what research will be pursued by the office of research in this area and every other area. It's a user need process, and we also have alternatives to that, including technical advisory groups.

And what we're pursuing right now is that we have this plan in front of the Office of NRR, and in front of the other offices, and they're in the process of deciding what their response will be.

My understanding is that the response will be supportive to a great extent. And Mike can discuss that in greater detail. Clearly we've come to you today at a time when this area is undergoing a great deal of debate.

We're not coming to you and to your subcommittee for you to decide where the Agency will go. I mean you have an advisory role, and we look forward very much to the kind of advice you can give us.

But ultimately it's a management decision involving the Office of Research and the -- and our user offices which way we'll go. But I think that given the level of -- the number of different perspectives that you see throughout the

Agency, I think that this is one case where the advice of the ACRS will be particularly useful to us.

I feel that the Office of Research has played perhaps a somewhat unusual role here in terms of defining a plan and putting that plan up for discussion as opposed to waiting for user need.

I think that ultimately that will prove to have been a wise choice of -- a wise course of action for the Office or Research to take.

CHAIRMAN WALLIS: I think you might find precedence where this has happened. I'm trying to remember them. And we used to know some precedence where an Office of Research pursued research and then persuaded NRR that it was necessary although originally they didn't think it was.

And it turned out to be a crucial element in some later decision. And I forget just what the issues were, but it might help you if you could quote some of those.

MR. BARRETT: You may find that aging management was one of those.

DR. LARKINS: Yes, I think --

MEMBER APOSTOLAKIS: Ultimately I think the -- we have provided advice, not in context like this, but within professional opinions, right, that ultimately came to us?

CHAIRMAN WALLIS: I think an awful lot is going to be sorted out by the Staff themselves --

MEMBER APOSTOLAKIS: But anyway, let's listen to the Executive Director.

CHAIRMAN WALLIS: --before we hear about this again.

DR. LARKINS: Yes, well George, the DPO thing is a different process. And that's outside of the normal role of the ACRS. But the ACRS has several situations, cases over the past several years -- made strong recommendations on some research activities.

Sometimes it wasn't always clear to the user office the value of those, but a lot of times they were very influential in getting those programs started.

And it turned out to be a value. I can think of some things, some PRA, license plan again, and other areas.

MEMBER APOSTOLAKIS: So there's nothing in our charter that prevents us from doing this, it's just something that we don't do very often.

MR. BARRETT: Let me say we're not here

to ask you to resolve a DPL or to resolve this management issue. We come to you under your -- with your normal charter, which is to give us independent technical advice on this plan.

CHAIRMAN WALLIS: We're going to have subcommittee meeting on this, and I think -- I suspect that by then a lot of these internal matters will have been sorted out.

MR. MAYFIELD: Yes.

CHAIRMAN WALLIS: We will not be asked to be a referee in some sort of kindergarten fight. Actually it will be a mature presentation by you guys, and there will be some -- the issues will be clearly stated, and so on.

MR. MAYFIELD: If I could, this is Mike Mayfield from NRR. I would say that the Office nor my division, neither have asked the Committee to engage in this role that was just discussed.

We will take this on, as Rich says, as a management matter. And we will come back with the committee. We -- historically there have been a number of issues where the offices have not agreed, and then as a management matter the Office of Research engages in a research program they feel is appropriate.

And I'm sure that's how this will move forward. If at some point at we go forward that offices feel there is value to the Committee to present the two views on a matter and to ask for your advice, we will do so, but we will do so through Dr. Larkins and through the Committee management.

MEMBER APOSTOLAKIS: Well the thing that's not clear to me is how to we -- should we structure the Subcommittee meeting? I mean as I said at the beginning, whenever we look at the research plan, we have a couple of questions that I think are important questions, like what is the current state of the practice within the Agency.

Where does Agency management feel that there are needs, that there are holes that we need to improve things, without necessarily implying that the way things are now are bad.

I mean there's always room, you know, -- or maybe due to external reasons there is a need now to get into a particular area and do something about it.

So where are we now? And why is this -- where is this plan taking us?

CHAIRMAN WALLIS: Well I think, George,

we rely --

MEMBER APOSTOLAKIS: Five years, ten years down the line. Some of it is anticipatory. Some of it is answering immediate needs. I mean these are important questions that help.

And the thing that's confusing this time is that on the one hand there is a memo that everything is fine. And on the other hand there is all these research projects that say well good enough, you know, we can improve here and there and there.

And I -- what I would not like to see next time is to have again one person presenting and saying we don't need anything, and another person saying no, we needed.

MR. MAYFIELD: Dr. Apostolakis, I started by saying that Mr. Dyer will be signing out a memorandum. And he speaks for NRR. And I would encourage you to wait until you get the signed memorandum.

We will make sure that Dr. Larkins receives a copy as soon as it is signed that he --

MEMBER APOSTOLAKIS: Now what you say wait, what do you mean wait?

MR. MAYFIELD: -- can distribute to the

Committee.

MEMBER APOSTOLAKIS: Should we postpone the Subcommittee meeting?

MR. MAYFIELD: No, sir. I think -- but rather than assuming what Mr. Dyer may say based on a draft memorandum and a response to that draft I would urge you to wait until you get the signed memorandum and see where the office has come down.

CHAIRMAN WALLIS: George --

MR. MAYFIELD: And I think that's the appropriate --

CHAIRMAN WALLIS: We rely on your wisdom and skill to work with Mike and Rich and the other people to construct a good subcommittee meeting.

MEMBER APOSTOLAKIS: Yes, but at some point I want to get the members views, this afternoon perhaps.

CHAIRMAN WALLIS: We can talk this afternoon. Now we're going to break. And the break -- we're not going to have the reconciliation because we're late, but we'll have it after lunch.

We'll have a lunch break for an hour, and please be back in 15 minutes to be trained in ethics, in 15 minutes, 12:15, right here. Break. And we don't need the transcript, you know very much, after lunch.

(Whereupon, at 11:59 a.m. the above-entitled matter was concluded.)

CERTIFICATE

This is to certify that the attached proceedings before the United States Nuclear Regulatory Commission in the matter of:

Name of Proceeding: Advisory Committee on Reactor Safeguards 522nd Meeting

Docket Number: n/a

Location: Rockville, MD

were held as herein appears, and that this is the original transcript thereof for the file of the United States Nuclear Regulatory Commission taken by me and, thereafter reduced to typewriting by me or under the direction of the court reporting company, and that the transcript is a true and accurate record of the foregoing proceedings.

Rebecca Davis

Rebecca Davis
Official Reporter
Neal R. Gross & Co., Inc.

