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UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION
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JOINT MEETING
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
(ACRS)
SUBCOMMITTEES ON MATERIALS & METALLURGY AND
THERMAL-HYDRAULIC PHENOMENA
\+ + + + +
WEDNESDAY, FEBRUARY 4, 2004
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ROCKVILLE, MARYLAND
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The Subcommittees met at the Nuclear Regulatory Commission, Two White Flint North, Room T2B3, 11545 Rockville Pike, at 8:30 a.m., F. Peter Ford and Graham Wallis, Co-Chairmen, presiding.

COMMITTEE MEMBERS PRESENT:

F. PETER FORD, Co-Chairman
GRAHAM B. WALLIS, Co-Chairman
MARIO V. BONACA, Member
THOMAS S. KRESS, Member
VICTOR R. RANSOM, Member
STEPHEN L. ROSEN, Member
JOHN D. SIEBER, Member

ACRS STAFF PRESENT:

B.P. JAIN
MAITRI BANERJAN
BILL BATEMAN
CHRIS BOYD
JIM DAVIS
BOB DOWNIG
DON FLETCHER
MICHELLE HART
ALLEN HISER
KEN KARWONSKI
WILLIAM KROTIUK
DAVID KUPPERMAN
STEVE LONG
LOUISE LUND
JOE MUSCARA
JOEL PAGE
WILLIAM SHACK
ROY WOODS

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

PAGE

Thermal Hydraulic Conditions During

Severe Accidents:

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

(8:33 a.m.)

CO-CHAIRMAN FORD: The meeting will now come to order.

I'll just repeat the salient points of the introduction I gave yesterday.

This is the second day of the meeting of the Advisory Committee on Reactor Safeguards, joint Subcommittees on Materials and Metallurgy and Thermal Hydraulic Phenomena.

I'm Peter Ford, Chairman of the Materials and Metallurgy Subcommittee, and my Co-chair is Graham Wallis, Chairman of the Thermal Hydraulics Phenomena Subcommittee.

Subcommittee members in attendance are Mario Bonaca, John Sieber, Tom Kress, and Vic Ransom.

The purpose of the Joint Materials and Metallurgy and Thermal Hydraulic Phenomena Subcommittee meeting is to review the staff's resolution of certain items identified by the ACRS in NUREG 1740, voltage based alternative repair criteria.

I will not reproduce what was said yesterday about speaking clearly, et cetera, et cetera.

MR. SIEBER: Why not?

(Laughter.)

CO-CHAIRMAN FORD: I have a request from the members at the end of today's session I'd like their advice about the need for a lecture on this topic. The staff view this as an informational meeting, and they're not requiring a letter, as I understand it, but we may decide to issue a letter regardless.

And I'd also like their advice to the staff on their two-hour presentation to the full committee on Thursday. It's my understanding that the staff are just going to give a summary of each of the tasks. I'm not too sure if this is correct, presumably with back-up slides on salient points. But I'm sure you would like advice from the members on what goes into that two-hour meeting.

With that I'll pass it on to you, Joe, to introduce your speakers.

MR. MUSCARA: Okay. Thank you, Peter.

I think today we'll continue with our topics on thermal hydraulics and the premises and component behavior in the severe accident conditions in the PRA. So these areas relate essentially to severe accidents.

Just one other point. I did bring a few

copies of our integrated program plan that I'll share with the members, and I think without delaying very much we'll start with the hydraulics work and Chris Boyd is going to start off in that area.

MR. BOYD: Okay. My name is Christopher Boyd. I work in the Office of Research.

And I'm going to be going over the thermal hydraulic work that has been done in the past year and a half in support of the steam generator action plan.

The outline for what I'll go over is a quick overview of the thermal hydraulic work, some of the background issues.

We have a note about the ARTIST program, which is one of the steam generator action plan items. I'm not directly involved with that, but will give a note.

And then the bulk of my presentation will be on the SFD related work, steam generator action plan Item 3.4(e), and then Don Fletcher from ISL, Information Systems Laboratories, will give the SCDAP/RELAP 5 analysis, which is tied into the CFD work. The CFD work feeds that, and we'll take a look at how that has worked.

What we're looking at in general, the thermal hydraulic analysis predicts the thermal and mechanical loads that are applied to the reactor coolant system. We're going through a process of updating our predictions for the ZION plant during the TMLB prime station blackout transient.

We've updated our boundary conditions. We've got more realistic conditions and assumptions. We've significantly updated the mixing parameters based on a reanalysis of the one-seventh scale test, as well as the CFD data or predictions which I will present.

CO-CHAIRMAN WALLIS: Are these the more realistic boundary conditions, more realistic than the ones that we saw in the material that you sent us?

MR. BOYD: I don't believe we have a final report that we sent you.

CO-CHAIRMAN WALLIS: Oh, okay.

MR. BOYD: That's right, and when I say "more realistic," --

CO-CHAIRMAN WALLIS: You sent us two reports.

MR. BOYD: -- we took into account things like radiation that were ignored before.

CO-CHAIRMAN WALLIS: Well, maybe we'll get to that in your presentation.

MR. BOYD: We'll get to that, and these

more realistic boundary conditions that I'm mentioning here are part of the SCDAP/RELAP 5 work, and in general we've just improved the SCDAP/RELAP 5 modeling of design plant. Essentially we're sharpening our pencils, I guess, in preparation for the support to the PRA analysis to follow.

And in all of the work that we've done, the failure predictions still indicate the surge lines failing prior to the in flow of tubes, but you know, the timing between these two failures is still relatively close in time. So in some ways we're in the same position we were. After all of the changes and updates we've made, we're still in about the same position.

The approach and the tools we're using, SCDAP/RELAP 5 is the work horse. It provides the temperatures and pressures and heat transfer coefficients in general to the reactor system components. We've got three dimensional aspects of flow that are with this one dimensional code. So we're using one-seventh scale experiments to provide mixing parameters and other --

CO-CHAIRMAN WALLIS: Can I ask you about that? I don't know if you're going to talk about it.

In the material that was sent to us, there was a picture of these experiments, a cartoon, and it looked very strange because the core, the vessel was divided down the middle by a plate, and it looked as if the flow went to the right through one steam generator or to the left through the other.

But it wasn't a common upper plenum, and in the real system the flow has to decide which way to go, whether it goes to the one that's recirculating completely or the one that's recirculating with the counter current flow or if there are four generators, you have to figure out which one is in counter current flow and which one is in complete circulation, and you don't have a core which has a cut down the middle by a plate.

MR. BOYD: Okay.

CO-CHAIRMAN WALLIS: So half of the flow has to go one way and half the other or --

MR. BOYD: Are we talking about the one-seventh scale experiments?

CO-CHAIRMAN WALLIS: Yes.

MR. BOYD: Well, we did use a half a vessel. It was a four loop plant. They did cut the vessel down through the middle with a plate, and they had two steam generators on that.

CO-CHAIRMAN WALLIS: Well, that's very

different from the reality. There isn't a plate down the middle. I mean, the flow has to go -- there's a common header in the upper plenum, right? And the flow has to decide which to go.

I can understand why they had two, but in reality they're got four out of three that are in recirculation mode and one in counter current flow or are there three in counter current flow? How do you know?

MR. BOYD: Well, during the experiments, both were in this counter current flow situation.

CO-CHAIRMAN WALLIS: Yeah, but one had a complete loop circulation and one had the counter current flow in the --

MR. BOYD: No. In the facility there was no complete loop circulation because there was no cold legs, and in the outlet plenum, there was no outlet to --

CO-CHAIRMAN WALLIS: So the cartoon that introduced that seemed to be wrong then.

MR. BOYD: The cartoon could have been wrong. I'm not sure exactly which one --

CO-CHAIRMAN WALLIS: Well, we're going to get into this because what I'm going to ask you is how this -- one of the things I'm going to ask you is how what you did relates to what's happening in the other loops because you've got to solve the whole thing together, and maybe that will come out of the SCDAP/RELAP.

But there's an interfacing question there that we'll get into. Okay?

MR. BOYD: Okay.

DR. RANSOM: Well, isn't part of that due to I detect that you assume that the loop seals don't clear.

MR. BOYD: That's correct.

DR. RANSOM: So thus the flow cannot go in that direction. Are there any conditions where the loop seals would clear?

MR. BOYD: We're not seeing any in the SCDAP/RELAP 5 analysis that we're performing. So if you believe that, then the loop seal is not clearing.

In the one-seventh scale experiments, there was no chance for the loop seals to clear because the outlet plenum was a steel hemisphere with no outlet.

DR. RANSOM: Well, was that the reason for it?

MR. BOYD: I would assume. I wasn't planning that test, but I would assume they assumed the loop seals were plugged and we're not going to bother with a --

CO-CHAIRMAN WALLIS: Not all four of them.

MR. BOYD: All four?

CO-CHAIRMAN WALLIS: One of them is open. All four loops are in this --

MR. BOYD: Don, do you want to talk to this?

MR. FLETCHER: Excuse me. Don Fletcher of ISL.

In the SCDAP analysis we've modeled the four loops independently so that we have four identical cool loops with the exception of the pressurizer being on one loop. The model itself decides whether we have the split hot leg configuration with the recirculation through the legs and back to the vessel or whether we have a complete flow through situation, a normal flow direction, if you will.

The decision is based upon whether the loop seals are plugged or not and whether the bottom of the downcomer is plugged with --

CO-CHAIRMAN WALLIS: So there are various combinations of things that can happen.

MR. FLETCHER: That's correct. The model

is set up to look at it as the calculation proceeds and decide which mode each of the legs independently is in.

CO-CHAIRMAN WALLIS: Okay. So you cannot just impose a boundary condition of a temperature in the upper plenum. You have to calculate it knowing the heat transfer and all of these loops, whatever mode they're operating in.

MR. FLETCHER: That's correct.

CO-CHAIRMAN WALLIS: Okay.

MR. FLETCHER: Let me say in general the loop seals remain plugged with water.

CO-CHAIRMAN WALLIS: All of them?

MR. FLETCHER: In all of them, yes.

CO-CHAIRMAN WALLIS: Well, that makes it easier. Yeah, okay.

Thank you.

MR. BOYD: I'm not sure that makes it any easier, but --

CO-CHAIRMAN WALLIS: Well, it makes it easier if you know the mode of operation. If you're not sure whether they're plugged or not, then you've got different combinations of things to worry about.

MR. BOYD: So back to our toolbox, SCDAP/RELAP 5 is the workhorse code which predicts the transient behavior and is modeling all of these system type issues that we're talking about.

Because it's a one dimensional code and we've got three dimensional behavior, we're relying on a set of one-seventh scale experiments to provide mixing parameters. These one-seventh scale experiments are being augmented with --

CO-CHAIRMAN WALLIS: Well, excuse me. That's not the only problem. You have a problem of interfacing your one dimensional code with your three dimensional code quite apart from the experiments.

MR. BOYD: We're not directly interfacing those two codes.

CO-CHAIRMAN WALLIS: Well, I think you have that issue though. You have to figure out how to do it.

MR. BOYD: Okay. We can talk about that.

CO-CHAIRMAN WALLIS: Because SCDAP/RELAP has to put in somehow the flow rate in your counter current flow loop, right? Which itself is the variable that's derived from CFD.

MR. BOYD: No, it --

CO-CHAIRMAN WALLIS: Yes, it is, and we'll get to that.

MR. BOYD: Okay. That sounds good.

CO-CHAIRMAN WALLIS: You don't, but it should be. We'll get to that.

MR. BOYD: Okay. So we've got these one-seventh scale experiments which are determining a lot of information about the three dimensional behavior. They're being augmented and extended with computational fluid dynamics.

Then in the area of fission product transport, we're going to do analysis with MELCOR, kind of a repeat of some of the SCDAP/RELAP 5 analysis, and that will be augmented with data from the ARTIST program when that becomes available.

So the issues raised in NUREG 1740 that related to the thermal hydraulic work are there was a comment made the 1D codes are tuned by comparison with experimental results, and this is correct. The scale of the experiments is criticized. There's a concern that mixing may be overestimated. There was a note that the test did not simulate tube leakage and its effect on mixing.

I saw comments in some transcripts where there was a doubt whether there was any mixing at all. So there was a lot of questions about this inlet plenum mixing.

The sensitivity studies may not have

covered the entire plausible range of variations was a comment. They didn't cover simultaneous variations. These are some of the issues that related to the thermal hydraulic work.

In the steam generator action plan in Section 3.3, these issues were more or less addressed by a series of tasks or subtasks. I'm not going to go through these in detail, but these are the specific milestones that address some of those.

And that concludes my overview and now we're going to go on to the next section with just a single viewgraph on the ARTIST program. This is the aerosol trapping in the steam generator. This is being conducted at Paul Sherrer Institute.

There is a series of tests that have started, but they're not the tests the NRC is specifically involved with or the tests that we're interested in. We plan on following these tests, getting the data when it becomes available and trying to incorporate that into our MELCOR analysis for the fission product release rate. So this is a task in the steam generator action plan that's kind of pending at this point.

And at this point we'll start into the CFD related work which will take up the rest of the discussion by me, and then we'll jump to Don for the SCDAP/RELAP 5 work.

CO-CHAIRMAN FORD: Excuse me. Just on the ARTIST program, you mentioned here that this will be going on to 2007, and yet in the SGAP milestone, I know there's a date of middle of this year, I think it was, '04, when it would be completed. Are these different issues or why the discrepancy between times?

MR. BOYD: I can only speak in generalizations here because I'm not directly involved. I do know that the ARTIST program is suffering from significant schedule problems. Apparently it's a lot more difficult to clean this facility after a test and prepare it for the next test. We may have somebody here who's more in tune with it, but that schedule, I believe, will slip.

CO-CHAIRMAN FORD: And how will that affect -- does that mean that it will be the end of 2007 before we have a definitive --

MR. ROSENTHAUL: Could I try? Jack Rosenthaul. I'm the Branch Chief of the Safety Margins and Systems Analysis Branch.

Right now you assume very pessimistic BFs for small aerosols on the secondary side steam generator, numbers of one to ten, and everybody anticipates that those numbers are going to be more likely ten to 100 maybe. Okay? So they would be at least an order of magnitude more entrainment and trapping of these small particles on all of that surface area on the secondary side of the steam generator.

But you need the experiments to show that that's true. Lacking the experiments, we do the analysis as best we know it. We can do the PRA. We can reach conclusions, but we'll know that at least that aspect is over conservative by an order of magnitude or more.

So I think that we can get on with the integral activity and the artist data that, you know, we're participating in will catch up when it catches up, but it doesn't stop the program. It just introduces what is a known conservatism.

CO-CHAIRMAN FORD: Okay. Thank you.

MR. BOYD: My understanding is we would have results before that 2007 date. That's the end of the program.

So in the CFD related work, CFD is really, in this problem in the overall steam generator tube integrity issue that we're talking about, it's really a subtask. It's extending experiments which support the SCDAP/RELAP work which feed into the overall PRA analysis.

So we're going to go kind of off the beaten track here and talk in detail of one little aspect of the problem, and our goal was to start with the one-seventh scale experiments and take a look at the method and see if it really is applicable and can do this type of work.

And then, of course, we'd want to go to a full scale steam generator and see how it applies there. On the way, it was decided to, because of geometrical differences, we were going to just take a look at scaling in the same geometry before we went to a full-scale steam generator.

We looked at the tube leakage effect on mixing. We did a whole series of sensitivity studies to see how our results vary with some of the main parameters, and then we also looked at a Combustion Engineering plant example, and we'll take a look at that.

The Combustion Engineering designs typically are significantly different than the Westinghouse inlet plenums, and there was a concern that the mixing could be different.

So if CFD plays this supportive role, and the predictions basically have indicated that the approach does appear to be valid at least to compute these integral parameters that we're interested in. We have found that the prototypical Westinghouse steam generator behaves a little differently than the one-seventh scale experiments would indicate.

Tube leakage does not eliminate inlet plenum mixing. There was a concern possibly that the hot plume was pulled to the leaking tube, and that's not the case.

A sample Combustion Engineering steam generator design resulted in significantly less mixing than what the Westinghouse experiments would indicate. We also can demonstrate that the secondary site heat transfer rate is a significant parameter.

Here's the flow pattern considered. I won't spend too much time. This is the counter current natural circulation flow. How this is interfaced to the SCDAP/RELAP model --

CO-CHAIRMAN WALLIS: I guess what I'm going to say later is that your region of interest should also include how the flow comes from the core into the hot leg.

MR. BOYD: And I would agree with you that these are coupled together.

CO-CHAIRMAN WALLIS: Yeah, we'll talk about that when you get to it.

MR. BOYD: And in the computational fluid dynamics we did not have any influence from the core.

CO-CHAIRMAN WALLIS: That's one of the points I wanted to make. You need to consider that, too.

MR. BOYD: Yeah, and we did consider it, but the problem is one of resources. The core is extremely complex.

CO-CHAIRMAN WALLIS: You don't do the core. I think you just need to do the upper plenum. We can talk about it individually in the break or something, but you can't just impose a flow coming from the core. That's something that responds to all of these natural circulation driving forces.

MR. BOYD: Right. We're relying on SCDAP/RELAP to do that coupling, and I don't think -- well, we argued amongst ourselves it's not just the upper plenum. It's the entire vessel circulation.

CO-CHAIRMAN WALLIS: Well, that's right, but we'll talk about how you can do that, but essentially you have flow coming in, counter current flow in the hot leg, which is really driven by having a hot plenum at one end and a cold plenum at the other. It's like the lock exchange model or the counter current flow, and that is what's happening, and if you don't have that natural circulation driving force, you wont get any flow. You cannot impose a flow.

We'll get to that when you get to it.

MR. BOYD: Okay.

DR. RANSOM: Incidentally, on the one-seventh scale model, I noticed that you pretty well match the Reynolds number and Railey (phonetic) number, Grashoff number. You never mention the Mendel number, and I guess you are simulating heat transfer between the primary and secondary.

MR. BOYD: That's right.

DR. RANSOM: In your what, sulfur hexafluoride is a stimulant?