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522nd ACRS Meeting
May 6, 2005

Overview

- Research is Being Conducted in a Variety of Areas
- NRR has Requested Research Related to ISI Capabilities, ISI Reliability, and Rupture, Burst, and Leakage Models
- NRR will use this Information in the Review of Licensee Submittals and to Provide Guidance to Regional Inspectors
- In Response to ACRS Feedback, Additional Work is Being Conducted on Crevice Chemistry and the Relative Susceptibility of Various Tube Materials to Cracking

OUTLINE OF PRESENTATION

- Task 3 - Tube Integrity and Integrity Predictions
  - Objective
  - Failure Models
  - Leak Rate Models
  - Pressurization Rate Testing
  - Secondary side Depressurization Study
  - Constant Pressure Crack Growth Study
  - Statistical Treatment of Models
  - Summary of Results
  - Future Work on Tube Integrity
- Task 1 - Assessment of Inspection Reliability
- Task 2 - ISI Technology
- Task 4 - Degradation Modes
- Conclusion

Task 3 - Tube Integrity and Integrity Predictions

- Objective – to Evaluate and Validate Models for Leak/Rupture Behavior, Failure Pressures, Leak Rates for Degraded SG Tubes – Normal and Accident Conditions

Tube Integrity and Integrity Predictions (Cont)

- SG Tube Materials are very Ductile
  - Failure Under Design Basis Conditions is by Plastic Instability
  - Failure Under Severe Accident Conditions is by Creep and/or Plastic Instability
- Real Cracks have Complex Shapes
  - Bounding Equivalent Rectangular Crack Method can give Conservative Results
  - Methods Developed for Realistic Prediction of Ligament Rupture
  - Effort is Ongoing to Develop more Realistic Predictions of Burst

Tube Failure Models

- The Model for Predicting the Pressure to Cause Plastic Collapse of a Tube Containing a Through Wall Axial Crack is the Erdogan Model:

  $P_{cr} = \sigma h / m R_m = P_b / m$

  σ = flow Stress

  h = tube wall thickness

  R_m = mean radius of the tube

  P_b = failure pressure of the unflawed tube

  m = constant related to the flaw size and geometry (Computed from LEFM Model of Erdogan)

Tube Failure Models (Cont)

- For Part Throughwall Axial Cracks, the Pressure Required to Fail the Radial Ligament is Given by:

$$P_{sc} = \sigma h/m_p R_m = P_b/m_p$$

$$m_p = (1 - a/mh)/(1 - a/h)$$

a = crack depth

if $P_{cr} > P_{sc,}$ the throughwall crack is stable

- M_p is a Measure of the Stress Magnification in the Ligament; Useful Characterization of the Severity of a Crack for both Design Basis and Severe Accident Conditions

Tube Failure Models (Cont)

- The Equations for P_{cr} and P_{sc} Underestimate the Ligament Rupture Pressures for Short and Deep Cracks
- ANL Proposed the Following:

$$m_p = [1 - \alpha(a/mh)]/(1 - a/h)$$

$$\alpha = 1 + \beta(a/h)^2 (1 - 1/m)$$

β is a constant ≈ 1

ANL Modification Predicted Better for Short and Deep Cracks

Tube Failure Models (Cont)

- Equivalent Rectangular Crack Method – Rectangular Cracks have been Considered up to this Point – Actual Cracks may not be Rectangular and may Contain Ligaments
- For Complex Cracks, use the Equivalent Rectangular Crack Method – Crack Depth Profile Determined by Eddy Current or Fractography
- Series of Equivalent Rectangular Cracks Selected and the one with the Lowest Ligament Rupture Pressure (highest m_p) is Selected

Modeling for Predicting Rupture Pressure, Leak Rate, and Burst Pressure

- Equivalent Rectangular Crack Models Give Reasonable Results for Initial Ligament Rupture, but do not Predict well Subsequent Tearing of the Remaining Ligament Under Increasing Pressure or the Final Burst Pressure

Models for Circumferential Cracks and Severe Accidents

- Models for Circumferential Cracks
  - Models have been Developed – Using Fracture Mechanics Approach Instead of Plastic Instability
  - Model Correlates with TW EDM Laboratory Results
- Models for Severe Accidents
  - Creep Rupture Model (Combined with ANL m_p and Linear Damage Rule) Predicts Failure Temperatures more Accurately than flow Stress Model

Simple Orifice Model

- The Leak Rate Model based on Simple Orifice Flow Through a Crack with an Opening Area A is:

  $Q = C_d A\sqrt{(2\Delta p/\rho)}$

  C_d = coefficient of discharge = 0.6

  Δp = is the pressure differential

  ρ = mass Density of water

Simple Orifice Model

- For an Axial Crack:

  $A = 2\pi(c_e)^2 V_o \sigma / E$

  c_e = function of c, $(\sigma/\sigma_y)^2$, tube mean radius, tube wall thickness

  Where c is half the crack length

  V_o = function of c_e, the tube mean radius and tube wall thickness

  E = modulus of elasticity

Simple Orifice Model (Cont)

- Tests Show that due to Short Transit time Across the SG wall, Leaks over a Range of Crack Sizes can be Described by a Single Phase Orifice flow Model with an Opening Based on the Cracking Opening Area
- The Leak rate is a Function of L/D where L is the Crack Length and D is 2 times the Crack Opening
- Good Agreement for Slits, Orifices, and Open Cracks
- Models tend to Overestimate Leak Rates for Actual Cracks Because Remaining Ligaments the Crack Opening Area and Meandering Crack Paths Increase L

Simple Orifice Model (Cont)

- SCC tend to Undergo Incremental Ligament Rupture with Increasing Pressure Before Cracks Become Unstable Which Would Cause Leakage at Pressures Lower than Predicted
- The Equivalent Crack Method had been Generalized to Predict Incremental Ligament Rupture After Initial Ligament Rupture
- Predictions Based on Fractography Tend to be more Accurate than Those Based on EC

Test Facilities

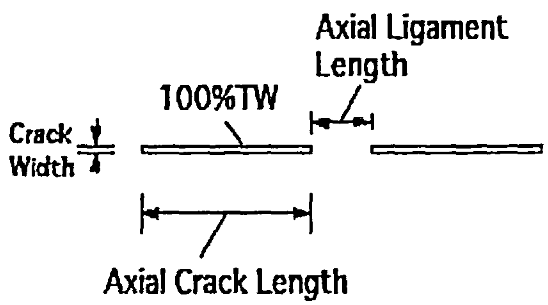
- Room-Temperature, High-Pressure Test Facility
  - Maximum Pressure - 7500 psi
  - Maximum Leak Rate – 12.8 gpm
  - Maximum Volume – Unlimited
- High Temperature, Pressure, and Leak Rate Test Facility
  - Maximum Temperature – 650 F
  - Maximum Pressure – 3000 psi
  - Maximum Leak Rate – 400 gpm
  - Maximum Volume – 200 Gallons

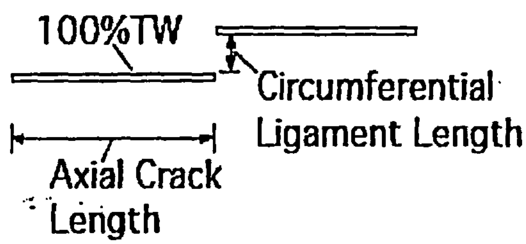
Testing - Pressurization Rate Effects

- Industry may Conduct Burst Tests to Demonstrate Adequate Margin as part of Condition Monitoring
  - Tests Conducted as part of Assessment of a Flaw at a Domestic Plant Suggested that There is a Pressurization rate Effect on Ligament Rupture Pressure
- Determination of rate Effect Inconclusive Since Protocols for fast and slow rate Tests Differed
  - Slow Rate Tests Conducted in 2 Steps, no Bladder and Foil Until Ligament Rupture, then Bladder and Foil Until Unstable Burst Pressure Reached
  - Fast Rate Tests Conducted with foil and Bladder from the Beginning
- Specimen to Specimen Geometry Variations Could Account for a Major Part of the rate Effect

Pressurization Rate Effects (Cont)

- Specimens Containing 1 inch Rectangular and Trapezoidal Notches 80-90% TW, and two 0.5 inch 80% TW Flaws Separated by a 0.05 inch Axial Flaw or a 0.05 inch Circumferential Ligament were Tested at Quasi-Steady State, 1000, 2000, 6000, and >10,000 psi/s
- No Effect of Pressurization Rate up to 6000 psi/s
- 2000 psi/s is the Maximum Industry rate





Secondary Side Depressurization Study

- Typical Analyses of Depressurization Events did not Consider the Bending Loads Imposed on a tube by the TSP when it is Locked to the Tubes by Corrosion Products
  - Concern with Dynamic Loads Raised by ACRS
- RES Calculated Dynamic Loads on TSP with RELAP5 and Benchmarked Against Experiments
  - Large SLB Produces Greater Pressure Drop than Small SLB or FWLB
  - Pressure Loading Acting on TSPs Transferred to Tubes Locked by Corrosion Products and Deposits

Secondary Side Depressurization Study (Cont.)