MR. BOYD: Yes. We looked at a steady state test, and it was sulfur hexafluoride was the stimulant with water on the secondary. It's a very good heat transfer.

DR. RANSOM: How does the parental number compare to water?

MR. BOYD: I don't have that. I'd have to look that up. I know the heat transfer to the secondary side on the one-seventh scale experiments for the steady state tests was not really prototypical, not representative of the full scale plant. The heat was drawn out of the tubes much quicker than it would be during what we see with SCDAP/RELAP 5 predictions, with water on the second --

DR. RANSOM: And that was an experimental result.

MR. BOYD: The experimental result. That's right, for the steady state tests.

The transient tests did have air on the secondary side, and the heat transfer was less. These had some other issues. So the parameters of interest, what we're getting out of the one-seventh scale experiments and inputting into SCDAP/RELAP 5, the recirculation ratio.

Now, keep in mind these are all inputs to SCDAP/RELAP 5. It's not calculating these. So we have to determine these off line.

The recirculation ratio, the mass flow going through the tubes over the mass flow in the hot leg, that's an input parameter. The mixing fraction as it's defined --

CO-CHAIRMAN WALLIS: It's an input parameter? Say that again.

MR. BOYD: That is not something that

SCDAP/RELAP 5 calculates directly. We --

CO-CHAIRMAN WALLIS: Does that say what was an input parameter

MR. BOYD: Well, the input parameters -- I lost it -- the input parameters are actually the loss coefficients at these junctions, but those are juggled until we get the recirculation ratio that we want based on the experimental results.

CO-CHAIRMAN WALLIS: So you juggle it to fit the data?

MR. BOYD: That's correct.

CO-CHAIRMAN WALLIS: You aren't really to be predicting it for a reactor.

MR. BOYD: I'm making the point that we are not predicting it in SCDAP/RELAP 5.

CO-CHAIRMAN WALLIS: I think, yeah, but you're predicting it with CFD.

MR. BOYD: We're trying to predict that with CFD.

CO-CHAIRMAN WALLIS: I think you need to predict it.

MR. BOYD: Okay.

CO-CHAIRMAN WALLIS: Now, let's talk about that a bit. If there were no heat sync on the steam generator side, if the heat transfer coefficient were zero, this thing would just heat up. There would be no MT. There would be no MH.

MR. BOYD: That's right.

CO-CHAIRMAN WALLIS: Right? Nothing would be happening, and the whole thing that's driving this circulation is the fact that you're cooling some fluid and it's flowing back. It's natural circulation that's driving everything, and so you cannot impose any kind of flow rate on this thing because in some circumstances there would be no flow at all.

Okay. Let's come back to that.

MR. FLETCHER Can I add a comment?

The word that this is input to RELAP 5 is the confusing part here. We are using flow coefficients which essentially force the flow as a function of the delta P across the various junctions. So it's not truly a loss coefficient. It's a flow coefficient.

CO-CHAIRMAN WALLIS: What drives the flow is buoyancy.

MR. FLETCHER: Absolutely.

CO-CHAIRMAN WALLIS: And it's not anything else that drives it.

MR. FLETCHER: That is correct.

CO-CHAIRMAN WALLIS: The delta P limits it by balancing the buoyancy with something else.

MR. FLETCHER: That is correct, and if you have no secondary heat transfer, you would have no flow of steam to the steam generators and the core would melt in place in the vessel.

CO-CHAIRMAN WALLIS: So this thing, this system here has certain characteristics of flow versus temperature at the end, which have to be then interfaced with whatever SCDAP/RELAP is doing.

MR. FLETCHER: That is correct.

CO-CHAIRMAN WALLIS: Right, and that has to be done carefully.

MR. FLETCHER: The only forcing that is done is done at the interface between the hot leg loop and the steam generator loop in RELAP 5. There are three separate loops, three main separate loops, one in the vessel, one in the hot leg, and another in the steam generator.

CO-CHAIRMAN WALLIS: That's good. That sounds good to me.

MR. FLETCHER: The forcing that we're doing as described here is at the interface between the hot leg and the steam generator loop. Between the vessel and the hot leg we're allowing RELAP 5 to make the calculation of that circulation pattern.

CO-CHAIRMAN WALLIS: I wanted to see how that's done, too.

DR. RANSOM: Are you using a dual hot leg?

MR. FLETCHER: Yes, we are.

DR. RANSOM: An upper region of the pipe and a lower region? So they're splitting the pipe and allowing fluid to flow counter currently through those.

CO-CHAIRMAN WALLIS: SCDAP/RELAP is calculating counter current flow?

DR. RANSOM: No, only by two pipes.

CO-CHAIRMAN WALLIS: Oh, two pipes. That's different.

MR. FLETCHER: This is actually the RELAP noding diagram.

CO-CHAIRMAN WALLIS: That's different. Okay. Well --

DR. RANSOM: And what, you have the boundary on the other end of the hot leg to the core in this figure?

MR. BOYD: Hooked to the vessel, yeah.

MR. FLETCHER: In RELAP 5, this is a typical vessel model, five channels and the core and an upper plenum model that circulates flow within the vessel.

DR. RANSOM: I don't quite understand what you were saying about forcing the flow at the junction to the inlet plenum to the steam generator. You're losing loss coefficients, adjusting them, right?

MR. FLETCHER: We're using flow coefficients.

DR. RANSOM: What does that mean?

MR. FLETCHER: A flow coefficient says that if I know the delta P across a junction and I know the flow coefficient, then that defines the flow rate.

DR. RANSOM: Are you doing that with a controlled variable or something?

MR. FLETCHER: Input the flow coefficients. It's essentially the same as inputting a loss coefficient, except if you input a loss coefficient for RELAP 5, RELAP 5 then determines what the flow across that junction is.

DR. RANSOM: If you do that, then are you specifying the pressure in the hot leg?

MR. BOYD: I think I'm confusing things. When I say it's an input, buoyancy driven flows are driving this whole process. By trial and error these flow coefficients are adjusted until we get the mass flow through the tube ratio to the mass flow and the hot leg ratio that we want.

DR. RANSOM: Well, that's supposed to be something that has been added since my days. It's like a pump, I guess, right?

MR. FLETCHER: More like a tank dependent junction (phonetic), that if you know the delta P across the junction --

DR. RANSOM: Then you set the flow rate.

MR. FLETCHER: -- then you set the flow.

DR. RANSOM: From tabular or a table or a function.

MR. FLETCHER: That's correct.

CO-CHAIRMAN WALLIS: Well, the purpose of CFD is to model a more realistic steam generator and to calculate MT, which is related to the way in which the flows mix in the plenum and that gets your recirculation ratio. I'm not sure if SCDAP/RELAP model is mixing particularly well and plumes and that sort of stuff. There's a counter current flow in that plenum, too, which CFD does very nicely the way you've done it, and I'm not sure how SCDAP/RELAP does or even if it tries to.

The rational thing, it seems to me to do is to say let SCDAP/RELAP model the rest of the world. Let CFD model this thing, which it does very nicely apart from the connection with the core, and then find a way to couple them together at the place where they meet, which is at the top of the vessel, top of the core, you know. Don't try to get SCDAP/RELAP to model this thing because CFD does such a good job of it.

MR. BOYD: The way it's done, the way it has been done is from experiments or CFD we calculate the mixing in the plenum and the temperatures entering the tube, but there's no feedback to the vessel in this, and it's an iterative process. You go back and forth and back and forth.

So for a given hot leg mass flow -- and I will say that the results for the hot leg mass flow are not all that sensitive on some of these other parameters. So the feedback is not killing us there.

The end result is the temperatures entering the tubes after the mixing. In this simplified mixing model you've got hot flow coming out of the hot leg. Part of it goes basically directly to the hot tube. Part of it goes to a mixing chamber right here, and then part of that goes up into the hot tube, and this mixing fraction that has been defined determines their split ratios, and the net effect of that is in a quasi steady sense. If you've got these parameters correlated to the data, you'll get the same entrance temperature into the tube.

CO-CHAIRMAN WALLIS: You can do that. So what your philosophy is is you take your CFD, which gives you a much more realistic picture of what's happening, three dimensional mixing and so on, and then you say, "Okay. How can we represent that in a more global way with boxes like this?" which reproduces the macroscopic feature of the CFD in a realistic -- =and is compatible with what SCDAP/RELAP can do. I think that is also a reasonable approach.

But one has to be careful about how one does that because you're simplifying a three dimensional model down to a box type model.

MR. BOYD: That's what we're doing. The answer doesn't come out of the CFD. The CFD is really providing these coefficients that I'm showing on this slide. So the final transient result comes out of SCDAP/RELAP 5.

CO-CHAIRMAN WALLIS: I think that's what I'm saying, is what I would prefer would be if SCDAP/RELAP did the rest of the system and then interfaced with this whole thing at the upper plenum of the reactor and then you used CFD for this piece and you simply interface them, and your strategy is to use CFD and incorporate it into the system model, not to try to reduce it to SCDAP/RELAP in order to use the system model.

That's what I'm aiming at, and I think eventually this is going to happen with system models.

MR. BOYD: A couple of code set-ups will eventually happen. We don't have that tool now.

CO-CHAIRMAN WALLIS: Working on it.

MR. ROSENTHAUL: Yeah, about two years from now, and we've already put it in the budget.

CO-CHAIRMAN WALLIS: Right. Let's keep it in the budget. Don't let it go. Put that in the record.

MR. FLETCHER: We couple trace and most likely in phase.

CO-CHAIRMAN WALLIS: That's the way it should go. I agree tha this could be a way to do it now.

MR. BOYD: So let's keep our sights lower this morning, and what we've got now is this set-up, and we've got the one-seventh scale experiments providing these coefficients, and we're going to use computational fluid dynamics to extend the experiments into regions, such as tube leakage or a Combustion Engineering plant that are not covered directly by the experiments.

So some of the other things, we talked about the recirculation ratio, this mixing split fraction, the percentage of tubes carrying the hot flow in the bundle. That's also experimentally determined up front and then fixed into the model. These air flow areas are fixed.

Number four, the percentage of core power going to the steam generators, that's experimentally determined up front. And again, in my mind I say that's an input parameter.

Now, the code calculates it, but we mess with these flow coefficients until it calculates the value we want it to.

CO-CHAIRMAN WALLIS: And I think you should have a number five, which is MH.

MR. BOYD: Mass flow in the hot leg.

CO-CHAIRMAN WALLIS: Because that is not something you can impose. It's something that comes out of the --

MR. BOYD: That really is tied into this right here, the percentage of core power to the steam generator. So this really is setting MH. If you're going to say 30 percent of the power goes to the core.

CO-CHAIRMAN WALLIS: But it's driven by the fact that you have this hot fluid in the upper plenum of the reactor which then sees some cold and then the counter current flow is drive by that. And you really should tie in the MH to this temperature difference between the core and the steam generator. It's not something that you can impose.

MR. BOYD: I guess I"m arguing that number four does dictate that MH in some way.

CO-CHAIRMAN WALLIS: It's related to it because if you don't have enough MH, then the stuff gets hotter and hotter. Fluid in the upper plenum gives you bigger MH, but your imposing an MH doesn't allow that to happen, and you shouldn't.

MR. BOYD: Now, again, SCDAP/RELAP 5 calculates MH.

CO-CHAIRMAN WALLIS: How?

MR. BOYD: It has these coupled natural circulation flows in the vessel.

CO-CHAIRMAN WALLIS: From an energy balance, doesn't it?

MR. BOYD: Say again, please.

CO-CHAIRMAN WALLIS: MH and the temperature at the top in the upper plenum are related by an energy balance from the core. If you have a lower MH, you have a higher temperature. A lower MH, you have a higher temperature in the top.

MR. BOYD: Right.

CO-CHAIRMAN WALLIS: In the hot leg, if you have a higher temperature in the top, you have a bigger MH. So you've got two things balancing. One is if the temperature is bigger, they have a lower MH in the core, but you have a higher MH in the hot leg. So they have to meet; they have to coincide.

But there are two phenomena there. There's the limiting counter current flow, if that's where it is, in the hot leg and the heat balance of the core interact, and I think six -- RELAP does a great job of the heat balance on the core. RELAP doesn't say anything about the counter current flow phenomenon in the hot leg.

MR. BOYD: This was recognized, and when looking at the vessel as a modeling thing for computational fluids we threw up our hands basically. It's a very complex geometry.

CO-CHAIRMAN WALLIS: Don't throw up your hands. You can do it. We'll talk about it later.

MR. BOYD: Okay. With enough money.

CO-CHAIRMAN WALLIS: No, no, no. It's not all that complicated. Let's talk about it later in private.

MR. BOYD: Okay. So this is the approach

we have taken and here's the CFD analysis steps that were carried out. Step one, take a look at the one-seventh scale data; get our feet on the ground. We did about 100 sensitivity studies at this point, really determined how the model worked and convinced ourselves that at least for these integral parameters we can calculate them.

Step two, we scaled the model up, using the exact same geometry. We multiplied every dimension by seven, but we put in the boundary conditions from the ZION station blackout transient. So now we're not using sulfur hexafluoride. We're using steam at 2,400 psi and the mass flow rates and things like that, and we basically repeated the analysis to isolate the effect of scale.

In step three we took those exact same boundary conditions, but now we changed the geometry to a Westinghouse Model 44. This was necessary because the facility and the Westinghouse Model 44 were slightly different geometries, and we didn't want to go from step one to three and then have a concern whether it was scale effects or geometry effects that caused our differences.

In step four we did a tube leakage analysis.

CO-CHAIRMAN WALLIS: Excuse me. I was trying to figure out from your work in the red what seventh scale meant. Does it mean that you had seventh scale in all the dimensions including the height?

MR. BOYD: Yes, that's --

CO-CHAIRMAN WALLIS: How did the height get scaled?

MR. BOYD: The height was real close to one-seventh scale.

CO-CHAIRMAN WALLIS: And in the real thing you've got a much bigger height. So you've got sort of a bigger driving force for natural circulation, but you've also got seven times the friction length, too because you've got seven times the LMD.

So I was sort of arguing to myself what would be the scaling laws for natural circulation between one and the other.

MR. BOYD: There was an attempt made to balance the driving force and the viscous losses in the tube, and there's a scaling --

CO-CHAIRMAN WALLIS: It kind of works out when you've got one side working as a chimney and the other as a downcomer, when you've got a maximum circulation, then you've got the driving force, which is the head at the height of the thing, but you've also got the friction, which is 4 FL over D. So L also goes up and you can sort of convince yourself maybe that it's about the same velocity that you get because the two are balancing. But that's a quasi. Really you should model them both and see how they do.

DR. RANSOM: Well, in your CFD model, reading about it, you used a Forest matrix approximation for the tubes, I guess, right? So they're little rectangular channels. Was wall friction modeled in that case or did you have to just put in loss coefficient?

MR. BOYD: No, wall friction was turned off because the velocities in those channels was larger -- smaller because of the increased diameter. So the frictionless walls and there was coefficients put in --

DR. RANSOM: To adjust the flows?

MR. BOYD: -- tuned over a wide range of flows and temperatures to basically add in the frictional losses.

DR. RANSOM: So you have to understand friction was not really modeled.

CO-CHAIRMAN WALLIS: There was no friction in the tubes?

DR. RANSOM: No.

MR. BOYD: We'll go into the tube model and I'll show you.

CO-CHAIRMAN WALLIS: That's very important. They're long tubes.

MR. BOYD: There was losses in the tubes to account for the frictional losses.

DR. RANSOM: But those were input actually.

MR. BOYD: That's right.

DR. RANSOM: So they had to be determined, I guess, from the experiment?

MR. BOYD: No, we determined those using CFD in this case. We'll go into how that was done.

CO-CHAIRMAN WALLIS: Now, the tubes were the same diameter as in the real thing in this?

MR. BOYD: No, not in this case. We'll go into the tube model. Tube modeling posed a real challenge in this.

CO-CHAIRMAN WALLIS: Were their tubes smaller diameter than the real steam generated tubes?

MR. BOYD: In the one-seventh scale experiment, I think the tubes were slightly smaller.

CO-CHAIRMAN WALLIS: They weren't a seventh of the --

MR. BOYD: They were not one-seventh.

CO-CHAIRMAN WALLIS: Because they had fewer tubes.

MR. BOYD: They were roughly three-eighths of an inch and maybe half, three-tenths.

CO-CHAIRMAN WALLIS: But then this FL over D is an important parameter for them if they're much longer. You've got to put that friction in there.

MR. BOYD: We did put the friction in there.

CO-CHAIRMAN WALLIS: But not in the form of an FL over D.

MR. BOYD: Not in the form of --

CO-CHAIRMAN WALLIS: But just as a K.

MR. BOYD: -- boundary layer with viscous losses, and we'll see the reason for that when we get to the tube model.

CO-CHAIRMAN WALLIS: Okay, okay.

MR. BOYD: So step four, tube leakage analysis. We repeated the work at step two, the only difference being a boundary condition that pulled mass out of the system at various rates, and then step five we looked at a Combustion Engineering plant example. This is the primary side of the steam generator from Calvert Cliffs, a replacement generator, and we applied SCDAP/RELAP 5 boundary conditions from an analysis of Calvert Cliffs.

So now we'll go through these steps, and I'll spend a good bit of time on step one so that we get an idea of what we're doing, and then the other steps we won't quite spend as much time on, but we'll try and develop a method here.

This is a picture here on the right of the one-seventh scale at facility one of the steam generators. These were both connected to that half vessel that you had mentioned, and basically we did a pretty good job of predicting the mixing parameters from this.

The model set up. We are looking at a steady state test. This is basically the extent of the geometry that we modeled, the hot leg, the tube bundle, and the plenum walls.

When we first set out on this, our target was right here, inlet plenum mixing. The tubes, the say we looked at it to set this up were a boundary condition to the inlet plenum, and the hot legs serves the same purpose.

There was attempts made by others to just inject flow into the inlet plenum and then pull it out through the top. I think our two bundle model is superior to that, although the tubes aren't maybe prototypic. We'll look at that, but the goal here is inlet plenum mixing, and that's the only place where we focus on the results.