- Detailed FEA and Fracture Mechanics Analysis were Carried out for Model 51 SG TSPs and tubes
  - Loads on Tubes are Primarily Axial
  - Dynamic Loads have Virtually no Effect on Failure of Tubes with Axial Cracks
- If only one or two Tubes are Locked, the Stresses on the Locked Tubes Exceeds the Ultimate Tensile Strength
  - Because Displacements are Limited, Unflawed Tubes Would not Rupture, but the Tolerance for Circumferential Cracks Would be Severely Limited
  - If > 1.5% of Tubes are Locked, the Maximum Axial load is < 3 Kips and TW Circumferential Cracks < 180° are Stable

Constant Pressure Crack Growth Study

- Objective
  - Determine the Influence of Flaw Geometry on Flaw Tearing and Subsequent Leak Rate Behavior
  - Determine the Mechanism for Flaw Growth and Increases in Leak Rates at Constant Pressure
  - All Testing Conducted using the Room Temperature-High Pressure Test Facility

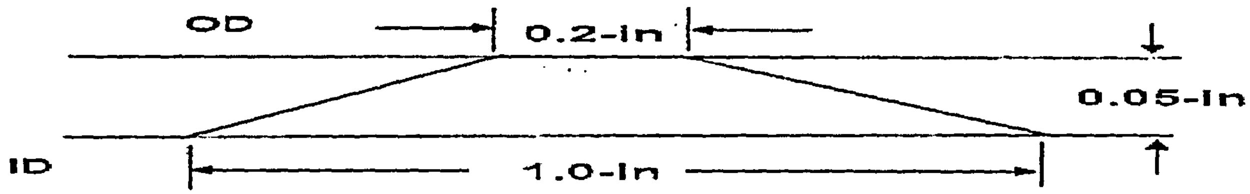
Time Dependent Crack Growth

- Early work on SCC Showed that the leak Rates are time Dependent
  - Attributed to Tearing of Ligaments and Opening of the Crack due to Limited time Dependent Deformation (Steady-State Creep rate very low at Operating Temperatures)
- Recent Tests show that, at Least at Room Temperature, Actual Crack Growth Occurs and at high Rates

Time Dependent Crack Growth Tests Program

- Test Material – Alloy 600, 7/8 inch Diameter Tubes, 0.05 inch Wall Thickness
- EDM Flaw Shape
  - Trapezoidal - 0.2 in OD, 1.0 in ID
  - Trapezoidal - 1.0 in OD, 0.2 in ID
  - Rectangular – 0.2 in, 0.4 in, 0.6 in,
  - EDM Notch Width 0.007 in
- With and Without a Foil and Bladder
- Open to air
- With a Small Shroud (1 ½ in Diameter)
- With a Large Shroud (4 in Diameter)

Trapezoidal Flaw Design

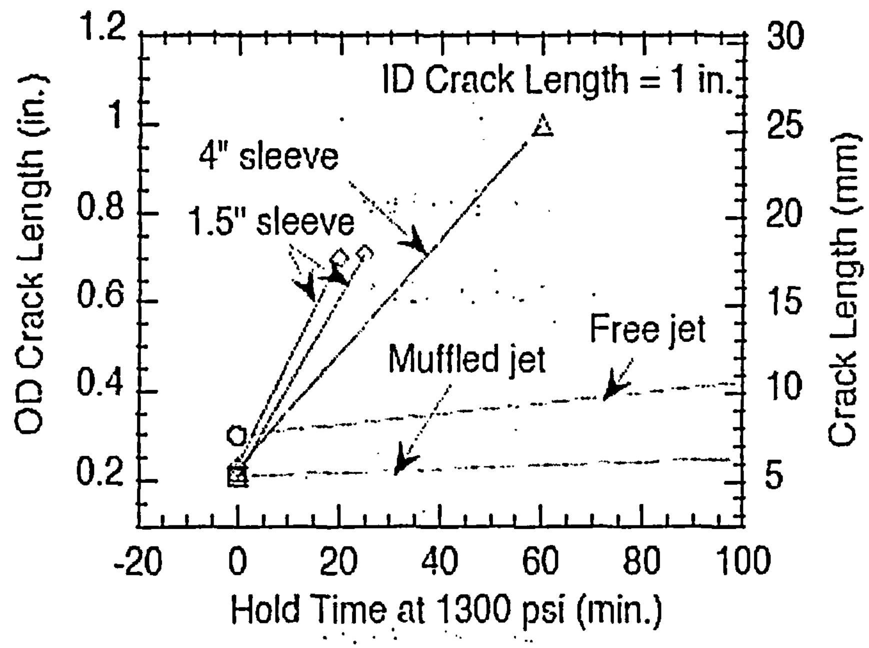


EDM Notch Approximately 0.007 Inches Wide

Test Results

- Jet-Free Tests with Bladder/Foil
  - No Crack Extension when Pressurized Using Nitrogen (wet or dry)
  - Low Crack Growth rate Using the Facility Pump
- Crack Growth Rates with Active jets
  - With Active jets Present, OD Increased from 0.2 in. to 1.0 in. in hours
  - Tests with Shrouds Filled with Water (to Simulate Expected jet Interactions with surrounding Tubes) Produced Higher Crack Growth Rates than Unconfined jets

Effect of Test Conditions on Crack Length for Trapezoidal Cracks



Proposed Mechanisms for Increase in Leak Rate at Constant Pressure

- Mechanisms for Crack Growth
  - Jet Erosion of the Crack Faces
  - Rapid Flaw Corrosion at Room Temperature
  - Jet/Flaw Structural Dynamic Interaction Resulting in Fatigue Crack Growth
  - Pressure Oscillation from the Pump Causing Crack Growth

Statistical Treatment of Models

- Candu Tube Inspection Assessment (CANTIA) – Developed by Dominion Engineering, Inc. for the Canadian Nuclear Safety Commission
- Determines Probabilities of Failure and leak rate from Primary to Secondary side During Normal Operation and Design Basis Accident Conditions
- Integrity, leak rate, and Degradation Models in CANTIA Specifically Intended for CANDU Steam Generators

Statistical Treatment of Models

- ANL Modified the CANTIA code Maintaining Basic Monte-Carlo Structure but Incorporating the ANL Revised Models for Predicting Ligament, Unstable Burst, Crack Opening Area, and Leak Rate of Flawed Alloy 600 Tubes
- Source Language was Updated from Visual BASIC 3.0 to Visual BASIC 6.0
- Basic Flaw was Changed from 1-D to 2-D
- Added two Models for Stress Corrosion Crack Growth Rate (the Scott Model and the Ford and Andresen Model)

Summary of Results

- Models Presented for Plastic Collapse of a Tube with a TW Axial Crack and a Part TW Axial Crack – Original Model Underestimated Ligament Rupture Pressures for Short deep Cracks, ANL Modification Provided Better Prediction
- Equivalent Rectangular Crack Method Presented – Gives good Results for Initial Ligament Rupture, not as good for Subsequent Tearing
- Simple Orifice Model Presented
  - Good Agreement for Slits, Orifices, and Open Cracks
  - Models tend to Overestimate Leak Rates for Actual Cracks Because Remaining Ligaments the Crack Opening Area and Meandering Crack Paths Increase L