CO-CHAIRMAN WALLIS: But that's not good enough. I mean, you revealed, I think, every well that the transfer in the tubes is very important. If you have very good heat transfer, it's like having a very cold chimney in your fireplace, and it wont work. It quenches the hot stuff after it has gone a short distance.

If you have no heat transfer, the other extreme from the tubes, they just get hotter and hotter and hotter, and there's again no circulation. So there's a maximum circulation rate somewhere in between.

MR. BOYD: That's right.

CO-CHAIRMAN WALLIS: Now, you don't get the maximum because you don't go to the limit of no heat transfer, but if you went to the limit of no heat transfer, this thing would just heat up forever. It wouldn't circulate at all, and you know, you haven't got to that in your analysis.

But it's fascinating. You have to model the heat transfer right to get that circulation right.

MR. BOYD: I would agree.

CO-CHAIRMAN WALLIS: And so it's not good enough to focus on the plenum, and then when you start working back, you say, well, you have to model the hot leg right because you have got counter flow in there, and then you've got, as I'm going to say it -- you can't impose this V. You've imposed a V at the inlet.

Now, if you imposed 1,000 feet a second coming in there, you would force more fluid in through the hot leg, although some of it would come back. You'd still force more through, and that V is itself a result of the T.

So I'm going to say you're going to have to do something better than imposing that because you can impose it for the seventh scale because you know what it is.

MR. BOYD: That's right.

CO-CHAIRMAN WALLIS: But in the reactor you don't know what it is, and it happens because of the driving force of the temperature.

MR. BOYD: And we're relying on another code to provide what that is.

CO-CHAIRMAN WALLIS: But you can't.

MR. BOYD: And that's the weakness. I would agree. We don't have experiments.

CO-CHAIRMAN WALLIS: Well, we'll talk about that in the break or something.

MR. BOYD: Okay. So the --

MR. ROSENTHAUL: Keep in mind that in the back of everybody's mind was that the most critical sequence was this high dry sequence so that the secondary side of the steam generator is steam. It's not cold water.

CO-CHAIRMAN WALLIS: It's a low heat transfer coefficient.

MR. ROSENTHAUL: Poor.

MR. BOYD: But even poor, it's still important.

CO-CHAIRMAN WALLIS: Yes, it's important to get it right. So that, again, I think that's not an easy problem because you've got natural circulation on the outside of the tubes in there presumably.

MR. BOYD: That's right.

CO-CHAIRMAN WALLIS: So there's another component that's got to be done right.

DR. RANSOM: Well, it's a secondary site condition. Is there still water in the secondary side or is it just steam?

MR. BOYD: No, it's dried out and in this case low pressure and the depressurized generator.

CO-CHAIRMAN WALLIS: But there must be some loop to take the heat away. So modeling the secondary side loop is important. Where does heat go?

MR. BOYD: In the CFD model it goes --

CO-CHAIRMAN WALLIS: Yeah, but where does it go in the reality? Where is the heat sync?

MR. BOYD: In the reality, you know, there's a lot of structures on that secondary side.

CO-CHAIRMAN WALLIS: But where does it go?

MR. BOYD: We would expect it to be heating up the upper internals and all of the --

CO-CHAIRMAN WALLIS: But is that the limiting case? You put a lot of heat into there. Eventually your ultimate heat sync is the air, isn't it?

MR. BOYD: All of the metal mass of the entire system just keeps rising in temperature. So heat is --

CO-CHAIRMAN WALLIS: That's what happens?

And as that rises in temperature, you get a different driving force and MH changes.

MR. BOYD: I would agree with you that these are all import.

CO-CHAIRMAN WALLIS: Okay.

MR. BOYD: We are not able to model the

whole plant with CFD.

CO-CHAIRMAN WALLIS: But it has to be done to get the right answer that you're after.

MR. BOYD: Okay. We aimed a little bit lower, and we were really just looking at what happens to that plume going through the inlet plenum.

CO-CHAIRMAN WALLIS: So I think you did an excellent job. I'm really impressed with it, but this goes back to, I think, the questions that we raised at the beginning of the first day, is that people are doing excellent jobs on pieces of this problem. Is the whole thing being addressed?

MR. BOYD: Right. But there were questions that we could answer. There was suggestions that the inlet plenum plume bypasses the or the plume bypasses the inlet plenum with no mixing. There was suggestions that a small tube leakage would pull the plume over.

So these types of questions we can answer, but I agree we're not getting the answer. We're still relying on SCDAP/RELAP to do all of this coupled integral analysis. It models a secondary side and the heat transfer over there. It models the core circulation. It does the entire problem. We're really just feeding it stuff for the inlet plenum, what happens at that point.

So let's move on. That's the model setup, the boundary conditions. These are basically set to match the experiment where heat transfer was only applied to the tubes. Everything else was adiabatic.

Here we'll just have a quick discussion, how to model the tubes. There's three options. We can directly model them, and with 216 tubes in the facility, that's possible, and we did that. It ended up in about ten million cells, and I never quite got it converged. So we abandoned that, and I wanted to have some information to pass forward.

So another approach is a smaller number of tubes, and I've seen this done, but this runs into all of the problems of this FL over D that you were talking about and all these issues.

So the third approach would be to use the porous media functions in FLUENT to give us the characteristics of the tubes without having to model the entrance effects and the boundary layers and things like that.

So here's an example. Here's one tube the size --

CO-CHAIRMAN WALLIS: What would be nice to do would be to use, again, the FLUENT in the places where you need it and say we can model the tubes for the SCDAP/RELAP thing.

MR. BOYD: I agree.

CO-CHAIRMAN WALLIS: But then we've got to have an interface between the CFD and this one dimensional type code which we know how to handle it because we had learned how to do it, and that's the way to do it.

MR. BOYD: I called FLUENT and told them I needed 1D components quickly, but they don't --

CO-CHAIRMAN WALLIS: Well, they don't know how to do it.

MR. BOYD: But a 1D component in FLUENT or the coupling that you're discussing with the code or what's needed.

CO-CHAIRMAN WALLIS: They can't do that either.

MR. BOYD: They can. We could do this coupling, but we haven't done the coupling.

CO-CHAIRMAN WALLIS: I think they have a problem. I've had a problem using fluent. If you have an outlet node and it starts to have inlet flow and so on, you get all kinds of problems. So we can't really do --

MR. BOYD: We want to avoid that.

CO-CHAIRMAN WALLIS: Yes.

DR. RANSOM: I'm curious. In FLUENT with this porous media approach you do keep the flows separate I guess through the channels, right?

MR. BOYD: That's right.

DR. RANSOM: And you go around the bend also?

MR. BOYD: Go around the bend, the full height, everything the same.

DR. RANSOM: So it's just a rectangular channel that is closed.

MR. BOYD: Rectangular only because it's easier to mesh.

DR. RANSOM: Right. Well, from a calculational point of view it doesn't matter whether it's rectangular or round. You don't know the difference, but you know the area.

MR. BOYD: Rectangles are nice because if you use four cells to represent it or ten, you get the same area, but with a circle if you use four or ten, you actually change the flow area because of the faceting. So that's why rectangles are ideal.

CO-CHAIRMAN WALLIS: But fluent does not allow mixing across the cell edges, I guess.

MR. BOYD: No. They're solid walls for

each tube. There's 216 individual flow paths. So let's take a look at the idea here.

Here's a tube of the correct dimensions, and here's the appropriate sized region if it was a one dimensional flow that would feed it in the steam generator. Here's a zoomed in area of that junction. All of these cells are set up so that the Y plus values are correct, and hopefully we can pick up the entrance effects, the whole nine yards.

This was basically for about a meter or two. This is a million cells. Over --

CO-CHAIRMAN WALLIS: Do you model every tube this way?

MR. BOYD: I did at one point.

CO-CHAIRMAN WALLIS: It's a lot of work.

MR. BOYD: Well, that was the point about the direct --

CO-CHAIRMAN WALLIS: That's got to be a simple way to do it. Maybe you could lump them in some way.

MR. BOYD: Well, when I modeled all of the tubes and ended up with a ten million or so model, they were a little coarser than this, but this was for an example here. This process was done for each steam generator, the Model 44, the facility, and the

Combustion Engineering. We always went through this process of modeling a few tubes in great detail, and then what we went over to a porous media approach; so imagine this tube now just continuing on like this.

We don't do the neck down at all, and then let's say we model it with four cells across. Here's a representation over here where we have the inlet area. We have an interface where we apply a loss coefficient to account for the loss coefficient for this neck down.

And then we have along this region, we have coefficients that we use to account for the viscous losses and the boundary layers that we --

CO-CHAIRMAN WALLIS: Why not just model the tube as a set of nodes the way that RELAP worked and say that these were FLUENT type nodes? FLUENT won't do that?

MR. BOYD: FLUENT is not good at just one cell across. So these are about five cells across.

DR. RANSOM: That's what they're doing, but actually the area is much larger than the actual tube, and so the velocity is much lower.

MR. BOYD: That's right.

DR. RANSOM: And so you have to scale the losses to get a dynamic loss coefficient that corresponds to reality.

MR. BOYD: Here are some results now for these two models from a pressure point of view. Here's the flow coming down the inlet for the million cell model. Here is the result of the flow necking down and going into the small tube, and then this slop here, this PDX would represent the viscous losses, and what we've got here is two plots, one with a million cells, and then one with the porous approach in FLUENT.

So from a pressure point of view we can get about the same. Now, what we did is we went through a whole range of velocities and temperatures, and we curfitted (phonetic) --

CO-CHAIRMAN WALLIS: Is it laminar flow?

MR. BOYD: This is laminar flow in these tubes.

CO-CHAIRMAN WALLIS: Is it laminar flow in the reactor, the real system?

MR. BOYD: My memory tells me it is, and it has been a while since I remember looking at that.

CO-CHAIRMAN WALLIS: You got something different.

MR. BOYD: Well, now, in the reactor, we did the same thing though. This is for the facility.

We did it here. Now, in the reactor, we did the appropriate flow rates with the reactor size tubes, and we repeated this whole process.

CO-CHAIRMAN WALLIS: And the number in the tubes is?

MR. BOYD: I don't have that in my mind right now.

CO-CHAIRMAN WALLIS: It would be nice to know.

DR. RANSOM: One point though. This is being modeled as a turbulent flow, as K one-half rho B squared, where laminar would be just velocity to the first power.

CO-CHAIRMAN WALLIS: No, it's turbulent for the inertial drop, but the viscous drop, I understand is for laminar.

DR. RANSOM: Well, he's modeling the viscous drop with a K one-half rho B squared --

CO-CHAIRMAN WALLIS: He is?

MR. BOYD: Actually I had to use a linear and a squared term to get a good fit on that.

CO-CHAIRMAN WALLIS: But if it's laminar flow, you shouldn't be using your V squared type thing.

MR. BOYD: I'd have to go back. I don't

have it in my -- this has been over a year since I set these up.

But this was the point. This was just talking about pressure drops, and then we could --

DR. RANSOM: Incidentally, this is a horizontal tube, I guess.

MR. BOYD: This was vertical in this case.

DR. RANSOM: This was a hydrostatic pressure component there?

MR. BOYD: I guess in this when we set the pressure up, we didn't worry about we had gravity off, but then we --

CO-CHAIRMAN WALLIS: You must have gravity.

MR. BOYD: -- heat transfer, and your goal there was to get the heat transfer rate from the tube such that the heat -- the temperature along the tube was the same. So the heat transfer had to be adjusted also is the point. So the same sort of fitting had to be done.

CO-CHAIRMAN WALLIS: You must have gravity int here. Otherwise, you wouldn't get any circulation. You've got to have hot fluid on one side and cold fluid on the other.

MR. BOYD: Are we talking about the model or this tube study that we're doing?

CO-CHAIRMAN WALLIS: Right.

MR. BOYD: The tube study is a one dimensional flow down a path.

CO-CHAIRMAN WALLIS: Okay. That's just comparing the ten to the sixth with the four. Okay. That's all.

DR. RANSOM: And after you fiddled, I guess, then you put it into the floor model.

MR. BOYD: That's right. We test everything on these little one to four tube section models, and then we use those same coefficients, the same tubes, but now there's 216 of them and we put it into the full model.

CO-CHAIRMAN WALLIS: This is a separate effects test in CFD.

MR. BOYD: That's exactly right.

So here's a summary now of where we stand. We're going to do a transient CFD solution. We'll use the Reynolds stress second order turbulence model, which is non-isotropic. We'll use the full buoyancy effects on turbulence as available in FLUENT.

CO-CHAIRMAN WALLIS: That's more appropriate than K epsilon because the buoyancy effects change the turbulence. In fact, there's a tendency to damp out turbulence because it's very obvious if you have an inversion at night and the window doesn't come down to the ground.

MR. BOYD: I will say that academically that's all correct, but I ran all of the turbulence models, and they didn't really make a lot --

CO-CHAIRMAN WALLIS: They didn't make much difference. That's good. That's nice to know.

DR. RANSOM: When you say second order, does that just mean second order difference approximation for the divergence on the velocity?

MR. BOYD: Well, K epsilon is considered like a first order. You've got K and epsilon. It's isotropic. With the second order turbulence model, you're trying to track the Reynolds stress, the UV, prime terms, and it's non-isotropic, which in this case is more appropriate. We wouldn't want to assume isotropic turbulence in that hot leg, complex hot leg flows or in the inlet plenum either I don't believe.

So we've got temperature dependence, software hexafluoride, half a million cells used in half the model. We put a symmetry plan in this model, second order differencing, and then we've got this porous media model for the tubes with 216 individual tube flow paths, each with solid walls, each with heat transfer from these solid walls, again, adjusted to give us the appropriate rate of heat loss, and we've got a symmetry plane.

So now we look at some qualitative results, and I say qualitative first because the experiments really didn't provide all of the information to do a full CFD validation.

CO-CHAIRMAN WALLIS: Do you have your pen there? Do you have your pen there?

MR. BOYD: I do.

CO-CHAIRMAN WALLIS: Would you show on here for the committee what confounding condition you have at the end vessel?

MR. BOYD: Right over here?

CO-CHAIRMAN WALLIS: Yeah, because I had to dig in your report to see what you were doing there.

MR. BOYD: I put in a uniform --

CO-CHAIRMAN WALLIS: Your forced the velocity like that.

MR. BOYD: Forced the velocity that way.

CO-CHAIRMAN WALLIS: And does that then allow it -- what happens to the bottom part? There's friction between that stuff coming in and the bottom part. So I had to figure out why it was you got more flow in the tube than you put in, and the reason is that jet coming in entrains fluid with it.

MR. BOYD: That's right.

CO-CHAIRMAN WALLIS: All right? You have to think that's sort of strange. In reality what happens is that this interface continues to go down. The reality would be --

MR. BOYD: This interface, you mean?

CO-CHAIRMAN WALLIS: The cold-hot interface. You can see it going down, right, between the right hand and middle? The profiles show the interface is going down.

MR. BOYD: A slope like this.

CO-CHAIRMAN WALLIS: But pours out like water out of a tube into the vessel. Cold fluid pours out like water out of a tube.

MR. BOYD: That's right. Cold water --

CO-CHAIRMAN WALLIS: Pours out like that.

MR. BOYD: -- falls into the --

CO-CHAIRMAN WALLIS: And the only thing driving that flow in there is the fact that the pressure in the pipe is less than the pressure in the upper plenum. The only thing that sucks that hot fluid in there is a pressure drop which by Bernoulli gives you a V.

MR. BOYD: Okay.

CO-CHAIRMAN WALLIS: Is that right? That's the physics. Thank you.

That's what I'm asking you to model.

MR. BOYD: Right, and again, we didn't. And in the facility experiment this was handed to us, that they made an attempt to estimate that match flow, and we used their estimation.

DR. RANSOM: Why wouldn't you have just started the calculation with the uniform pressure and then let the heat transfer and buoyancy effects establish the fall?

MR. BOYD: Well, we have to know -- well, we'd be trial --

DR. RANSOM: It would take too long.

MR. BOYD: We would be fooling around trial and error with pressure until we got the mass flow we wanted, and in one guess I can just put the mass flow that I want in.

CO-CHAIRMAN WALLIS: But that's nothing compared with the million cells you're dealing with. I mean, the fooling around with it, the simultaneous solution for the pressure is trivial compared with solving all of those cells.

MR. BOYD: The experiment said there's one kilogram per second going down the hot leg. That's what I want. So I put in one kilogram per second so that --

CO-CHAIRMAN WALLIS: But you get more going down the hot leg than you put in.

MR. BOYD: That's correct.

CO-CHAIRMAN WALLIS: And if you didn't have this hot fluid in there, you wouldn't get any flow at all. So -- okay.

MR. BOYD: I go back to my original goal was over in this region right here. What happens as the plume leaves the hot leg and goes into the inlet plenum, and this --

CO-CHAIRMAN WALLIS: So you're very interested in that plume. You'[re not interested in the other plume.

MR. BOYD: That's right. I'm interested in all of the plumes, but we have to do what we can.

Over here there was a series of boundary conditions applied, profiles fully developed, counter current flow profiles, all that sort of thing, and I found that by the time it reached this end of the hot leg there wasn't a significant variation, and the truth is --

DR. RANSOM: Incidentally, what was the

true boundary condition in the experiment?

MR. BOYD: There was a vessel.

DR. RANSOM: Just a vessel of hot fluid?

MR. BOYD: Electrically heated elements and an upper plenum that was hot, and it was pretty well mixed according to the data, and it was feeding over. So there was that suction that Graham talked about, fully --

DR. RANSOM: And it was closed so that the cold --

MR. BOYD: -- facility was coming in and dumping into the mixing --

DR. RANSOM: Vessel land being recirculated.

MR. BOYD: Going down into the hot, electrically heated things, coming back up, back over to the hot leg, right. So we cut that all off and we just applied the hot leg mass flow.

CO-CHAIRMAN WALLIS: Now, I suppose I could mention at this time I did some calculations of what you call the CCFL or something; you might call a lock exchange model. If you would simply have a hot vessel here and a cold one there, what flow rate do you get?