Summary of Results (Cont)

- Pressurization Rate Effects Presented – No Effect at Typical Industry test Rates
- Secondary Side Depressurization Study Presented
  - Dynamic Loads have Virtually No Effect on Axial Flaws
  - If >1.5% of Tubes are Locked, TW Circ Cracks < 180° are Stable
- Constant Pressure Crack Growth Results Shown
  - Active jets Produce Increased Growth Rate with Time
- Statistical Treatment of Models Presented

Future Work on Tube Integrity

- Conduct Tests on Complex Morphology Cracks and Develop Predictive Models for Leak and Rupture Pressure
- Assess Alternatives to the Equivalent Rectangular Crack Method to Estimate Failure Pressures and Leak Rates
- Continue Development of the CANTIA Code

Task 1 - ASSESSMENT OF INSPECTION RELIABILITY

- Objective – Evaluation of Existing ISI Methods for Detection of Current Day Flaws
- Review of EC Round Robin on NRC/ANL SG Mockup
  - Mockup also used to Assess new Probe Designs
- Signal-to-Noise Issue
- X-Probe Evaluation

Steam Generator Mockup Round Robin

- Eddy Current Data Collected by Qualified Industry Team to Current Industry Practices and Qualification Proceedures
- 11 Qualified Analysis Teams Participated in the Round Robin Using the ANL/NRC SG Mockup
- Teams Consisted of a Primary, a Secondary, and 2 Resolution Analysts and a Qualified Data Analyst to Resolve Disputes
- The Differences Between the Teams was not Great, Although one team did not do as well as the Others
- Flaws were Missed Because
  - Signals were too Complex (Phase Angle did not show Expected Behavior)
  - Low Signal-to-Noise
  - Human Error

Task 2 - Research on ISI

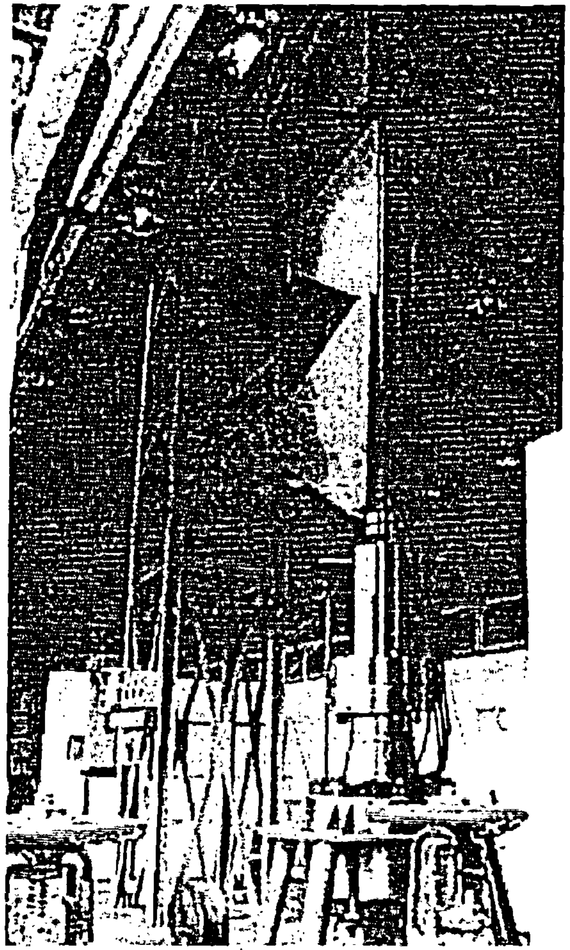
- Objective – Evaluate Advanced NDE and Signal Analysis Techniques – Improved Flaw Detection and Sizing
  - Practical need for Advanced Characterization techniques for Round Robin Because is was Impractical to Characterize Hundreds of Flaws Metallographlly

Task 4 - Degradation Modes

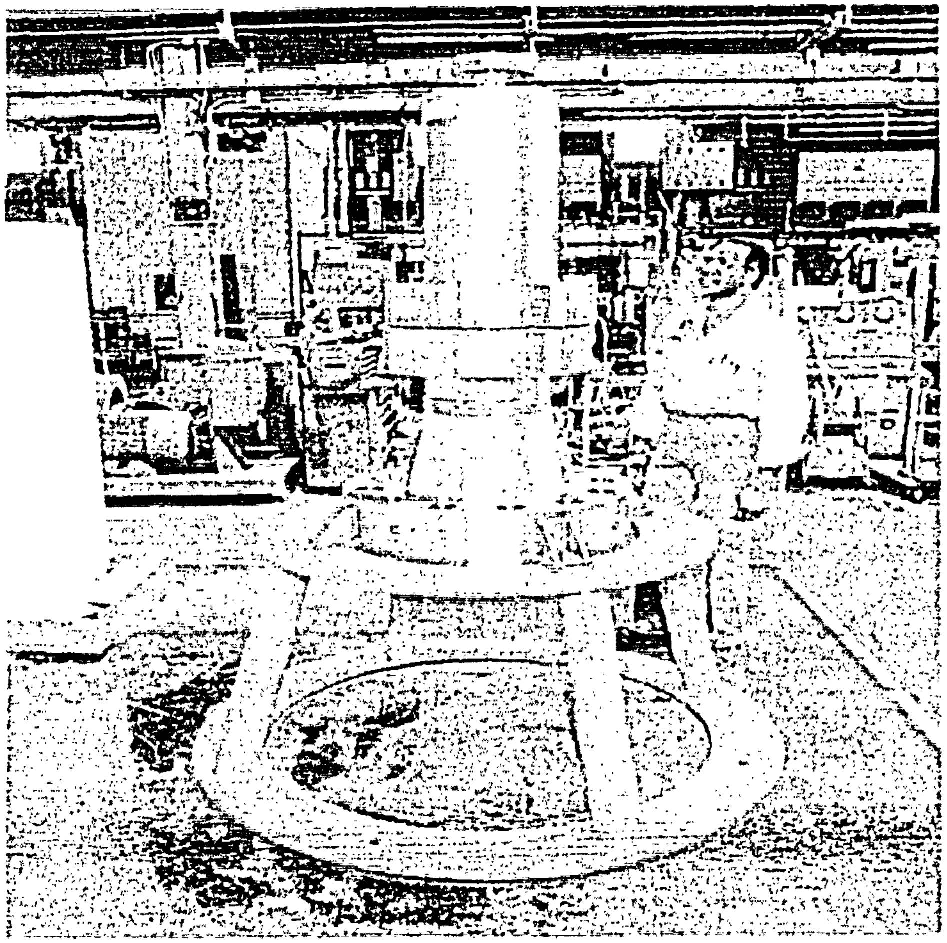
Objective –

- Evaluate and Validate Models for Degradation Modes
- Improve Understanding – Crevice Conditions, SCC Initiation, Evolution, Growth
  - Assess Implications of Known Susceptibility of Alloy 690 TT to SCC Under some Laboratory Conditions for Future Field Experience