And you're pretty close to that.

MR. BOYD: What I found is tha the experiments did seem to be pretty close to that. If I tried to, let's say, take my inlet velocity and multiply it by 50 percent, a lot of that flow ended up being rejected.

CO-CHAIRMAN WALLIS: That's right.

MR. BOYD: And I could not effect very strong --

CO-CHAIRMAN WALLIS: So a crude way to model this would be to say we've got CCFL in the hot leg.

MR. BOYD: That may be even better because the truth is the mass flow measurements in that experiment were true. They were measured by temperatures, very few temperatures, and assumptions on an energy balance. So --

CO-CHAIRMAN WALLIS: But that's really what's happening. You've got a cold plenum on the right and a hot plenum on the left in this picture, and the flow adjusts.

MR. BOYD: That would probably be a more accurate mass flow than the experiment gave you. I think there's some good --

CO-CHAIRMAN WALLIS: Thank you.

MR. BOYD: -- uncertainty on that as well.

CO-CHAIRMAN WALLIS: Thank you.

MR. BOYD: That's a good point.

Okay. So let's go on. This is, again, qualitative information.

What we can see here is a stratified flow. We see a highly stratified flow. We see an accelerating flow. You can see here with the velocity profile it's necking down. It continues to accelerate all the way through the nozzle, and at this point it's extreme --

CO-CHAIRMAN WALLIS: This is -- by Bernoulli the pressure is actually going down.

MR. BOYD: This also has a slow interface, which at least in some other experiments was qualitatively observed when they did the glass pipe.

Symmetry plane temperatures, we can take a look. The tube bundle -- now, here's where we adjust the tube bundle heat transfer rate to be consistent with the experiment, and essentially the experiment was crude in its tube measurements, but we got an idea of what the --

CO-CHAIRMAN WALLIS: Filled with water on the secondary side?

MR. BOYD: Filled with water on the second side.

CO-CHAIRMAN WALLIS: Which is a rather high heat transfer coefficient.

MR. BOYD: A very high heat transfer. We'll take a look at that.

CO-CHAIRMAN WALLIS: It's not realistic.

MR. BOYD: I would agree. It's not indicative of what we would expect, but at this point we're trying to validate the approach.

CO-CHAIRMAN WALLIS: So it quenched the rising fluid quite effectively.

MR. BOYD: Quickly, I think.

CO-CHAIRMAN WALLIS: Right. Whereas if you had poor heat transfer, you'd get that hot fluid going up and around part of the other side before it really cooled down. You'd have a different sort of circulation.

MR. BOYD: That's what the SCDAP/RELAP 5 analysis will show, is if temperatures go all the way around, they're losing heat all the way around the bundle.

CO-CHAIRMAN WALLIS: Right, right, because they have a poor heat transfer coefficient on the secondary side.

MR. BOYD: That's right.

DR. RANSOM: When you say you adjust the

heat transfer rate or a mechanistic model in which you try to calculate a film coefficient, then, you know, heat transfer across the boundary and to a secondary, or do you just set the heat loss per volume?

MR. BOYD: We set a heat transfer coefficient and a sync temperature. The sync temperature was the water temperature in the experiment.

DR. RANSOM: And that's the overall heat transfer coefficient.

MR. BOYD: That is the H on all the tubes, at all areas.

DR. RANSOM: Tube side conduction plus --

MR. BOYD: That's right. That's everything.

DR. RANSOM: Okay.

MR. BOYD: Now, our problem was that with our big, porous, wider tubes, we couldn't get the heat out fast enough to match the experimental observations. So we also had to augment the conductivity a little bit in the porous media to get the heat closer to the walls quicker so that we could lose the heat fast enough.

These big --

DR. RANSOM: I don't quite understand

that.

MR. BOYD: These larger tubes carry the heat better than a smaller tube.

DR. RANSOM: But you have no profile. You just have one temperature for that fluid.

MR. BOYD: There is cells across. There was a profile. I didn't just use one dimensional stuff.

DR. RANSOM: Oh, you mean this is when you did the single tube?

MR. BOYD: Each of the 216 single tubes had several cells across them.

DR. RANSOM: Oh, it did?

MR. BOYD: So they were profiled across there.

DR. RANSOM: Oh, so not just rectangular single cells, but how many cells were in each tube?

MR. BOYD: I think it was three by five. They were slightly rectangular.

DR. RANSOM: -- varied the thermal conductivity in the fluid.

MR. BOYD: We had to augment that a little bit to help us get the appropriate heat transfer rate that we wanted.

DR. RANSOM: Well, does the model include any convective mixing from cell to cell within that tube?

MR. BOYD: Yes, there is mixing from cell to cell within the tube.

DR. RANSOM: You mean there can be, I guess. It depends on --

MR. BOYD: There can be. In fact, in some of the larger models I did I actually saw some recirculations in the lower parts of the tubes. So I saw flow going up one side of the tube and down.

DR. RANSOM: But I guess irrespective of that you still had to increase the thermal conductivity to get the laminar part -- to get the heat out.

MR. BOYD: That's right, to match the experimental indications of what the temperature profile should be up into the tubes.

CO-CHAIRMAN WALLIS: I have a list of questions, and I've gone through most of them.

MR. BOYD: Okay.

CO-CHAIRMAN WALLIS: There was one I noticed we hadn't answered yet. We know the mass flow in the hot leg that you quote is bigger than the flow you put in. In fact, the mass flow is changing along the tube because some of the flow recirculates.

Now, when you say MH, where is MH measured?

MR. BOYD: I measure it in the center of the tube.

CO-CHAIRMAN WALLIS: In the middle of the tube. That's what you mean by MH. Okay.

MR. BOYD: That's right.

CO-CHAIRMAN WALLIS: It's not the same as what goes into the plume in the steam generator. It's not quite the same as what you put in.

MR. BOYD: But it's very close.

CO-CHAIRMAN WALLIS: Okay, but I just wanted to know which one it was you were using.

MR. BOYD: I used the --

CO-CHAIRMAN WALLIS: Thank you. Thank you.

MR. BOYD: And this all, I guess, is less uncertainty than what I considered --

CO-CHAIRMAN WALLIS: The fact that they're all about the same indicates to me that the friction and the entrainment at the interface in that hot leg is not really all that important. It's probably just like two fluids flowing counter current flow and the kind of potential flow almost. There isn't that much in --

MR. BOYD: They don't seem to interact as much as I had expected.

CO-CHAIRMAN WALLIS: Too much, right, right.

MR. BOYD: There's a big temperature gradient that --

CO-CHAIRMAN WALLIS: Because if there were a lot of friction at that interface, you wouldn't get the flow to occur. If you reached a sort of a stirring up, turbulence in there, but in fact, the buoyancy helps to keep them stratified.

MR. BOYD: And it is a very strong buoyancy.

CO-CHAIRMAN WALLIS: It is, yes.

MR. BOYD: This sulfur hexafluoride --

CO-CHAIRMAN WALLIS: Puts a ratio of two to one or something density. It's huge.

MR. BOYD: Yeah, the cold stuff has densities --

CO-CHAIRMAN   WALLIS: That   really impressed. You have a huge density.

MR. BOYD: Right.

DR. RANSOM: Well, I think the flow in that hot leg is dominated by just like a sewer pipe, a hydrostatic head in the cold fluid, you know. It has a sloping interface as you flow toward the entrance and --

CO-CHAIRMAN WALLIS: The friction on the wall.

MR. BOYD: Pardon?

CO-CHAIRMAN WALLIS: It's friction on the wall that does that rather than interfacial friction. It's the friction of that cold fluid on the pipe wall which is bridging that interface rather than friction at the interface.

DR. RANSOM: Actually it turns out that's pretty small in the sewer pipe. It's really the sloping interface that provides the potential part of the flow.

CO-CHAIRMAN WALLIS: It balances the friction on the wall. Balance something.

MR. BOYD: We've got to get our minds out of the gutter here.

(Laughter.)

CO-CHAIRMAN WALLIS: Do you want a different analogy? It's like pouring out of a bottle of wine. How about that?

MR. BOYD: Okay. So here's where the adjustments were made. Now, what we do at full scale conditions where we don't have a good indication of the secondary site heat transfer rate -- we'll see this -- is we just do a whole series of them, and then we take a look and compare them with the data.

But let's go on. This is all, again, qualitative to give us an indication of what's going on. Here's a representation of the inlet plenum with three horizontal planes. We've got contours of temperature.

This is the plume just leaving the hot leg. You'll see that when it is almost impacting the tube sheet, it's still pretty intact, hasn't really grown. You can see the mixing. It's a little bit lighter.

When it hits the tube sheet, what you've essentially got is almost a stagnation point, but a porous stagnation point. Some of the flow is going to go in, but others act just like a stagnation point.

DR. RANSOM: It spreads out.

MR. BOYD: It spreads out in all directions. That's right. So this gives us an idea of what the flow pattern looks like.

Here is three vertical planes, normal to the hot leg access, and what we see in the first plane is we see the strong upward flow. This is essentially the plume, and you can see this flow going out in the side directions. That's your stagnation portion of the flow.

Back further in the central region we see a strong, you know, flow along the top, and at the back wall we see the same thing, but what you're going to see here is this strong set-up like this.

CO-CHAIRMAN WALLIS: You have the fire underneath these tubes in the maple syrup boiler.

MR. BOYD: Okay. That sounds like a New England point of view.

DR. RANSOM: Well, the tubes that attach to that upper face, you're getting up flow, I guess, through the central part of that and then down flow through the --

MR. BOYD: Right, and that's all determined by the model. They just had these porous tubes with the appropriate loss coefficients and the appropriate viscous losses. The code decides which tubes go in up-flow, which tubes come in down-flow. The idea is we hope we're pulling out the right amount of mass in the right location such that these inlet plenum flows are appropriate.

DR. RANSOM: And the up is going all the way over into the outlet plenum?

MR. BOYD: All the way over to the outlet plenum.

DR. RANSOM: Up through those and back.

MR. BOYD: That's right, and all of that just happens.

CO-CHAIRMAN FORD: Let me ask a non-thermal hydraulicist question. This seems reasonable to me, not being a thermal hydraulicist.

What data are there to show those numbers that you have been quoting in terms of temperature and those flow configurations are, in fact, correct? And how much could you be in error?

MR. BOYD: We could be in error. We're going to get to that data. We're still in the qualitative, let's understand the flow.

CO-CHAIRMAN FORD: Okay, right.

MR. BOYD: We're only going to compare with some rather crude numbers though. So we're not really doing a pure validation of the CFD, and we have some qualitative information on the flow patterns from some crude amounts of thermocouples, and it looks similar, very similar.

CO-CHAIRMAN FORD: Now, are they similar enough to have a no consequence as far as material degradation is concerned?

MR. BOYD: That would be my view of it.

In the greater scheme of things, I think at least in this case we're doing close enough. The problem with these tests is they didn't have all of the thermocouples on it all the time. They had some nice rakes, but they didn't turn them on when they wanted to measure hot leg flows and things like that.

And when they measured the rakes, they didn't have the rest of the system instrumented. So we have -- and they never repeated an experiment, and luckily every time they did a different experiment with new regs. they would change the conditions drastically.

CO-CHAIRMAN FORD: Let me turn the question over to you, Joe. This comes back to our questions we had yesterday about interrelationships between these various studies. Is that correct; have you yet in the materials degradation area, have you yet taken these predictions plus uncertainties and decided whether, in fact, you've got a big "oh, heck"?

MR. MUSCARA: Yeah, we've taken the predictions and determined whether groups would fail or not fail under the particular transient given the temperatures and pressures that apply to us. We haven't done the sensitivity or the uncertainty analysis yet, but in addition, you know, this work is still evolving.

CO-CHAIRMAN FORD: Yes, sir, right.

MR. MUSCARA: And doing cases. So we're looking for new input which may modify the result of it.

CO-CHAIRMAN FORD: No, I recognize this is not finished by any means, but from what you've seen so far, you haven't seen something, "Oh, heck, we've got a major problem looming here from the materials degradation aspect"? No?

MR. MUSCARA: Well, that's the thing we're evaluating. We're evaluating whether given this input for the tubes, when different tubes would fail given different flaws and flaw distributions in the tubes.

And the next part, of course, is to also get this same kind of data for the primary system components and determine the time to failure of those components, and you'll hear about some of that this afternoon.

CO-CHAIRMAN FORD: Good.

CO-CHAIRMAN WALLIS: Let me help my colleague here. It seems to me I have looked at the data for the flow patterns and the crude picture. Actually this comes pretty close to what's observed, and they predict very nicely some overall parameters, like how many tubes have up flow and how many tubes have down flow and that sort of thing, and what's the match flow circulation rate in the steam generator compared with what's happening in the hot leg?

All of these macroscopic things are predicted very nicely. The questions that might remain would be, okay, you've done a very good job of modeling the macroscopics. How about the hottest flow that goes into the particular tube? And if that tube is in the middle of the steam generator bunch and isn't cooled as well as the other ones, it's these variations between tubes and between streamlines about which I think there will be uncertainty. So if you're predicting a maximum temperature of 1,800 degrees, it might well be 2,000.

MR. MUSCARA: That's the kind of data we're using, you know, in conjunction with what is the probability that a flow exists in the hottest tube and then calculate how that behaves.

MR. BOYD: We'll move on.

One thing that we saw in the experimental results was significant mixing. We had some thermocouples at this point and we had some thermocouples at this point, and we had some thermocouples at this point, and there was a significant drop in temperature.

CO-CHAIRMAN FORD: So could you just wiggle your -- I didn't catch where you --

MR. BOYD: Right here we had some thermocouples, four, and right here we had some thermocouples, and there was a significant drop in temperature from here to there, and there was questioning, I guess, of what in the world is going on. How can the temperature drop that much.

We saw that flow pattern that was described on the previous slide. On the symmetry plane, what that results in is flow meeting up at the symmetry plane and going vertical, part of that flow trying to find its way back to the hot leg. You've essentially got intersecting jets here. You've got the hot plume coming out and you've got fairly good flows hitting it right on the side.

And we look here at contours of turbulence intensity --

CO-CHAIRMAN WALLIS: Chris, this is very nice. In fact, the cold flow going into the hot leg comes around that jet from all dimensions, not just from the bottom.

MR. BOYD: That's correct.

CO-CHAIRMAN WALLIS: The thing that is a

bit funny is at the bottom of the vessel you seem to have a source because the flow velocities are all going up from there. It doesn't look quite realistic.

MR. BOYD: Yeah, what that source is is right here. We're looking at this flow coming around stagnating at this lower point --

CO-CHAIRMAN WALLIS: And splitting up. Oh, okay.

MR. BOYD: -- and going up. There's your source.

CO-CHAIRMAN WALLIS: But to go back to my point, you're looking at what happens at this end of the pipe. Something very similar happens at the other end of the pipe.

CO-CHAIRMAN FORD: Because it goes into the reactor.

CO-CHAIRMAN WALLIS: Right. It pours out in a jet and the flow goes around the jet and mixes with it.

CO-CHAIRMAN FORD: So, again, the materials guy --

CO-CHAIRMAN WALLIS: What he has drawn here is what's happening at the -- if you turn it upside down, this is what's happening at the reactor end.

CO-CHAIRMAN FORD: Exactly, exactly. So could you have like in the BWR a nozzle cracking phenomena because of several stratifications that you see in feedwater lines? And you've seen the BWR nozzles.

MR. MUSCARA: Our evaluations are not necessarily of normal operating conditions. We're talking about severe accident conditions, and given the shortness of the transient, I don't think we'll get the BWR and also corner cracking, which is very petit.

MR. SIEBER; That would be the least of your problems.

(Laughter.)

CO-CHAIRMAN FORD: Yeah..

MR. MUSCARA: By the way, just to make sure some of us understand, the seven scale test that Chris is talking about is not the test that the NRC planned and conducted with Westinghouse. So we're trying to make use of that test and to validate some and see if the work that he's doing. So we had no control on how that -- I don't think, unless it was a cooperative effort.

MR. BOYD: I don't know. We were involved in some way because we got the data. We paid a little bit. I'm not sure how well we helped plan.

Now let's go into what we can do with quantitative results real quickly and then get on to the full scale results.

The tube flow split ratio, the red --

CO-CHAIRMAN WALLIS: This is something for the committee if they want to understand what's happening you have to understand.

MR. BOYD: Okay.

CO-CHAIRMAN WALLIS: It's not obvious.

MR. BOYD: I just don't want to take up the whole morning and cheat Don out of --

CO-CHAIRMAN WALLIS: No, well, I'm just asking them to pay attention if they want to understand.

(Laughter.)

CO-CHAIRMAN FORD: They are paying attention.

DR. RANSOM: Are you comparing these extension tubes? You mentioned having a thermocouple rate. Do you compare those to CFD calculations?

MR. BOYD: There was a rake in the experiment, but it was not -- the conditions feeding the rake were not the same test conditions feeding this steam generator. They didn't repeat things.

They had an issue with the data system. You know, 200, 300 transducers, whatever the number was, and 100 data channels, and when they switched all of their data channels from one set to the other, they didn't keep the conditions the same.

So it's very difficult to make -- I have hot leg data, and I can compare the hot leg flows and show that I'm getting the right profile, but they don't correspond to this run, and when I have hot leg data, I don't have a bunch of other data. So there's this kind of mixed matches.

So, no, I don't have the rakes to show with this particular run.

So we take a look here at the flow split ratio. These are the tubes and up flow. The CFD results are the black and they're, of course, symmetric because we ran a symmetry model. On one side we see the data matching fairly well and we see five tubes out and five tubes in. So on one side we've got exact agreement.

On the other side we're one tube over. The data are one tube shifted in, but in general we're pretty much picking up.

And now if we go in here --

CO-CHAIRMAN WALLIS: I think if they ran

the experiment again, in my experience with this multitude type thing, they'd get a different panel.

MR. BOYD: I would agree. If you look at their tube split ratios over the wide range of tests, they have significant asymmetries and significant variations.