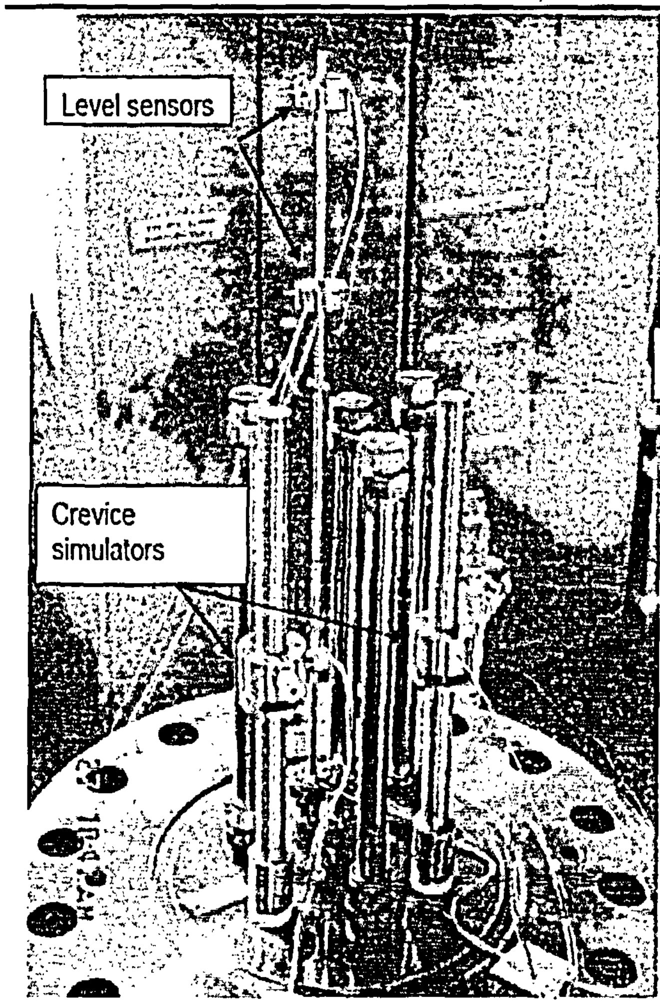
Model Boiler

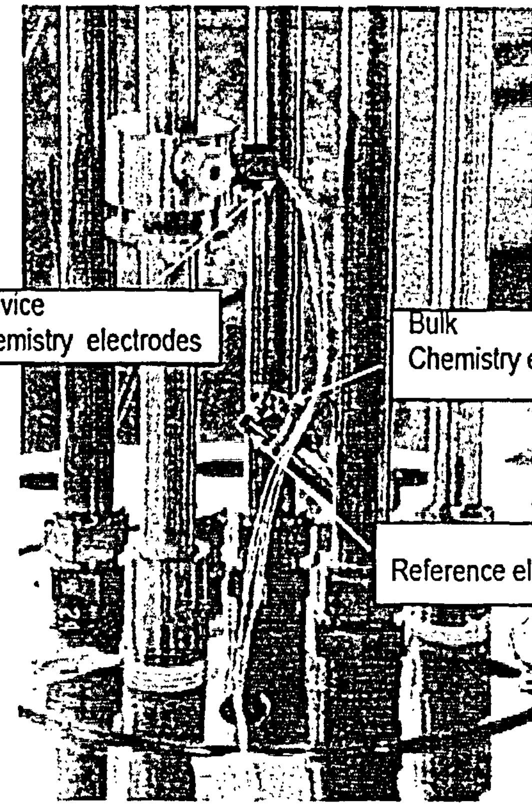


Argonne Model Boiler (Primary / Secondary Chambers)



Model Boiler
Crevice / Bulk Water Instrumentation





Overall Conclusion

- Task 3 - Tube Integrity and Integrity Predictions
  - Models Developed for Predicting Rupture and Burst Pressures for Axial and Circ TW and Part TW Cracks
  - Developed Models for Severe Accidents
  - Models tend to Predict Ligament Rupture Better than Burst Pressure
  - Simple Orifice Model Provides Good Agreement for Idealized Cases, not as good for Actual Cracks
  - On Pressurization rate Effect At Industry test Rates
  - Secondary side Depressurization Study Showed no Effect of Dynamic Loads on Axial Cracks, if a few Tubes are Locked, need big TW Circ Cracks to fail
  - Cracks Grow at Constant Pressure if Active Jets are Present

Overall Conclusion (Cont)

- Task 3 -Assessment of Inspection Reliability
  - SG Round Robin – Teams were Fairly Consistent – Flaws Missed due to Complex Signals, Low Signal-to-Noise, Human Error
- Task 2 – ISI Technology – Advanced Characterization Techniques Developed to Supplement Destructive Evaluation
- Task 4 Degradation Modes – Showed the Model Boiler

Overview

- Research is Being Conducted in a Variety of Areas
- NRR has Requested Research Related to ISI Capabilities, ISI Reliability, and Rupture, Burst, and Leakage Models
- NRR will use this Information in the Review of Licensee Submittals and to Provide Guidance to Regional Inspectors
- In Response to ACRS Feedback, Additional Work is Being Conducted on Crevice Chemistry and the Relative Susceptibility of Various Tube Materials to Cracking

NRC DIGITAL SYSTEM RESEARCH PLAN
FY 2005 THROUGH FY 2009

Michael E. Waterman, Sr. I&C Engineer
William E. Kemper, Section Chief
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OVERVIEW

- Provides a flexible, adaptable framework for identifying NRR, NMSS, and NSIR research initiatives
  - 27 Projects across 6 Research Programs
- Oriented toward providing more consistent processes for regulating nuclear applications
  - Technical guidance
  - Regulatory-based objective acceptance criteria
  - Assessment tools and methodologies
  - Review and inspection procedures
  - Staff training
- Draft – comments to be incorporated

CURRENT SITUATION

- Issues facing NRC
  - Licensees are replacing analog systems with digital systems
  - Licensing these digital systems presents challenges to NRC
    - Increased complexity
    - Rapid changes in digital technology
    - New failure modes
  - NRC licensing processes should be kept current
  - A risk-informed, performance based safety assessment process should be developed for licensing digital systems

RESEARCH FOCUS

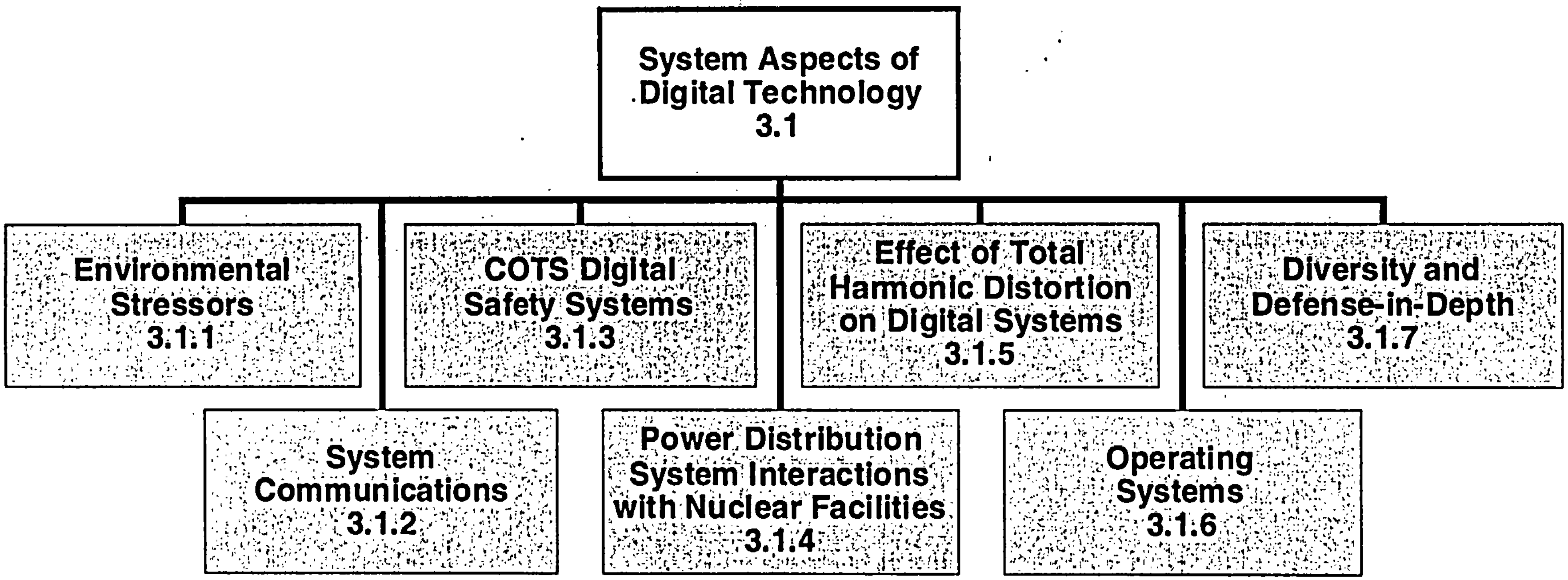
- Structured to develop better methods and understand new technologies
  - Risk-informed (e.g., risk assessment capabilities)
  - Performance based (e.g., dependability assessments)
  - Objective and repeatable (e.g., software quality evaluation methodologies)
- Broad-based, focusing on improving traditional review methods for
  - New applications of existing technologies
  - Advanced technologies
  - New issues and regulatory requirements

RESEARCH PROGRAMS

NRC Digital System Research Plan

- System Aspects of Digital Technology 3.1
- Software Quality Assurance 3.2
- Risk Assessment of Digital Systems 3.3
- Securiy Aspects of Digital Systems 3.4
- Emerging Digital Technology and Applications 3.5
- Advanced Nuclear Power Plant Digital Systems 3.6

SYSTEM ASPECTS OF DIGITAL TECHNOLOGY PROGRAM 3.1



ENVIRONMENTAL STRESSORS
PROJECT 3.1.1

- Environmental compatibility for safety-related I&C systems depends on maintaining the expected environment in the nuclear power plant and qualifying the equipment to withstand that environment
- Specific, comprehensive regulatory guidance
  - EMI/RFI – Updated RG 1.180
  - Lightning – DG-1137
  - Environmental qualification (EQ) – DG-1077

SYSTEM COMMUNICATIONS PROJECT 3.1.2

- The trend in digital safety systems is towards networked intrasystem architectures using dedicated communication microprocessors and proprietary communication protocols
- NRC requires expertise to evaluate these complex digital communication systems and the failure analysis techniques for these architectures
- The research will provide acceptance criteria and methodologies for reviewing these systems

COTS DIGITAL SAFETY SYSTEMS PROJECT 3.1.3

- The nuclear industry is retrofitting existing analog systems with COTS-based digital systems
- Research will evaluate methods for performing more quantitative safety assessments
  - Fault injection method for estimating digital system (HW, SW, HW+SW) dependability in COTS
- This project will further refine these methods for incorporation into NRC review methodologies by using realistic safety-related COTS systems as test beds

ELECTRICAL POWER DISTRIBUTION SYSTEM INTERACTIONS PROJECT 3.1.4

- NPP digital-controlled power equipment sensitivity to changes in grid voltages has resulted in undesirable equipment responses
- Research will support RES/DSARE/AREAB efforts to model highly distributed, complex systems composed of digital, analog, discrete, high voltage, high current power components to determine the effects of grid voltage fluctuations on digital equipment

EFFECT OF THD ON DIGITAL SYSTEMS PROJECT 3.1.5

- Newer digital components are more sensitive to total harmonic distortion (THD)
  - Higher IC circuit densities
  - Lower voltage requirements for memory states
- THD could be a potential CMF mechanism
- Currently, no methods exist in NRC to evaluate the effect of THD on digital system components
- This research project will evaluate the effect of THD on digital systems and provide guidance on acceptable THD thresholds

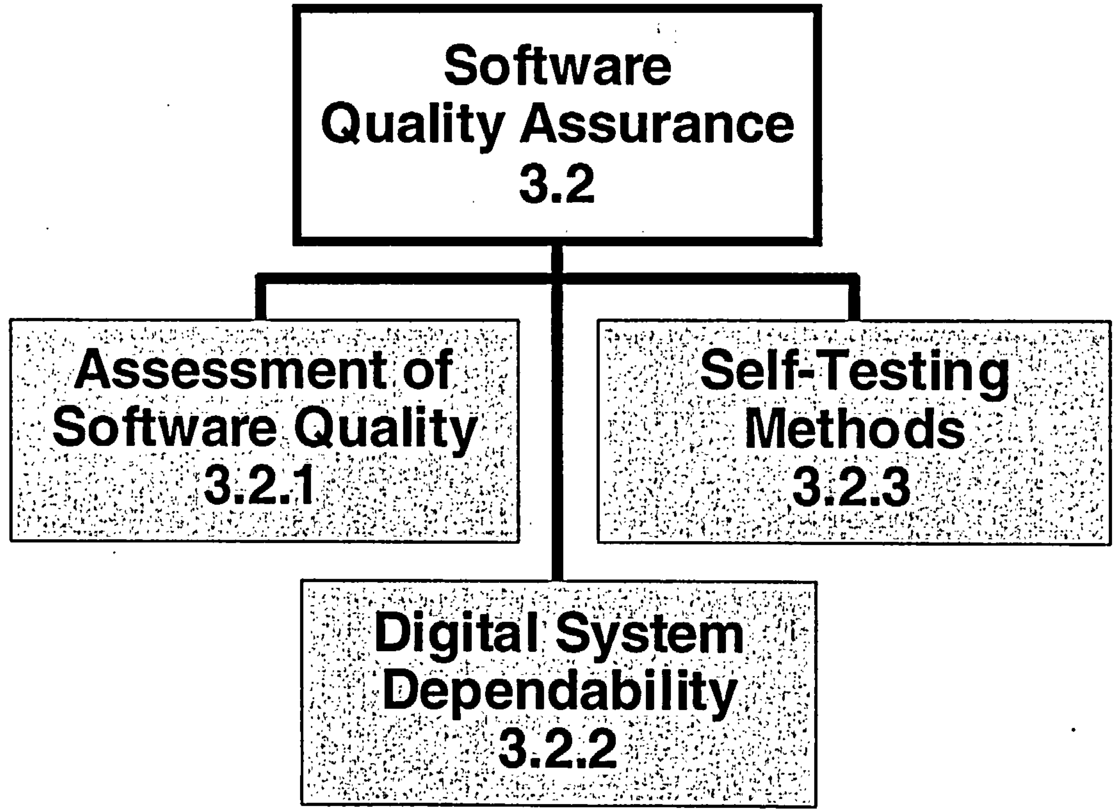
OPERATING SYSTEMS PROJECT 3.1.6

- NRC has not been able to assess proprietary COTS operating system characteristics
- RES initiated a study of operating system characteristics
- The results were inconclusive
- Further research will
  - Identify safety-critical design aspects of operating systems
  - Develop processes for performing safety assessments of operating systems

DIVERSITY AND DEFENSE-IN-DEPTH PROJECT 3.1.7

- D3 position and guidance are deterministic
- The nuclear power industry has proposed using risk insights from PRAs
- This project will
  - Verify, deterministically, that existing guidance (SRP BTP HICB-19) is realistically conservative
  - Evaluate NUREG/CR-6303 coping strategies
  - Perform case studies of digital safety system configurations to evaluate their susceptibility to CMF
  - Evaluate the fault injection process as a methodology for identifying CMF vulnerabilities