CO-CHAIRMAN WALLIS: It's just because it's a question of which one gets started. The plume comes off and wanders around a bit, and then some of them get started going up and some of them get started going down. You cannot predict exactly which one, on the boundary whether it will be up or down. It's just a probability there.

Now, do my colleagues understand that the flow has to come up here, go down the other side into what's called the outlet side and the come back up some tubes and go down the inlet side again?

Okay.

MR. BOYD: All of these tubes are flowing upward, and all of these tubes are flowing downward.

CO-CHAIRMAN WALLIS: And on the other side, the same corresponding ones are going down and up again.

MR. BOYD: You see the exact pattern on the other side with the center going down and then the rest coming up.

CO-CHAIRMAN FORD: But what you're saying, one of those contours is observed, and the other one is calculated, and where they don't match is a discrepancy between observation theory. My question then is: how much is that discrepancy? Are we talking 100 a piece K (phonetic) or --

MR. BOYD: Five percent of the tube sheets, something like that maybe, and when we run that, there's a sensitivity in SCDAP/RELAP. We don't see a big sensitivity to that discrepancy, to the number.

CO-CHAIRMAN WALLIS: The total number that matters is where they are. It's not the problem at all because it's going to be random anyway, but the total number of tubes is predicted very well, isn't it?

MR. BOYD: And we don't see that as a big sensitivity anyway in the --

CO-CHAIRMAN FORD: No, but my question really was how much is the prediction off. I mean you partially answered the question, Graham, by saying, "Hey, some tubes won't be exactly -- have the temperatures exactly as predicted," and you're assuring which of those tubes it might be.

How much is the discrepancy between observation and theory? Is there enough for 100 of --

MR. BOYD: Are we talking about the number of tubes? Well, in this 216 tube model, we were seven tubes off, which is three percent of the tube sheet. So you can multiply that now by 3,200 tubes for Westinghouse or 8,000 tubes for a CE plant and get an estimate maybe of how far off.

CO-CHAIRMAN FORD: Maybe I'm off line here, but it doesn't really matter whether it's one tube or 100 tubes, which are not in agreement with observation. It's how much they are off because even if you have one tube or three tubes, which is 200 degrees K away from prediction, those seven or eight tubes failing by another mechanism might be even not controllable.

MR. BOYD: Well, these tubes on the boundary are not really our concern in my opinion anyway. We'll get to that, but it's the core central hottest tubes that are the problem. These tubes are closer or much lower temperature, significantly more mixing, and you know, the difference here is they are either significantly mixed, significantly cooler than the hottest tubes or they're in cold flow return, but either way these are not the most challenged tubes to begin with out on the periphery of this.

CO-CHAIRMAN FORD: Okay. So it's never mind.

CO-CHAIRMAN WALLIS: I think it's never mind, but I think that another question which I think is answered is that sometimes with these situations you worry about a tube being sometimes out flow, sometimes down flow. Sometimes it's a hot tube, sometimes it's a cold tube.

If you did get oscillation like that, you'd get a thermal fatigue problem, but I don't think that happens. I think once a tube gets going, it's a chimney. It stays as a chimney. There's no mechanism for it to revert to going the other way.

MR. BOYD: That's what the model shows.

CO-CHAIRMAN WALLIS: I think it's true.

MR. BOYD: Not in this case, but at full scale, we're looking at an example where that's the case.

CO-CHAIRMAN WALLIS: Do they actually revert, oscillate between up and down flow?

MR. BOYD: No. We look at a case where you would think if they're going to they would and they don't.

But now, we can change them though. If I take this run and run it as a transient and then change the tube heat transfer rate, those tubes on the edge do change, and it either grows or shrinks. So the code is able to based on that tube heat transfer rate to change a tube's flow.

CO-CHAIRMAN WALLIS: If you're in a house with four chimneys and you have a hot house and a cold outside and the dampers are open, two of those chimneys will probably have hot air going up and two of them will have cold air coming down, and that's what happens.

And once it happens, it doesn't suddenly change.

MR. BOYD: Unless you change the heat transfer on the chimneys.

CO-CHAIRMAN WALLIS: Unless you light a fire in the cold chimney. Then, of course, the smoke comes into the room, you know.

MR. BOYD: If you light a fire, all bets are off, but we'll take a look at that.

So now we're looking at some of the key --

CO-CHAIRMAN WALLIS: Are you going to analyze my house?

(Laughter.)

MR. BOYD: So here's the key parameters as we see them that are input into SCDAP/RELAP, some of the keys. The biggest discrepancy we have is in the number of hot tubes. We're seven tubes over.

This is interesting. The mass averaged hot flow temperature entering the tube, we're within a degree of what's reported in the experimental observations. Now --

DR. RANSOM: Is that the hottest?

CO-CHAIRMAN WALLIS: That's average.

MR. BOYD: That's average. Now, they averaged them differently than I did. I took a mass average over the entire flow area. They took the finite number, 25 percent of the tubes were instrumented, scattered in a patter. They just took them and averaged them numerically. So it is a different process.

But we're close to the bulk average flow going in.

DR. RANSOM: Aren't you more interested here in the maximum temperature?

MR. BOYD: In the maximum temperature I don't show it on the table. We match that very well in this, in this run.

CO-CHAIRMAN WALLIS: How much is it?

MR. BOYD: In this case --

CO-CHAIRMAN WALLIS: It's nowhere near the 159 you're putting in?

MR. BOYD: No, no. It's 106, 106 degrees, something like that, in this test, and we matched that pretty well.

CO-CHAIRMAN WALLIS: That's what you're you're interested in for materials purposes, isn't it, the maximum temperature?

MR. BOYD: That's right.

CO-CHAIRMAN WALLIS: So perhaps we need some sensitivity studies on how much will wander around if you get some of the heat transfer coefficients to be different.

MR. BOYD: So, now, here is another important parameter. This mass flow through the tubes, now, this is not something we're inputting. This is like the code is doing this based on the natural circulation and based on the loss coefficients and the heat transfer.

There was no tuning here. These things, heat transfer and those loss coefficients were all done in this one dimensional model off line and then input once and not looked at again. And we picked up the mass flow essentially exactly.

The mixing fraction down here, this is a very sensitive parameter. In my mind this is essentially an agreement between the mixing fraction, and the recirculation ratio, which is in this case only a measure again of the mass flow through the tubes because we input the hot leg mass flow, but we match that recirculation ratio.

And the rest of these --

DR. RANSOM: What is that recirculation ratio?

MR. BOYD: That's the ratio of the tube flow to the hot leg flow loop. The lot leg flow, let's say, has four kilograms per second circulating through it in a plant and the tubes have eight. So the recirculation ratio is two.

CO-CHAIRMAN WALLIS: Now, let me give you what would happen if you coupled in the reactor. FLUENT would now be saying the heat loss of the tubes is 3.69, and there's really I'm putting in 3.56. So I've got an energy balance that's not right. So, therefore, I've got to go back and change the tube that's coming in from the core, which then changes the M hot leg, and you go through that loop.

MR. BOYD: That's right. Those types of iterations were not really deemed necessary.

CO-CHAIRMAN WALLIS: You don't need to do it. I'm just saying that if you did have the other end with sort of an energy balance in there, then this would automatically --

MR. BOYD: Well, we tinkered with this and got good agreement. There was really no need.

CO-CHAIRMAN WALLIS: No, I agree. I agree. It's just that then you would have equality of some things instead of them being slightly different.

DR. RANSOM: The recirculation ratio is driven by entrainment; is that right?

MR. BOYD: No, it's driven by the tube buoyancy flows. If the tubes have no heat transfer, then the recirculation ratio would go down to essentially zero, no tube flow.

DR. RANSOM: Right.

MR. BOYD: As you increase the heat transfer, you pull; you're able to drive more fluid around that loop and --

DR. RANSOM: You're comparing, I thought, the net mass flow to the mass flow in the hot leg.

MR. BOYD: The net mass flow through the tubes to the mass flow in the leg. That's right.

CO-CHAIRMAN WALLIS: Right.

DR. RANSOM: Then why is that two?

CO-CHAIRMAN WALLIS: The flow up the

chimney is bigger than the flow into the fire. It draws in from the room.

DR. RANSOM: You do entrainment.

CO-CHAIRMAN WALLIS: Yeah.

DR. RANSOM: You've got flow that's coming down that's going to recirculate.

MR. BOYD: And it is entrained to go back up. Oh, I see. I see what your point is. That's right.

DR. RANSOM: That's what causes this. How is that measured in the Westinghouse data? How would you know that value?

MR. BOYD: The mass flow in the tubes was measured by an energy balance. So the uncertainty on that would be fairly high. They had -- basically they measured the heat loss from the system, rejected in the water loop on the outside, and this was steady state. That gave them an energy, and then they measured the inlet temperatures with these few thermocouples which they averages, and then they measured the return flow temperatures. So they have a steady state, steady flow problem. They had the mass flows. They had the energy.

I'm sorry. They had the temperature difference and the energy, and then they could get the mass flow directly from that, and that's the way they got the hot leg mass flow because the hot leg energy balance was the same energy value. They had an upper temperature and a lower temperature, and they got the mass flow from that.

So these mass flows have some uncertainty to them. The hot temperature in the lot leg that they measured was from one thermocouple in a very steep gradient. So we have to -- not all of the digits are significant.

CO-CHAIRMAN WALLIS: What would be really pretty would be if you had done this calculation before they did the test.

I was in high school, I guess. So that would have been tough.

CO-CHAIRMAN WALLIS: But then you wouldn't have been able to guess the in-flow rate from the core.

MR. BOYD: The only way to do that would be to have the vessel, and we attempted this with the vessel, Graham, just to let you know. Our first model included the vessel, but the vessel was a complex mass, and we got into the process of then having to specify loss coefficients in --

CO-CHAIRMAN WALLIS: Well, let's talk

about how you might do it easier.

MR. BOYD: Okay. Now, here's something that would be of interest. These are tube-to-tube variations now. So we've got this hot up flow. Now, this is what is going to really feed in --

CO-CHAIRMAN WALLIS: This is good.

MR. BOYD: -- to the tubes intake analysis.

CO-CHAIRMAN WALLIS: We're saying this is good. Put it in the record.

MR. BOYD: Okay. These tubes --

MR. MUSCARA: That would be of use.

MR. BOYD: These tubes on the periphery that you were concerned about earlier as to whether they're an up flow or down flow, that would be these tubes over here on the left side of this plot, normalized temperatures in the .2 range.

So these are the tubes on the periphery with lower mass flow rates, which you know have kind of some uncertainty. These tubes over here are the core flow tubes in the hottest part of the bundle, and here we've got normalized temperatures of .525.

We start normalizing things so that we can start comparing with the full scale results. The way we normalized is we assumed the hot leg, hot leg, hot temperatures, your hot sources. The cold flow return temperatures, your low point temperature, that provides the ultimate delta T, and then we just do a T minus T cold or a T hot minus T cold.

So what you're seeing here is that the hot temperature gets about halfway down to the secondary side temperature by the time it enters the tubes, and that's basically what this plot is showing us.

CO-CHAIRMAN WALLIS: So the statisticians could play with that if they wanted to.

MR. BOYD: This slide I don't plan on going over, but just to demonstrate, this is just a sample of the sensitivity studies, and these are some of the major inputs to the code, but we also varied everything from wall functions to turbulence options and to grid sizes.

We probably ran about 100 runs on this thing to really make ourselves feel comfortable that there was no point that we were being fooled by. So the code was pretty stable over all of these. We found no discrepancies.

So the summary here, Step 1, we've compared with one-seventh scale data. We've got some level of confidence and we feel more comfortable now going over scaled conditions. The model was stable.

Qualitatively we matched the experimental characteristics that are noted from the two sets of experiments.

The quantitative comparisons with mixing parameters was very good. The results were most sensitive to the heat transfer rate, and we feel like at this point we've got a much better understanding of what's going on.

CO-CHAIRMAN WALLIS: To go back to that, if you went to the heat transfer rate even lower than you did here, you'd get the situation where you'd get the flow going over the top and the hot flow actually comes all on the downcomer and you get no flow again. You've got a piece of it, whereas you counter to what you'd expect, your intuition, as you have a lower heat transfer coefficient. You actually have more circulation.

MR. BOYD: We'll look at a plot that has a --

CO-CHAIRMAN WALLIS: -- you're going up, but if you lowered it enough, you'd actually come down again.

MR. BOYD: I would agree. You would have several.

CO-CHAIRMAN WALLIS: And so there might be some concern about whether there is enough -- whether you are in that range of descending heat transfer in the real situation of the steam generator and the real life situation.

MR. BOYD: Okay.

CO-CHAIRMAN WALLIS: So you might want to extend it in that region.

MR. BOYD: We'll take a look at some plots that will shed a little bit of light on that.

Now we'll go to Step 2. We feel a little comfortable, and now we want to do a full-scale geometry. We realize up front that the geometry of a real plant is a little bit different. So we're going to take this intermediate step of scaling up the geometry and changing the conditions to the expected plant conditions. We stay with 216 tubes. We stay with basically the exact same model, and we put steam in it, 2,400 psi and the appropriate mass flows in the hot leg from SCDAP/RELAP 5.

And now at this point what we really have is a plant with 3,200 tubes, not 216. So what we did is we grouped the tubes together and created our porous tube, and we ran a CFD evaluation in great detail here to come up with the coefficients here. We ran that with steam at 2,400 psi with a seven-eighths inch tube. So we changed our analysis coming up with a totally different set of coefficients.

Now, where we're lost is on the heat transfer rate, and we recognize that. So what we did is we applied a whole series of heat transfer rates, which I'm going to label here H-1 through H-7. We --

CO-CHAIRMAN WALLIS: These are heat transfer coefficients for just where?

MR. BOYD: On the outside of the tubes. This is the heat driven --

CO-CHAIRMAN WALLIS: That's what we're talking about.

DR. RANSOM: This is the CFD model?

MR. BOYD: This is the CFD model. That's right. So we've got this range of effective heat transfer rates. So down here at H-7 what we've done is we've hit it with such a high heat transfer rate that all of the heat leaves the model by the time the flow reaches .3.

CO-CHAIRMAN WALLIS: You're quenching the chimney. You have to fill it back.

MR. BOYD: That's right, and with heat transfer rate one, the lowest heat transfer rate, by the time the flow reaches the top dead center of the steam generator tube, the normalized mass average temperature has dropped from .28 to .14. It has lost half of its, let's say, temperature range, but there's plenty of -- what it's going to do is still be hot and losing heat all the way down, and it's going to come back up.

CO-CHAIRMAN WALLIS: If each one went to zero -- excuse me -- you'd have a flat line, or not a flat line. It would go all around and wouldn't cool down at all.

MR. BOYD: I'm sorry?

CO-CHAIRMAN WALLIS: If each one was zero.

MR. BOYD: Oh, if each one was zero.

CO-CHAIRMAN WALLIS: it would go all the way around and wouldn't cool down at all.

MR. BOYD: If each one was zero, it may not even go around.

CO-CHAIRMAN WALLIS: You'd have a flat line. The temperature would just be flat in that picture.

MR. BOYD: Yes. If each one was zero what would happen is the flow would come in and it would come right back out.

CO-CHAIRMAN WALLIS: It would go at .28 all the way across.

MR. BOYD: It's questionable whether it

would even enter the tubes.

CO-CHAIRMAN WALLIS: But while it's in the tubes, it would have a constant temperature.

MR. BOYD: It would have a constant temperature. That's correct.

Okay. So what we did is with ignorance of the true heat transfer coefficient or not comfortable with the SCDAP/RELAP 5 predictions, we ran a whole range of them. The SCDAP/RELAP 5 predictions for this particular run with the four nodes and the steam generator --

DR. RANSOM: Incidentally, this is sulfur hexafluoride.

MR. BOYD: No, now we're talking full scale with steam.

DR. RANSOM: Oh, it's steam.

MR. BOYD: Yes.

DR. RANSOM: In your CFD model. Okay.

MR. BOYD: Okay. With a full scale steam generator that has the geometry of the one-seventh scale facility, a similar geometry, but at full scale. So there's no geometrical distortion. We're just scaling up.

DR. RANSOM: Because of this tube model though you have to adjust the heat transfer, I guess.

MR. BOYD: And the tube loss coefficients and all of that stuff. That's right.

Here's the effect of heat transfer rate on some of these key parameters. The tube fraction goes from, let's say, 48 percent, 47 percent of the tubes. As we change the heat transfer rate, this can go down to 37 percent of the tubes. So in a full-scale plant, we have just changed ten percent of the tubes in up flow or down flow just by changing the heat transfer coefficient.

This is demonstrating the importance of that heat transfer coefficient and if I want to make comparisons between one-seventh and full scale, I had better be consistent with that, and that's why I show the one-seventh scale data here as the blue dots, the blue hexagons. We're going to compare that with H-5, but when we go to full scale and want full-scale conditions, we're going to want to compare with H-3 and H-4 up in here.

So we take a look at the two bundle mass flow can change significantly. It goes from 12 kilograms per second down to eight. That's a significant --

CO-CHAIRMAN WALLIS: And if you went to a lower H, it would go down on the left-hand side. It would be a bell shaped curve.

MR. BOYD: That's right. We would expect some of these --

CO-CHAIRMAN WALLIS: Right.

MR. BOYD: But we feel like we've covered the range of where we are.

CO-CHAIRMAN WALLIS: I understand.

MR. BOYD: But I would agree with you that these are not trends that continue. They would then --

CO-CHAIRMAN WALLIS: It goes down again.

MR. BOYD: As you drive the chimneys, that's right.

CO-CHAIRMAN WALLIS: It short of shows up. You've hit the maximum really. It's just beginning to go down. There is a maximum in that curve at a certain H.

MR. BOYD: We look at things like the recirculation ratio.

CO-CHAIRMAN WALLIS: There's a maximum there at a certain H, too, right.

MR. BOYD: The recirculation ration is an important parameter governing the tube temperatures in the end, and we see it can change from three to two or 1.9. So we see some significant variations.