SOFTWARE QUALITY ASSURANCE PROGRAM 3.2



ASSESSMENT OF SOFTWARE QUALITY PROJECT 3.2.1

- NRC evaluates the quality of digital systems development processes manually
- This research project is developing a more effective and thorough supporting process
- Complements the fault injection testing assessment methodology already developed for digital system dependability testing
- HRP is evaluating SWE practices and criteria that may be effective in assuring software quality

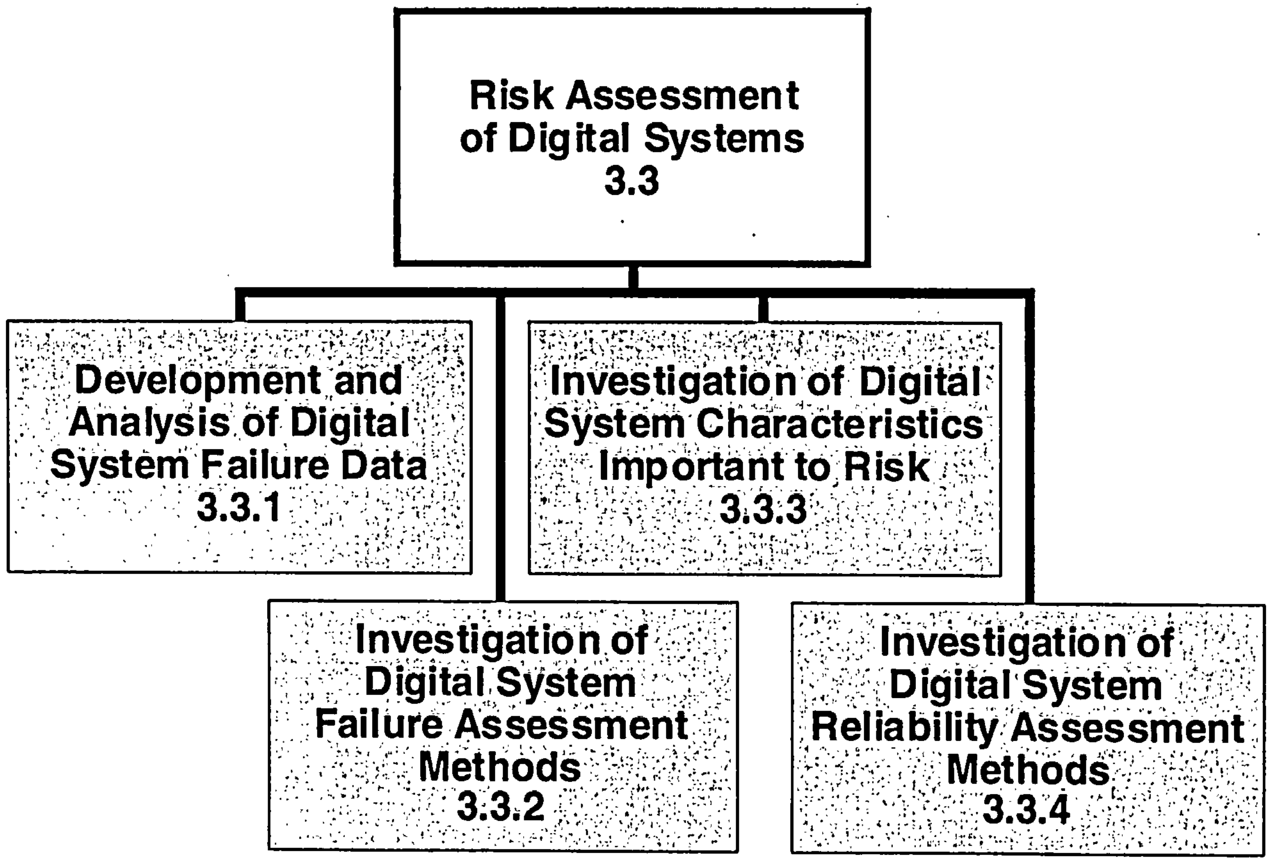
DIGITAL SYSTEM DEPENDABILITY PROJECT 3.2.2

- Safety significant errors in digital systems may not be detected by V&V processes
- Methods are needed to evaluate digital systems
- A fault injection methodology has been developed to evaluate dependability
- This project will produce a process for using this tool to determine the dependability of digital safety systems
  - Three SR COTS platforms will be evaluated

SELF-TESTING METHODS PROJECT 3.2.3

- Self-testing methods test hardware and software continuously to improve availability
- The technical issues concern
  - Effectiveness in determining system performance
  - Adverse effects on safety system performance
  - Identifying acceptable self-testing methods
  - The amount of self-testing that is sufficient
- This research project will develop technical guidance and review methodologies for evaluating self-testing features in digital systems

RISK ASSESSMENT OF DIGITAL SYSTEMS PROGRAM 3.3



DEVELOPMENT AND ANALYSIS OF DIGITAL SYSTEM FAILURE DATA PROJECT 3.3.1

- The NRC is risk-informing its activities
- Assessing failure probabilities requires that the NRC have a standard process for collecting, analyzing, and using digital system data
- The purpose of this research project is to
  - Collect and assess digital system failure data
  - Evaluate digital system failure assessment methods and data used by defense, aerospace, and other industries
  - Develop a process to identify the frequency, severity, cause, and possible prevention of digital system failures
  - Maintain the digital system reliability data for use in modeling digital systems in PRAs

INVESTIGATION OF DIGITAL SYSTEM FAILURE ASSESSMENT METHODS PROJECT 3.3.2

- To support risk assessments, NRC should develop or identify methods for assessing digital system failure modes
- Guidance and criteria on the use of these methods and how to support risk assessments of digital systems in an integrated process should be defined
- This research project will
  - Survey analytical methods for identifying digital system faults and their impact on safety
  - Describe the advantages and disadvantages of each method
  - Provide guidance for using digital system failure assessment techniques, and the criteria for using the techniques

INVESTIGATION OF DIGITAL SYSTEM CHARACTERISTICS IMPORTANT TO RISK PROJECT 3.3.3

- PRAs model digital systems as "black boxes"
- Need to incorporate risk models into PRAs
- Need a consistent approach and acceptance criteria for reviewing risk-informed systems
- This research project will
  - Develop risk models of digital systems
  - Identify digital systems to be modeled and the level of detail to be modeled
  - Identify sub-components that may warrant attention
  - Develop a methodology for performing these activities

INVESTIGATION OF DIGITAL SYSTEM RELIABILITY ASSESSMENT METHODS PROJECT 3.3.4

- The NRC needs a standard methodology for analyzing digital system reliability so that acceptance criteria can be applied to risk-inform safety system designs
- This research project will
  - Identify digital system reliability assessment methods
  - Develop a digital system reliability assessment methodology
  - Conduct case studies to assess the methodology
  - Support the development of acceptance criteria (Reg. Guide 1.17x)

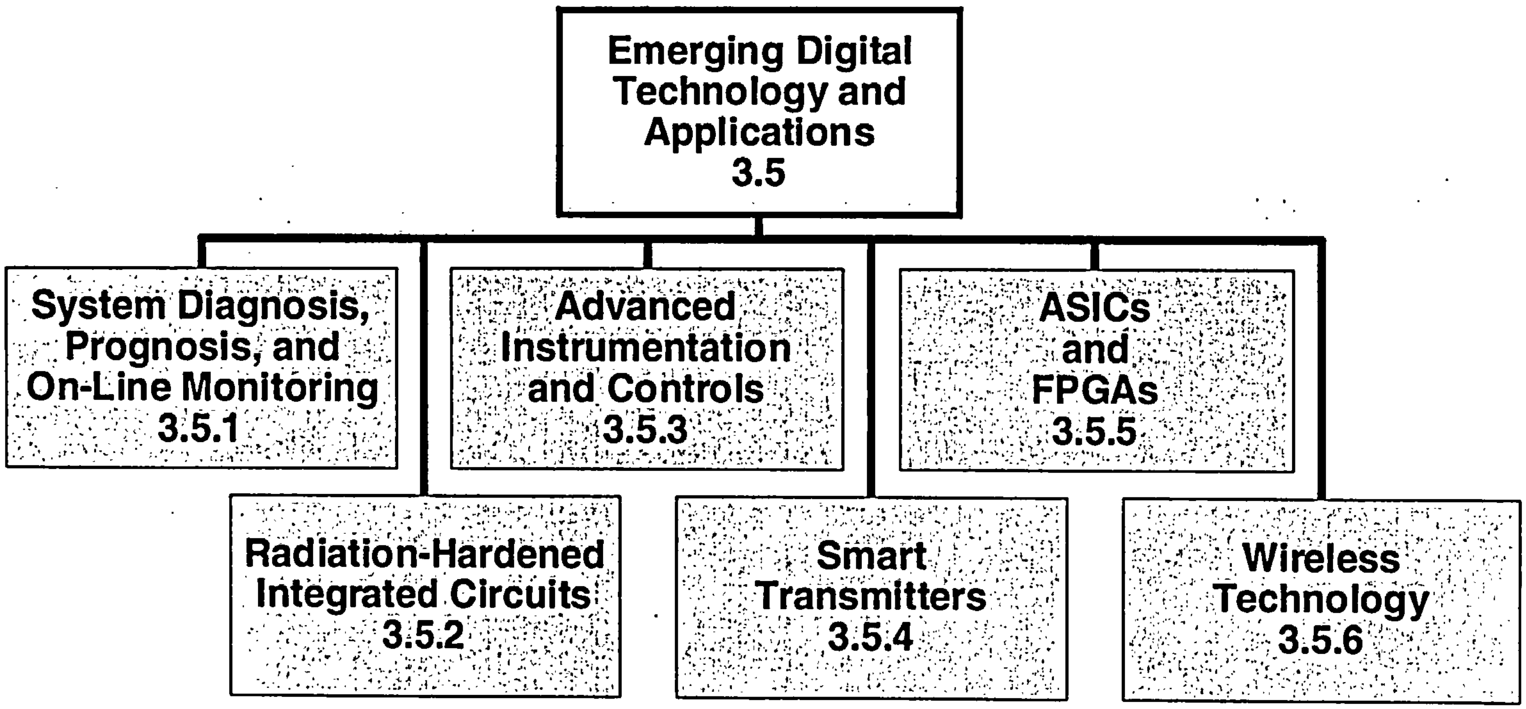
SECURITY ASPECTS OF DIGITAL SYSTEMS PROGRAM 3.4

- **Security Aspects of Digital Systems 3.4**
  - **Security Assessments of Cyber Vulnerabilities 3.4.1**
  - **Security Assessments of EM Vulnerabilites 3.4.2**
  - **Wireless Network Security 3.4.3**
  - **Firewall Security 3.4.4**

SECURITY ASPECTS OF DIGITAL SYSTEMS

- Cyber security is an NRC concern that has been heightened since the events on 9/11
- Digital system security requires addressing potential vulnerabilities during system development and after installation
- Four projects are being initiated
  - Security of digital platforms
  - Site-specific protocol analysis
  - Secure network design techniques
  - Guidelines for NPP cyber security policy development

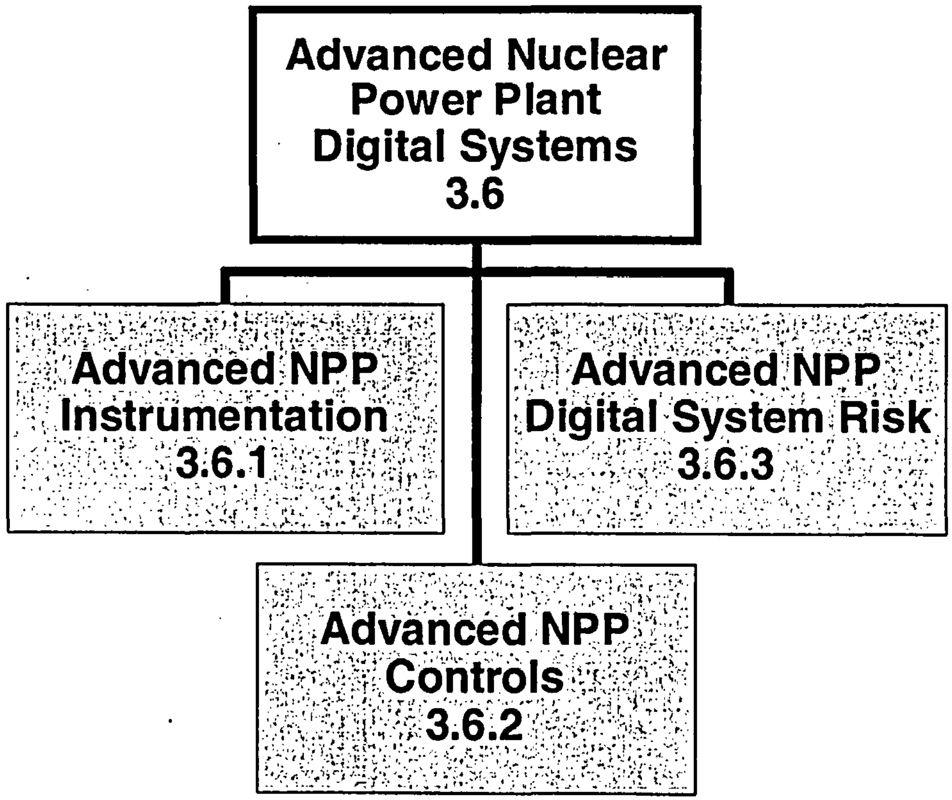
EMERGING DIGITAL TECHNOLOGY AND APPLICATIONS PROGRAM 3.5



EMERGING DIGITAL TECHNOLOGY AND APPLICATIONS

- Knowledge about new, emerging technologies is critical for NMSS, NRR, and NSIR staff to license safety related applications in an effective and realistic manner
- This research will provide regulatory guidance for reviewing NPP applications
- Ongoing projects include
  - Emerging technology evaluations
  - On-line Monitoring
  - Advanced flow meters
  - Wireless technologies

ADVANCED NPP DIGITAL SYSTEMS PROGRAM 3.6



ADVANCED NPP DIGITAL SYSTEMS

- Advanced reactor designs (ACR-700, EPR, ESBWR, PBMR, etc.) may apply new I&C technologies, and thereby present challenges for identifying risk-informed characteristics
  - Robotics, fuzzy logic controls, autonomous controls, fully integrated DCSs, new instrumentation, etc.
- Research projects are dependent on future advanced reactor design pre-application submittals
  - No research in progress at this time

SUMMARY

- Provides a flexible, adaptable framework for identifying NRR, NMSS and NSIR research initiatives
- Broad-based program oriented toward providing more consistent processes for regulating nuclear applications; improving review methods for new applications of existing technologies, advanced technologies and new issues; and developing regulatory requirements
- RES is looking forward to working closely with the ACRS as these programs are implemented