Now we're going to look at what I call the scale effect. We take the full scale calculation: steam, 2,400 psi, four kilograms per second down the hot log comparing it to sulfur hexafluoride with .2 kilograms per second down the hot leg, much lower temperatures.

CO-CHAIRMAN WALLIS: Now, there is a key question here. When you had a seventh scale, you imposed a velocity from the vessel.

MR. BOYD: That's right.

CO-CHAIRMAN WALLIS: Now here you have to impose a velocity from the vessel in the full scale.

MR. BOYD: That's right.

CO-CHAIRMAN WALLIS: In the seventh scale you know what it is because you have an experiment. In the full scale, it comes out of some phenomena, and you still impose something. How do you know what to impose?

MR. BOYD: We don't. So we use the value from SCDAP/RELAP 5 and assume that that RELAP 5 --

CO-CHAIRMAN WALLIS: Which comes from an energy balance from the vessel. Really what it does is it ties together M, hot leg, and TH. That's what's happening in the vessel. It's a coupling between them because of the energy being produced, and --

MR. BOYD: With lack of better information, we're letting SCDAP/RELAP 5 do all of those predictions for us of the coupled system.

CO-CHAIRMAN WALLIS: And it's modeling your steam generator the way you described earlier.

MR. BOYD: That's right. It's doing the exact same thing.

The point of all of this is to show that the re-circ ratio is essentially the same. The number of tubes and up flow is essentially the same.

Now, these tubes weren't locked in place. These tubes changed as we changed the heat transfer rate, but when we kept the heat transfer rates consistent, we got the same number of tubes.

The mixing fraction, what we see is a little bit more mixing at the full scale conditions.

CO-CHAIRMAN WALLIS: Do you know what H is in the real life in the steam generator on the outside of the tubes?

MR. BOYD: The H?

CO-CHAIRMAN WALLIS: The H, the H that you varied.

MR. BOYD: We could make some assumptions on that, but there's going to be some complex flows over there, and it's probably not uniform across the tubes. We're using uniform on all --

CO-CHAIRMAN WALLIS: Maybe that's an area which requires some study.

PARTICIPANT: Did Jack go away?

CO-CHAIRMAN WALLIS: Well, he can read the transcript.

MR. BOYD: So now we'll take a look at the histogram. In general these results are pretty similar, but we're comparing with like heat transfer rates. You'll see that the full scale results are skewed a little bit toward the cooler end of the spectrum, but they have generally the same range of temperatures. That skew would be representative of the little bit higher mixing fraction that we saw.

But, again, this is not too significant in light of what we're going to see later.

Here's the flow split ratio. The blue is the Westinghouse one-seventh scale experiment predictions. The black is case H-5, and you'll see that there are the same number of tubes. They trade off one -- these two tubes are switched between the two, but nonetheless, they still have 38 percent of the tubes.

CO-CHAIRMAN WALLIS: I would say the tubes on the boundary that have a 50 percent probability of going up or down. So I wouldn't worry about that at all.

MR. BOYD: With case H-1, we reduce the heat transfer rate, and you'll see that we pick up these extra tubes out here, and that's the difference that we saw on the table.

So in summary --

CO-CHAIRMAN FORD: Sorry. I'm going to ask another non-thermal hydraulicist question. As I understand it going through this scale-up argument, you changed the heat transfer coefficient to have certain parameters in alignment, these MT, ML ratios, et cetera.

Graham brought up the question of what is heat transfer coefficient in a real plan, and surely there you're going to be worried about the surface condition, crud build-up, and things of this nature. How much would you expect that physical phenomena to change that heat transfer coefficient? And would it be enough that it would be within these parameter changes you made to H?

MR. BOYD: The reason why we ran this whole series is that now we could go back and look at what we think the value is, look at the uncertainty on that, and look at the effect of that compared to my variations, and see what impact it has.

Now, I would say that I have a wide range of variations where I'm hitting it so hard that I lose all the heat within the first 30 percent of the bundle all the way over to letting the heat go all the way around the bundle. So these H-1, H-2, they're significantly different heat transfer rates. This isn't plus or minus ten percent or anything like that.

But I don't have a direct answer for you. It would have to be looked at and look at the uncertainty in the heat transfer rate and then compare it to the difference that we see. But we would be more in line with between H-3 and H-4 of my heat transfer rates as opposed to going from one end to the other. You're not going to add some crud and make these kinds of drastic changes that I'm doing to the heat transfer rate here.

CO-CHAIRMAN WALLIS: That's a fact, is it?

MR. BOYD: I can't see how you can make a small change and have it change from drawing all of the heat out of the bundle in three meters or letting the heat go 24 meters without --

CO-CHAIRMAN WALLIS: The crud won't do it, but something on the secondary side might do it, and how the steam generator is actually cooled might have some effect.

MR. BOYD: Okay. The steam generator secondary side is a very complex --

CO-CHAIRMAN WALLIS: I think to summarize what you're doing, what you're doing here is you're convincing us that you have a valid tool for analyzing this steam generator problem. You're not at this stage saying this is actually what we think happened in a particular situation in a real plant.

MR. BOYD: I would say we're trying to get an idea -- that's right -- of what the effective scale is, what the effect is of some things are. What's important at this point we're trying to nail down, but before we run off and spend, you know, a lot of money doing details, I think we really need to look at the overall PRA for this entire problem, and where does our uncertainty fit into the big picture.

CO-CHAIRMAN WALLIS: So why are the PRA guys way behind in telling you that?

MR. BOYD: We got a little bit of a head start. We cheated, I guess. But the point is before we -- if somebody doesn't know, this has to be compared side to side with flaw distributions.

CO-CHAIRMAN WALLIS: Right.

MR. BOYD: Before we run off and spend a

year of effort doing more tubes and more detail, we got estimates of what it can mean.

CO-CHAIRMAN FORD: But in answer to my specific question, when you go to the real steam generator, you're saying, "Hey, uncertainties on heat transfer coefficient because of crud build-up, et cetera, is not going to be a major item that would swing your conclusions so far or way off to one --

MR. BOYD: Not swing them so far, but uncertainties, there is uncertainty though in that secondary side. We need to get a handle on that to try and make an estimate of where we fit and how varied it can be.

DR. RANSOM: Well, in the system transient calculation that the secondary site is full of just low pressure stagnant steam, the major energy must be going into just structure, end of the tubes, whatever else is modeled as a heat structure because there can't be much heat transfer to the fluid.

MR. BOYD: It is a very small heat transfer coefficient on the secondary side in the SCDAP/RELAP 5 analysis. We would argue that it's probably higher.

DR. RANSOM: So it's mostly just thermal inertia of the structure that's --

MR. FLETCHER: Well, there is a circulation of steam on the secondary side. The way we've modeled it is a two pass model with a downcomer and a boiler side. So there is a mechanism to circulate steam. There is heat loss off the outside of the steam generator shell, and so there is an ultimate heat break out there for some of the steam, some of the heat to get there.

DR. RANSOM: The secondary is basically a closed volume?

MR. FLETCHER: In one steam generator it is blown down. We have a stuck open valve on the top of the steam generator, and so it is closed, except for an opening on the top. The other steam generators are closed, but dry by the time we get to this point.

CO-CHAIRMAN WALLIS: At their high point, there's no way that this circulates around to the condenser or anything.

MR. FLETCHER: No, none whatsoever.

CO-CHAIRMAN WALLIS: No. So you're really stuck for a good heat sync.

MR. FLETCHER: Yes.

CO-CHAIRMAN WALLIS: Very bad heat sync. So probably the whole plant is heating up.

MR. FLETCHER: Yes.

MR. MUSCARA: Peter, maybe a comment on your question. You're correct. The nature of the crud build-up on the tubes does affect the heat transfer.

CO-CHAIRMAN WALLIS: It does, put it puts some water in somewhere.

MR. MUSCARA: In fact, it affects it enough that it affects plant efficiency, and the plants, in fact, go in and do chemical cleaning to improve the efficiency. So at the time of the severe accident, you'd expect that the heat may be degraded, but not tremendous amounts because it affects the efficiency in the solution taken care of.

MR. SIEBER: I would think all that would really affect ultimately is the timing of things. You know, if you aren't transferring the heat, you heat up faster, and so there just can't be a whole lot of heat transfer.

CO-CHAIRMAN WALLIS: So to go back to the scenario, what you're concerned, you heat up the thing. You heat it up, heat it up. Which fails first?

MR. FLETCHER: Right.

CO-CHAIRMAN WALLIS: That's the question.

MR. MUSCARA: And I guess in conjunction with this, it's not necessarily the hottest tube that may fail first. It depends on the flow. So we do need to know the distributions and temperatures of these tubes in the distribution and --

CO-CHAIRMAN WALLIS: So you should put a little diaphragm on the surge line, which is designed to pop before anything else does.

MR. MUSCARA: Yeah.

MR. SIEBER: A diaphragm?

CO-CHAIRMAN WALLIS: Or whatever. I mean a release disk. What do they call those things? Procter disk, something, something.

MR. BOYD: So I'll summarize step two. The results are similar to the one-seventh scale facility. We've got a slight increase in mixing. Tube bundle heat transfer rate is a significant governing parameter. We've demonstrated that here with a whole series. That's something we learned at one-seventh and demonstrated here.

And the purpose for these predictions is an isolation of the effect of scale. So we feel like, I guess. that the facility was pretty well scaled and it did represent in some respects the full-scale behavior.

Now, of course, there's geometrical

issues. It wasn't geometrically the same. There's radiation issues, hydrogen issues, all sorts of other issues, but in some respects the scaling was pretty good.

So now we're going to go on to go on to a prototypic geometry, and the design was a Model 44, and we look at the Model 44 geometry next to the facility scaled up. What we see for starters is that the hot leg sits closer to the tube sheet. I think generally this results from the way they built the facility.

There was a hemisphere for the lower plenum, and it was welded into a large disk, but it was welded in several or let's say about two inches below the tube sheet face. Well, that two inches at full scale is 14 inches. So it adds a little bit more mixing length.

There's also a difference in the way the hot leg enters and the diameter of the nozzle flares out on the plant. So we see over here we see a symmetric design for the facility, and then we see an off angle --

CO-CHAIRMAN WALLIS: It comes in off center.

MR. BOYD: Off center. There's a manway

over here, which I guess is the reason why it's off center.

CO-CHAIRMAN WALLIS: So that's why you can't model half of it now.

MR. BOYD: That's right. No more symmetry. So we go on, and we create a full scale geometry based now on the primary side of a Westinghouse Model 44. We take the same boundary conditions we just used, and we just bring them over. So what we're now doing is only changing the geometry. Before we changed the conditions. Now we change the geometry.

It worked out with even tube. The way we split it up was 201 individual tube sections, no symmetry plane. This turned out to be a million cells instead of half a million. We made all of the cells' dimensions as close as we could to the other study. So if we had 42 cells across the hot leg, we used 40 cells across the hot leg.

CO-CHAIRMAN WALLIS: I'm going to ask you the obvious question then. Is the number of cells you can take limited by the computer facilities at the NRC or by something else?

MR. BOYD: We have limits, of course, here at the NRC. There's also some issues with the codes converging with very large numbers of cells, and there is an issue there also.

CO-CHAIRMAN WALLIS: Typically, say, if you double the number of cells, the thing begins to take five times longer to run or ten times, something like that, and therefore, you don't do it because you have to wait forever. There's a tradeoff.

MR. BOYD: That's right.

CO-CHAIRMAN WALLIS: But if you have quicker computers or better clusters or something, then you could easily do two million cells.

MR. BOYD: Yes.

CO-CHAIRMAN WALLIS: Are you limited? Do you feel limited by the facilities here, Jack?

MR. BOYD: I feel limited.

(Laughter.)

MR. ROSENTHAUL: Well, we have a CFD cluster, and each year we add -- I don't know -- half dozen, dozen nodes. So the thing keeps growing, and Chris by hand, I think, changed out the mother boards and got each node running faster.

So at this point --

MR. BOYD: We're increasing capacity every year.

MR. ROSENTHAUL: Yeah, we're growing.

MR. BOYD: And research has been keeping for the past three years a steady budget for this, but it has jumped --

CO-CHAIRMAN WALLIS: It's important that it be done.

MR. BOYD: -- to a full system, but within the next couple of years, within the next few upgrade cycles, we'll be at our steady state value, and we'll have probably an order of magnitude more computing power than we had when this was done.

MR. BOYD: Well, you may feel limited, but looking at all of the things you have been able to do here, it appears as if it wasn't a critical limitation. You weren't sort of off for 24 hours and everything.

MR. BOYD: I have to maintain the line that I'm limited so that I can ask for money each year.

CO-CHAIRMAN WALLIS: Certainly if you were to do more complicated problems you might need more.

MR. BOYD: That's correct.

MR. ROSENTHAUL: I think actually what drives the machines, and it has got nothing to do with this, is fire CFD, which is what we're gearing up to do, and of course, you're doing both chemistry and fluid flow.

MR. BOYD: This model that we're looking at here took 60 days to converge. So having --

CO-CHAIRMAN WALLIS: For one run?

MR. BOYD: For one run. So having more power would have been nice.

CO-CHAIRMAN WALLIS: So I think you are limited. You do have to wait a long time.

MR. BOYD: It is nice to have.

CO-CHAIRMAN WALLIS: That's not good.

MR. BOYD: Power is nice.

MR. ROSENTHAUL: If you were to rerun this today --

MR. BOYD: We're squeezing out bottlenecks and trying to improve our networking.

CO-CHAIRMAN WALLIS: That's not good. Two months, you're off worrying about some other project and all of that. You really need a turnaround in a day I would say to do really good CFD.

(Laughter.)

MR. BOYD: Okay.

CO-CHAIRMAN WALLIS: You can't wait forever for these results.

MR. BOYD: Now, I will say that the symmetry model I could run in a week, and the reason why this took so long, and we're going to get into that in a moment, this was an unsteady plume. The symmetry plane unleashed it or else this asymmetric hot leg unleashed it, and now we had to run for a long time and pick up statistics as opposed to just reaching a steady state value.

CO-CHAIRMAN WALLIS: Oh, that's to bad.

MR. BOYD: So in summary here, we're going to repeat the scale-up analysis with a different geometry. We're going to use all the other same conditions.

CO-CHAIRMAN WALLIS: One of my suggestions is that these vendors design systems are analyzable because a lot of expense has to do with the fact they made it so difficult to analyze them.

MR. BOYD: There is a lot of leg work that goes into looking at the data. Getting that handle on the results so that you can do things is still not as good as it should be.

This is on the hot leg symmetry plane. It's not symmetric up in the tubes. This is --

CO-CHAIRMAN WALLIS: But you do get unsteady flow.

MR. BOYD: This is the plume, the unsteady plume.

I visited some people at IRSN over in France, and they're doing similar calculations with the large eddy simulation. They see the same behavior.

Now, they took the approach of a different tube model. They used shorter tubes and a fewer number of tubes, but nonetheless, they still got this unsteady plume behavior. They called it flow dragging as the plume is pushed back and it doesn't reach the tube sheet directly.

Here is a path line --

CO-CHAIRMAN WALLIS: Like combustion instability.

MR. BOYD: Here's a path line animation. We don't see that same behavior that we discussed before with the symmetric stuff and the things coming up. Now we see the plume coming up and partially stagnating on the tube sheet. The flow comes over to the right, immediately hits a wall, and is tracked back around --

CO-CHAIRMAN WALLIS: That makes waves in the hot leg. That makes waves in the hot leg.

MR. BOYD: That's right.

CO-CHAIRMAN WALLIS: That's not good for --

MR. BOYD: There is some waviness in the end of the hot leg. So the flow behavior significantly differs.

Now here's looking straight down at just above the tube sheet. What we see here is we see the hottest tube was over here. Now all of a sudden that's a relatively cool tube. Now the hottest tube is down here.

CO-CHAIRMAN WALLIS: So there is thermal fatigue or the potential for thermal fatigue.

MR. BOYD: The temperature instead of going like this is going like this, but it's still going up.

CO-CHAIRMAN WALLIS: Well, yeah, but it's oscillating.

MR. BOYD: It is oscillating.

DR. RANSOM: The tubes in up flow though seem to remain relatively constant.

MR. BOYD: That's the point that you made earlier, and the percentage of tubes in up flow does not change in this calculation, and if they were going to change, this is where I would predict they would change.

CO-CHAIRMAN WALLIS: I would doubt if they'd change. Once you've got that flow going, it's very different from --

DR. RANSOM: At the hottest point it's going to move around.

MR. BOYD: But I can change the heat transfer coefficient, and they will turn around.

DR. RANSOM: They will.

MR. BOYD: So they can be turned around.

CO-CHAIRMAN WALLIS: So this is new from what we've read i your reports.

MR. BOYD: This is in a draft NUREG right now being reviewed. So I did not send you the draft.

CO-CHAIRMAN WALLIS: How long does it take to do that?

MR. BOYD: To review it? Just starting.

CO-CHAIRMAN WALLIS: You could send us a draft though, can't you, for ACRS use only or something? Yeah, you can do that.

MR. SIEBER: It comes as a DVD, too.

MR. BOYD: But there's a lot of results at full scale conditions. I'm just showing you the tip of the iceberg. We have a good bit of information.

So what we see is a totally different behavior. I throw up this plot again just to show where we fit into the grand scheme of things with my scale-up runs. The hexagons in this case are the

Model 44 runs, and what you see as I come down through here in a heat transfer temperature reduction that's kind of parallel to this case H-4. So we want to make a --

CO-CHAIRMAN WALLIS: This is the average of some sort?

MR. BOYD: This is the mass average temperature going up through the tubes. So if we're going to make a comparison with H-4, and I compare with several of them, but the one thing you'll see is you'll see a higher temperature level here. That's the result of the hot leg being closer to the tube sheet. That's your first indication.

We'll take a look here, and we have fairly good agreement with the mass flow tube.

CO-CHAIRMAN WALLIS: Excuse me. You're imposing this flow from the vessel still?

MR. BOYD: That's right, and I'm imposing the exact same flow.

CO-CHAIRMAN WALLIS: Because there's oscillating flow in the hot leg. This might affect that end as well.

MR. BOYD: Not in this model though.

CO-CHAIRMAN WALLIS: Not in this model, but again, it's a physical thing that could happen.

MR. BOYD: That's right.

CO-CHAIRMAN WALLIS: The last thing you want to do is to develop the big interfacial waves in the hot leg and, you know, disturb that circulation there.

MR. BOYD: That wasn't seen here, and it also wasn't seen in the large eddy simulation that the French did. They had five million cells in --

CO-CHAIRMAN WALLIS: Well, they have better computer facilities than we do?

MR. BOYD: They probably --

CO-CHAIRMAN WALLIS: We can't let there be a computer gap with the French.

(Laughter.)

DR. RANSOM: Well, actually this moving around of the stagnation point is probably beneficial. I mean, it's going to spread the energy out over more tubes than you would otherwise, but I doubt if it has any effect on the macroscopic behavior. Minor.

MR. MUSCARA: Can I make a short comment again, Peter?

When you look at these temperatures, you know, I'm not really concerned about fatigue. Those temperatures are high enough that the tube will rupture. I agree.

CO-CHAIRMAN FORD: Yeah.

MR. MUSCARA: A good tube will rupture by a creep at about 800 Centigrade.

MR. BOYD: We ran this at two temperature ranges, too. We're right now at the temperature ranges where we are at near the failure points.

We also ran this again with the hot leg temperature close to 1,000 Kelvin instead of 1,400. So earlier in the transient, and we got very similar results.

So my point here is that the mass flow through the tubes, which is a calculated parameter was very similar to H-4 with a similar heat transfer. The recirculation ratio, very similar. The mixing fraction was less. So less mixing. We got .8 instead of .87, and all of these values for the Model 44 have a plus or minus standard deviation on them because we had to run it through what we would consider a cycle or two and take some statistical values.

CO-CHAIRMAN WALLIS: It's good that you have this non-steady flow. If you had tried to converge on a steady flow, it would not have given you very good residuals.

MR. BOYD: The code would just not. Yeah, it would not converge. That's right.

Even the other run we couldn't really get to converge well on the steady state solver. It was run as a transient also. The transient solver is a little more robust.

CO-CHAIRMAN WALLIS: Although what the steady state solver does often is it kind of emulates the transient as it tried to balance things out.

MR. BOYD: But sometimes you need to force small time steps to refine.

CO-CHAIRMAN WALLIS: Yeah, yeah.

MR. BOYD: So now we'll look back at this histogram, which we've looked at earlier, and before we sat these temperatures ending at about .5 halfway between the hot and cold sync temperatures, and now for this Model 44 design we've got temperatures that are approaching .7. So here's where, again, the result of having the hot leg closer to the tube sheet. It is picked up here as in other cases.

CO-CHAIRMAN WALLIS: It's interesting. It looks as if you've picked up a tail of a distribution that you didn't have before.

MR. SIEBER: Right.

MR. BOYD: Well, the black line, some of those look more like a tail. They varied a little bit.

CO-CHAIRMAN WALLIS: Yeah, you'd think you'd have more of a tail with the black lines on the right just as if you didn't pick it up somehow. Anyway, this still --

MR. BOYD: The hottest tubes we saw in the scale-up model were at this temperature in the very core of the hot plume, and now in the core of the hot plume we're seeing, you know, a little bit hotter temperatures.

So the Model 44 behaves a little bit differently than the facility is the point of all of this.

Here is an indication now we're going to look -- this is a figure out of the report. We take a look at the hottest tube region over one cycle, and we can get an indication of the movement of the hot plume, but then I'm showing this to say the next plot, what I take is those central eight regions where the hot tube generally ranges, and we plot the temperature versus time.

And for instance, in A, tube region A, we see it's the hottest tube at what I'm calling time zero. Twelve seconds later in that section, it's one of the coldest tubes, with a normalized temperature of about .2.

CO-CHAIRMAN WALLIS: This must be interesting for the materials people.

MR. BOYD: Yeah, they're going to have more fun with this type of data.

CO-CHAIRMAN FORD: So you've got creep fatigue interactions. But these frequencies are pretty high. You wouldn't expect much creep fatigue interaction.

MR. BOYD: I think in these temperatures, I think creep will take care of it.

MR. BOYD: Just to avoid the question, I'll note --

CO-CHAIRMAN FORD: This is fascinating. This is dead on.

CO-CHAIRMAN WALLIS: It's amazing. I mean it keeps getting better.

MR. BOYD: We'll melt some tubes here again.

CO-CHAIRMAN WALLIS: This is like one of those --

DR. RANSOM: This is a fluid temperature though, right?

MR. BOYD: These are fluid.

DR. RANSOM: Not the metal temperature.

MR. BOYD: This is the fluid temperature

entering the tube sheet, which would then be put into SCDAP/RELAP 5, which would then take out heat losses in the big tube sheet and then, you know, calculate the temperature drop through the tubes and all of that good stuff.

DR. RANSOM: Well, if you're talking about cycling variations of the thermal inertia will damp out some of this.

MR. BOYD: So summary of Step 3 for Model 44. We've got a different flow pattern. The hot leg is closer. That would be the obvious reason. There's less of a mixing distance.

The hotter tubes are predictive, but their location and level vary with time. So a more detailed consideration of tube heating is needed than what we've been doing.

And the mixing is still significant though. We see less mixing, but in general, we're not bypassing the inlet plenum. We're still seeing mixing, and it's not too far from what we've been assuming. So we're not off the scale yet.

So now we're going to look at tube leakage analysis. We went back to the full scale geometry based on the one-seventh scale facility because this could run in a week, and I wanted to make a series of runs. The tube leakage rates of -- what we started with was 150 gallons per day tech spec limit of some sort. That's essentially a --

CO-CHAIRMAN FORD: Excuse me. Chris.

Ladies and gentlemen, it's 10:30. Do you want to take a quarter hour break at this point or do you want to go on until we get --

MR. BOYD: I think the rest of the talk goes a little quicker because you guys don't ask as many questions.

MR. MUSCARA: I think it needs to be because there's not much time left for the remainder of the presentation in this area.

CO-CHAIRMAN WALLIS: It probably would be best if he finished.

CO-CHAIRMAN FORD: Okay.

MR. BOYD: Yeah, I think the rest of the talk will drift along quicker.

CO-CHAIRMAN WALLIS: You can just say you must finish by quarter of.

MR. BOYD: Okay. Good. So we started with 150 gallons per day. This is essentially equivalent, when you take a whole size and compute mass flow rates, it's equivalent to the mass error in the code. It was irrelevant.

So we multiplied it by ten, 100, 1,000, and 2,000, and that's approaching 200 gallons per minute operational condition leak rates. So those are the leak rates. We had several leak positions, three leak locations on the symmetry plane and then the distributed lean in a pattern all over the tube sheet.

The big conclusion here is that (a) the hot plume is not drawn to the leak, at least at these leak rates. In fact, in this example, I've got a plot as a back-up slide, but I won't bother showing it. As you increase the tube leakage rate, the plume actually moves out further away from the leak as opposed to being drawn to the leak, and that's because we're reducing the flow that's coming in this way because it's going out the leak.

So even when I put the leak right next to the plume, I couldn't draw the hottest portion in. I really don't see the movement of the plume that I had thought I might see, and --

CO-CHAIRMAN WALLIS: Because the plume is sucked by the natural convection, and this leak fills the natural convection.

MR. BOYD: Yeah.

CO-CHAIRMAN FORD: Did you do a sensitivity analysis to find out if the leak was above a certain amount then you could draw the plume over?

MR. BOYD: I did not go high enough to draw it over. In fact, I pulled almost as much as the hot leg flow, and it still seemed to want to travel around and go up. The plume seemed to want to do what it wanted to do, and when you draw really hard, you start pulling from the outlet plenum, too.

Here's a histogram. Now, I plotted this as lines as opposed to bars because the bars got a little confusing all side by side, but what you see is that up to 1.4 kilograms per second, which is your 100 gpm leak, there was no change in the hottest tube predicted.

When we went to 200 gpm equivalent type leak, I did get hotter tubes not because I pulled the hot plume into the leak, but because I reduced the mixing somewhat in the inlet plenum.

And then I also went to 300 gpm leak. Now, this is the hot leg flow. It was four kilograms per second basically, and I did see again --

CO-CHAIRMAN WALLIS: Where does this leak go?

MR. BOYD: This leak went into --

CO-CHAIRMAN WALLIS: The steam generator. So you've got a feedwater flow.

MR. BOYD: I am feeding into the steam generator with a stuck open relief valve. So it's --

CO-CHAIRMAN WALLIS: -- heat transfer on the secondary side? You're now flooding up the steam generator?

PARTICIPANT: There's no water.

CO-CHAIRMAN WALLIS: Oh, it's all steam leak? I'm sorry

MR. BOYD: Super heated steam and it's going over there an venting.

CO-CHAIRMAN WALLIS: I see you're right.

MR. BOYD: Okay. So we've got a bunch of data. We did a whole series of runs here, but we were not seeing -- the concern, I guess, is different from -- the concern is not as severe as what some might have hypothesized here. So the smaller leaks in the area of 1,500 --

CO-CHAIRMAN WALLIS: Why do you have gallons per minute of steam?

MR. BOYD: I have gallons per minute; I talk in gallons per minute because that's the way the agency also talked about --

CO-CHAIRMAN WALLIS: Do you mean gallons per minute of steam of is this a --

MR. BOYD: No, that is gallons per minute of water.

CO-CHAIRMAN WALLIS: That is crazy.

MR. BOYD: At standard operating conditions, but that's the way --

CO-CHAIRMAN WALLIS: Standard room conditions or it would have --

MR. BOYD: No, at the plant operating conditions.

CO-CHAIRMAN WALLIS: That's always so uncertain what they mean by 100 gpm.

MR. BOYD: Well, in the report what I do is I say we based on this to just get an estimate. Then we're going to talk in terms of kilograms per second and leave all that --

CO-CHAIRMAN WALLIS: That's right. That's the only way to do it.

MR. BOYD: -- and leave all that to the break flow guys to argue out later. That's right.

So I'll switch over, but I'm relating it to that to give some -- that gives some people a grounding as to what size hole we're talking about and how realistic it could be in a plant.

So the smaller leak rates basically provided no difference in the solution. If I compared them with zero leak, all of the parameters were essentially unchanged. Direct inlet plenum bypass is not predicted.

We get some hotter tubes at the highest leak rates, but that is a result of the decrease in mixing, and I will say that I did not increase the hot leg mass flow. I kept it fixed. So the system would probably feed more mass to that leaking generator in reality.

Now we'll go on to the final step, the Combustion Engineering steam generator. We'll try and run through this quickly. We've got 8,000 tubes now, a 42 inch hot leg. We're going to take the boundary conditions from a SCDAP/RELAP 5 analysis and apply it to this model.

This model was, again, symmetric. So we used 1.3 million cells for the symmetry model. So we did use a significantly increased number of cells for this bigger generator. We tried to keep the cell sizes similar.

Take a look at the geometry compared to a Westinghouse. What you see is a 42 inch pipe sitting, you know, a number of roughly ten inches from the tube sheet. So you've got a plume this big, maybe on the order of a foot if it's a quarter of the pipe sitting that far from the tube sheet, and that's the concern with the CE plants.

What we see here is some predictions. We see the vessel exist temperature range is red. We see those hot leg temperatures exiting the hot leg nozzle and doing very little. There's obviously some mixing, but we see some entrance temperatures into the tube sheet that are very similar to the hot leg temperatures.

We look on kind of a normalized scale. This is kind of --

CO-CHAIRMAN WALLIS: Is this a horizontal hot leg? You seem to show it going down at 90 --

MR. BOYD: That's a skewed angle.

CO-CHAIRMAN WALLIS: Is it horizontal?

MR. BOYD: It is horizontal.

CO-CHAIRMAN WALLIS: Oh, okay.

MR. BOYD: This is a three dimensional view. That's the way it looked there.

So what we see here is the CE steam generator is geometrically different and the mixing we see is different. We take a look at the mixing parameters. We've got mixing fractions on the order of .6. We ran two cases, one hotter than the other.

Recirculation ratios, reduced from what we've seen before. There's not a lot to say here other than we've got less mixing and it's not really all that surprising.

We take a look at the histogram for this plant, and what we see is temperatures are approaching .95 on a normalized scale. So we've got very little temperature reduction.

In summary, we've got a significant variation in inlet plenum geometry compared to what we've been considering for inlet plenum mixing based on the one-seventh scale experiments. We've got this difference in inlet plenum mixing. A small portion of the hot leg flow appears to reach the tube sheet with little or no mixing.

The SCDAP/RELAP 5 analysis is starting up right now for the Calvert Cliffs plant with using these new mixing coefficients. So we'll get some kind of general feedback from a systems point of view on what this all means from a tube failure point of view.

So a summary. We've done one-seventh scale analysis to provide some confidence. Then we looked at full scale conditions for a Westinghouse steam generator. We've got some indication of tube-to-tube variations, what tubes are how hot in those histograms.

We've also got tube temperatures versus

time. We've considered tube leakage in many aspects, and in the plenum bypass is not expected. We do see some overall decrease in mixing at high leakage rates. Interplenum mixing is significantly different for the Combustion Engineering Example that we looked at, and in the future we're on some sort of a standby. If updated predictions are needed for some reason, we could carry this on.

We've also started a hot leg surge line analysis so that we can get a better idea of the mixing that goes on in the heat transfer in that area.

This final slide is another overview. So we've used this CFD to help augment the one-seventh scale test. We've looked at them together, and we've dome up with a whole new set of mixing coefficients and re-circ ratios and things like that to input into SCDAP/RELAP. That's been done. The ZION work that he'll present has these new coefficients.

We've got a much better understanding of the interplenum flow mixing behavior, tube-to-tube variations, as well as the effect of tube leakage, which was questioned in the past, and this analysis of the CE plant indicates some different mixing, and we're starting up a process of feeding that into SCDAP/RELAP, and we'll go from there.

DR. KRESS: The implications of that are it's more likely to fail the tubes than the hot leg surge?

MR. BOYD: Yeah, I don't want to jump the gun, but if you've got temperatures in some tubes that are on a normalized scale 95 percent effectively the hot leg temperature, so that you've got a big, thick hot leg wall seeing essentially the -- now, these are entrance temperatures. There's some reduction in the tube sheet, but the point is that it is significantly hotter, and it's going to have to be worked through in an integral fashion.

But my guess would be it may be an easier thing to calculate.

CO-CHAIRMAN WALLIS: You know, I've run out of superlatives to describe what you've done. I mean, you have not only done some very good work, but you presented it extraordinarily well.

MR. BOYD: Thank you.

CO-CHAIRMAN WALLIS: And the way in which you respond to questions indicates that you know what you've done, and you also know a lot more than you present. And I just wish that all of the staff could do the same thing.

MR. BOYD: Thank you.

CO-CHAIRMAN WALLIS: It's a real pleasure. It's one the best presentations I've ever heard in front of the ACRS. It really is.

Thank you.

DR. KRESS: Agreed.

MR. BOYD: Thank you. I'll take a tape of that.

(Laughter.)

CO-CHAIRMAN FORD: For your next performance review.

We'll recess for a quarter of an hour. Be back here at 11 o'clock.

(Whereupon, the foregoing matter went off the record at 10:46 a.m. and went back on the record at 11:03 a.m.)

CO-CHAIRMAN FORD: I'd like to come back into session.

Joe, would you like to introduce your next presenter?

MR. MUSCARA: Well, it's essentially a follow-up to the thermal hydraulic work. Don Fletcher will be providing the next presentation.

MR. FLETCHER: Thank you, Joe.

CO-CHAIRMAN WALLIS: Is this the only thing we have before lunch?

MR. FLETCHER: I'm sorry?

CO-CHAIRMAN WALLIS: Is this the only presentation before lunch? Or I just want to keep track.

MR. MUSCARA: Yes.

MR. FLETCHER: Yes.

CO-CHAIRMAN WALLIS: So all of these other characters are not going to show up? We don't have Lynn Ward. We don't have -- it's just your presentation?

(Laughter.)

CO-CHAIRMAN FORD: I've just been reminded that we do have to stop sharply at 11:45 because there is a PMP Committee meeting at that time.

MR. FLETCHER: So you would like to get through --

CO-CHAIRMAN FORD: Can you forego PMP for a bit?

CO-CHAIRMAN WALLIS: It depends how interesting it is here.

CO-CHAIRMAN FORD: Okay. Just keep going, Don.

MR. FLETCHER: Okay. I will try to give you the 45 minute version if at all possible.

We have covered some of the ground in here already. The purpose of this analysis is to evaluate the progression of PWR station blackout/severe accidents to determine whether the steam generator tubes are expected to fail prior to the failure of other reactor coolant system components, the idea being that if the steam generator tubes fail before the hot legs or surge line, then you have a release to the steam generator, which can then go out of the steam generator safety valve source through a break on the secondary side to the atmosphere directly.

So the risk is, therefore, affected by the order at which things fail.

The work we're doing with SCDAP/RELAP 5 is centered on the ZION plant, which is a Westinghouse four loop plant, and the Calvert Cliffs 1 plant, which is a CE plant.

We are looking at a base case accident event scenario that is based on what was called the TMLB prime station blackout event, which is a loss of off-site power, following by the failure of all diesel generators to start and the failure of the turbine driven auxiliary feedwater to start, and an additional failure that was not included in TMLB prime, that is, we have a failure of one steam generator PORV valve such that one of the steam generators blows down shortly after the accident begins.

So the accident leads to a core dry-out and a heat-up of the coolant system at a high reactor coolant pressure, with one of the steam generators secondary depressurized, and the other three steam generators essentially remaining at pressure, roughly 1,000 psi.

You're all heard about RELAP 5 before. It's a six equation code conservation of mass, momentum, and energy with the steam water model, with also capability to handle a noncondensable phase that's tracked along with the steam.

The SCDAP part of this code models severe accident behavior, such as fuel rod heat-up, oxidation processes, fuel rod ballooning and rupture, fission product release, melting of fuel, flow of fuel, freezing of materials after it has been melted and flown inside the reactor vessel, and also the creep rupture failure of structures.

The code versions we're using are listed on the bottom of the page there.

Actually there's quite a bit of background on this. It has been going on for a number of years at several different organizations. The Idaho National Engineering Laboratory developed SCDAP/RELAP

5 system models for several plants of which ZION and Calvert Cliffs were two, and analyzed this same accident, the TMLB stuck open steam generator PORV event, with a variety of accident variations as well.

They've looked into sensitivities to such things as steam generator tube leakage, PORV --

CO-CHAIRMAN WALLIS: Does INEL have a model for this counter current flow in the hot leg --

MR. FLETCHER: Yes.

CO-CHAIRMAN WALLIS: -- and the plume and the steam generator and all of that sort of thing?

MR. FLETCHER: Yes. The model that I am using was developed at INEL. The basis of the model was from there. It has been --

CO-CHAIRMAN WALLIS: -- at least at some crude level the phenomena that we heard about from Chris?

MR. FLETCHER: Yes.

CO-CHAIRMAN WALLIS: Okay.

MR. FLETCHER: And I will attempt to explain to you how what Chris has said fits into the RELAP 5 scheme so that you will understand what we're doing.

ISL has also evaluated a number of sensitivities to such things as time step size. Each structure meshes and so forth, and then ISL also developed this idea of the plume being represented using this nondimensional temperature ratio, which is essentially a mixing of the steam temperature coming up the hot leg and the steam temperature coming back through the cold steam generator tube returns.

And then, of course, you have just heard Chris' on the CFD work, which fits into this analysis.

The next few slides discuss the summary of the current work scope that we were doing at ISL. Task 1 is an updated base case calculation which has been completed. This establishes a new reference case for the project, and I will summarize today the results of that case.

Task 2 is our sensitivity studies that we're doing to evaluate the effect on the results of variations in plant configuration, operating parameters, natural circulation, mixing process variables, and other model parameters.

We are going to use the results of these sensitivity studies to determine which are the appropriate independent variables to be looked at, an uncertainty study that's going to follow very shortly.

This task is nearing completion. I'll give you preliminary results today for everything that has been completed to date.

Task three is an uncertainty study which we've not yet started, except we've looked a little bit into how we might do it. We will evaluate the uncertainty in the updated base case results. We're currently considering using a Monte Carlo response surface method similar to what was used in the code scaling applicability and uncertainty study.

For the response parameter, we're considering the use of a Larson-Miller tube stress multiplier as the parameter. This parameter is used in SCDAP/RELAP 5 to determine whether the tubes fail before or after the hot leg research line, and I'll explain that in a little bit.

The creep rupture model in SCDAP/RELAP 5 is based on this Larson-Miller correlation, and it has in it a best estimate response for nondegraded tube creep rupture.

CO-CHAIRMAN WALLIS: Can it handle this fluctuating temperature type of thing?

MR. FLETCHER: I believe it can. It works by calculating on it -- during the calculation itself, it comes up with the extent of the life, the creep rupture life that has been extended, and when it gets to 100 percent of life, then the tube is assumed to fail.

DR. KRESS: It's developed for transient temperatures. So it can handle fluctuations.

CO-CHAIRMAN WALLIS: Now, can I ask you about this tube? You've got this tube sheet, and the tubes are attached and some of them are hot and some of them are cold.

MR. FLETCHER: Yes.

CO-CHAIRMAN WALLIS: And then they go up to these support plates which we understand now are locked on the tube. So the tubes are cold and hot. There's thermal expansion and all of that which is trying to push against this locked support plate.

MR. FLETCHER: Yes.

CO-CHAIRMAN WALLIS: And are all of those kind of stresses factored into the --

MR. FLETCHER: No. Let me say the calculation we're doing here is just to scope the --

CO-CHAIRMAN WALLIS: Somebody is going to look at that.

MR. FLETCHER: Absolutely.

CO-CHAIRMAN WALLIS: Maybe Argonne or somebody.

MR. FLETCHER: That is correct. Argonne is going to eventually use the RELAP 5 pressures and temperatures on the inside of the --

CO-CHAIRMAN WALLIS: Because this locking of the support plates to the tubes may be great for the steam line break we heard yesterday, but if you're doing it in this situation, it's imposing some boundary conditions on the thermal expansion and contraction of these tubes, which may not be desirable.

MR. FLETCHER: That is correct. I am not trying to represent what RELAP 5 is using here for the creep rupture calculation as the one that will be used in this analysis. I'm only using it as a scoping tool at this point to determine where we are with respect to the steam generator tube failure.

DR. KRESS: It doesn't recognize cracks or defects.

MR. FLETCHER: No. Well --

DR. KRESS: Just pressure internally and the temperature gives --

MR. FLETCHER: The correlation itself is based on pristine, nondegraded material, and we will in our calculations put a stress multiplier on that.

CO-CHAIRMAN WALLIS: But you need to know the stresses in that, don't you? And if there's this thermal count, thermal expansion pushing on the --

that's going to effect --

DR. KRESS: That's good for the pressure.

CO-CHAIRMAN WALLIS: It's not -- the actual stress doesn't come into it at all?

DR. KRESS: No, it's hoop stress (phonetic).

CO-CHAIRMAN WALLIS: It doesn't make a difference?

DR. KRESS: I doubt it. I think --

CO-CHAIRMAN WALLIS: It does in the failure criteria.

MR. MUSCARA: I think yesterday we showed that for the axial it doesn't matter a great deal. It might matter for the circumferential cracks. Your primary system component evaluation, we are doing a comprehensive, 3D finite element analysis. We haven't done that yet for steam generator tubes, but I'm not sure it's necessary at this point.

MR. FLETCHER: The major output of the RELAP 5 calculations that you'll see will be the tube stress multiplier required to fail the tubes, whether it be the average tube or the hottest tube in the steam generator, and the higher the multiplier, the lower the stress that the tube is assumed to fail at, such that if a tube had a multiplier of two on it, that would imply that it actually only had 50 percent of the strength that it would have when it was new material.

So this is just a rough way to look at that creep rupture failure.

For the response surface method, we're going to develop a set of important parameters to use for the uncertainty study based on the sensitivity runs that you'll see today. We're considering the use of a fractional factorial or Plackett Burman experimental design to bring the number of variables and the number of calculations needed to develop the response service down to a reasonable number.

and then we'll use Monte Carlo sampling to obtain probability distribution for the tube stress multiplier that is the critical one.

We plan to use commercial statistical software for this.

DR. RANSOM: How many runs is considered reasonable?

MR. FLETCHER: Well, 50 is probably doable; 100.

DR. RANSOM: Fifteen?

MR. FLETCHER: Fifty, five, oh, is probably doable. When you get beyond that it starts to become less reasonable. These runs are essentially six hours each to date.

DR. RANSOM: Each one is like six hours?

MR. FLETCHER: Yes.

DR. RANSOM: Did you consider the nonparametric statistical methods that show that, you know, the 95-95 confidence level, like 59 runs would be required?

MR. FLETCHER: Can you help me there, Bill?

MR. ARCIERI: My name is Bill Arcieri. I work for ISL, and I've been working with Don on setting this up.

We're looking into what you're talking about, but I think the fractional factorial method has some advantages. One is it allows us for the variables that we might be looking at for the uncertainty study to look at interactions which, you know, could be of interest in gaining insight into how the problem responds.

As Don progresses in his talk, he's ending up by the end of his presentation with five parameters that will be evaluated, and if that holds up, then it would be 32 runs, which I think would help us, you know, keep our runs within some reasonable limit.

Obviously if we had more parameters, the number of runs goes up.

DR. RANSOM: All right. The one advantage of the non-parametric is that you can have as many parameters as you want or need. Anyway, I was just curious to know if you had considered that.

CO-CHAIRMAN FORD: Could I go back? I was out of the room when you discussed task two, which relates to the question that Graham brought up. This response parameter for materials degradation, will it be due to creep or creep fatigue interactions or what other material degradation?

I don't know whether it should be you or Joe who should be answering this question, but to what degree of qualification have these failure algorithms been subjected? Presumably the algorithm looks something like failure time or failure probability as a function of material, stress conditions, et cetera, temperature.

Has that algorithm been qualified against data?

MR. MUSCARA: For the steam generator tubes.

CO-CHAIRMAN FORD: Yes.

MR. MUSCARA: We conducted extensive work on modeling the creep failure with the tubes and, you know, it has been validated through testing.

CO-CHAIRMAN FORD: Okay, and so that is pretty well -- if I read the last sentence on your previous page, "task nearing completion. Preliminary results are summarized in this presentation." Is that correct? We'll be seeing --

MR. MUSCARA: Those are two separate activities. Evaluating the behavior of steam generator tubes in severe accident conditions, we've developed procedures and methods and validated with a tremendous amount of data. What they're using, it's somewhat different than what we're using, but for the program the results that you intend on paying attention to are the results based on our model.

CO-CHAIRMAN FORD: Okay.

MR. FLETCHER: The obvious answer is if we make SCDAP/RELAP 5 calculations and we find out that it makes a difference on the stress for the tubes. The question is: how significant is that?

And all I'm doing at this point is to try to scope the effect of that issue for the results of my calculation.

MR. MUSCARA: The results will start getting closer to what we're predicting based on this stress multiplication factor they use, which is very similar to the MNSP formulation that we have in our correlations.

CO-CHAIRMAN FORD: Okay.

MR. FLETCHER: Task four is a Cormell (phonetic) progression sensitivity study. This is starting at this time, and we're going to look at the sensitivity results to the oxidation rate, to the control rod guide tube interaction model that also affects relocation, melt and relocation of the control rod model.

CO-CHAIRMAN WALLIS: Well, let me ask you this. We saw this detailed model of the steam generator. In the core heat-up you have a cold stream pouring out of this hot leg.

MR. FLETCHER: Yes.

CO-CHAIRMAN WALLIS: Like sort of water out of a pipe.

MR. FLETCHER: Yes.

CO-CHAIRMAN WALLIS: Or wine out of a bottle onto whatever is there, the coil, upper plate or something.

MR. FLETCHER: Yes.

CO-CHAIRMAN WALLIS: And it goes down into the core and recirculates and so on. It would seem that how hot the hottest part gets is a bit like the question in the steam generator because you've got this natural circulation driven thing going on in the core.

MR. FLETCHER: Absolutely.

CO-CHAIRMAN WALLIS: So how do you do that without doing CFD there?

MR. FLETCHER: Well, of course, RELAP 5 is set up to calculate circulations, including buoyancy driven circulations, which is what we have here, and I will show you the results here of what RELAP 5 is doing in the core. We are getting what you would expect, a down flow in the peripheral channels of the core, an up flow in the center channels of the core.

CO-CHAIRMAN WALLIS: It seems to me Chris showed us nicely that you get mixing in that. The jet that comes out of the hot leg into the steam generator has cold fluid impinging on it, and there's a lot of mixing there so that that cools down.

The cold water coming out of the hot leg mixes with the hot -- the cold steam coming out of the hot leg mixes with the hot steam in the vessel in the same way.

MR. FLETCHER: I understand what you're saying. We're not applying a mixing process in the

RELAP 5 model at the hot leg, the vessel connection. We are not doing that at this time.

Task five is for iterative support to the PRA. We provided them with the base case results here, and they are analyzing those at this time. As their needs for thermal hydraulic data information on how systems might behave in order for them to do their bidding process, we will be talking with them, and performing additional calculations if needed in task six.

And in task seven is the Calvert Cliffs analysis that is starting right now.

Slide 11 is probably the one that was referred to as the cartoon earlier that didn't make sense.

CO-CHAIRMAN WALLIS: It doesn't make sense.

MR. FLETCHER: And what it is intending to imply -- and this is an old diagram, by the way. This is one that I just picked up and put in here because I thought it would clarify things, but apparently it did not.

CO-CHAIRMAN WALLIS: Actually it makes them worse.

MR. FLETCHER: Yes. What we say is there

are really two modes of operation for natural circulation of the loop. The one on the left is the normal direction flow where steam would flow around the loop, back through a vacated loop seal into the coal leg and then down the downcomer of the vessel.

The situation on the right is this recirculating mode, if you will, where we have a split hot leg with hot steam flowing across the top of the hot leg, some of it going up through the pressurized roof if the valve is opened, over to the inlet plenum of the steam generator, then the recirculation around through the tubes.

And in order for this to happen you have to have a loop seal that is filled with water.

CO-CHAIRMAN WALLIS: But to go back to this figure here, in reality you have four loops in some plants, and you were saying earlier that they may all operate in the right-hand mode together.

MR. FLETCHER: No.

CO-CHAIRMAN WALLIS: I was getting the impression that you could have three of them operating in the right-hand mode and one operating in the left-hand mode, in which case you'd have to worry about how will these different things affect the circulation and the core. There's no plate down the middle. It's all interaction.

MR. FLETCHER: No, I've given you the wrong impression. The way the model works is all four loops are modeled independently.

CO-CHAIRMAN WALLIS: Right, and some of them may be in one mode and some of them may be in the other.

MR. FLETCHER: Yes, and that decision is made independently during the calculation for each of the four loops.

CO-CHAIRMAN WALLIS: So you have an interesting circulation pattern in the core with sort of three of them behaving one way with this cold fluid pouring in and out of these pipes and the other one the cold fluid is coming in from the bottom. So it's going to be quite a different --

MR. FLETCHER: No, I still haven't clarified this.

CO-CHAIRMAN WALLIS: Oh, okay.

MR. FLETCHER: The code calculations that we run show the recirculating mode in all four loops all of the time.

CO-CHAIRMAN WALLIS: So we don't need to worry about left-hand side.

MR. FLETCHER: You don't need to worry

about the left-hand side. The left-hand side, however, is how the model looks before the point when the core uncovers and we get hot steam in the top of the system.

In other words, we use a representation similar to what's on the left-hand side during the early part of the transfer.

CO-CHAIRMAN WALLIS: So you've got water.

MR. FLETCHER: Yes.

CO-CHAIRMAN WALLIS: Ah.

MR. FLETCHER: Yes.

CO-CHAIRMAN WALLIS: You see, it shows steam here.

MR. FLETCHER: It does, and should the loop seal clear in any of the loops, then we would refer to the nodalization that would give you the flow through.

DR. RANSOM: Does the loop seal ever clear?

MR. FLETCHER: Not in the calculations we've done to date, although that's certainly a possibility once we change accident scenarios, if we have depressurization events that are significant enough. We could have the loop seals void by flashing late in the transient.

CO-CHAIRMAN WALLIS: Once you show a RELAP picture like this, it looks awfully like CFT.

MR. FLETCHER: It does.

CO-CHAIRMAN WALLIS: Everything is sort of connected to everything else, and it's neighboring boxes.

MR. FLETCHER: Okay. In the vessel we're modeling it with five channels with a radio power profile across those channels with the hottest channel in the center. We also have a nodalization scheme in the upper plenum that allows hot steam to rise out of those channels and flow over towards the hot legs, and in fact, in the calculations, what we see is the cold steam flow returns, flows down the peripheral channels, and then flows upward through the central channels with a steam flow going up to the top of the upper plenum in the center of the vessel and then flowing over to the hot leg.

CO-CHAIRMAN WALLIS: Well, how about variations around the periphery? Have you got a cold --

MR. FLETCHER: No, we're not modeling any azimuthal variation at all.

CO-CHAIRMAN WALLIS: But isn't that what happens because you've got hot legs coming in at specific places with cold fluid and the hot fluids coming up elsewhere? So you've got a three dimensional flow going on.

MR. FLETCHER: Which we've modeled as two dimensions.

CO-CHAIRMAN WALLIS: But it is three dimensions, definitely is. You've got cold areas of down flow in the core underneath the hot legs, and then you get up flow elsewhere. So if you looked around the circumference, you'd have areas of down flow and up flow the same way as you do in the steam generator.

MR. FLETCHER: I agree that's a possibility we have not --

CO-CHAIRMAN WALLIS: You have a cold pool. You have a cold area. You have a certain number of tubes in down flow and certain number up, just like the steam generator.

MR. FLETCHER: What you're saying is true, and the loops would be asymmetric, but not as asymmetric as you said a while ago when you thought that only one of the loops was in the recirculation mode. They are all four in the recirculation mode.

CO-CHAIRMAN WALLIS: So a quarter of the core being different, yeah.

MR. FLETCHER: That's correct.

CO-CHAIRMAN WALLIS: Within that quarter piece.

MR. FLETCHER: That's correct.

CO-CHAIRMAN WALLIS: So maybe we should get Chris to do this with CFD.

MR. FLETCHER: I thought I would spend a little time on two slides down on slide 14, which is the layout of the loop model showing the split hot leg nodalization.

Let me say we're allowing RELAP 5 to calculate the behavior in this loop except at certain locations, and those locations are related to the steam generator inlet plenum, which is shown as Volumes 105, 106, and 107.

CO-CHAIRMAN WALLIS: I'm trying to think back to -- I'm sorry -- my previous this. This is like the steam generator. So you have a certain number of tubes in the core with down flow and a certain number with up flow, just like in the steam generator, or am I wrong?

In that case, I'm not quite sure how RELAP handles it. You don't know how many tubes you've got in down flow and how many in up flow. How does it do that?

MR. FLETCHER: Well, as the cold stream enters the peripheral channel of the core --

CO-CHAIRMAN WALLIS: It goes down.

MR. FLETCHER: -- it goes down. There's nothing --

CO-CHAIRMAN WALLIS: It forces it to go down, but does it go down on the next one, too? You still have sort of in a much reduced configuration. You have five passengers. It can go down in two or 103.

MR. FLETCHER: What we see is the outer two channels are in down flow.

CO-CHAIRMAN WALLIS: So you have that. At least you have feature.

MR. FLETCHER: And the inner two channels are in up flow, and the center channel goes down at the top and then flows up through the bottom and --

CO-CHAIRMAN WALLIS: Okay. So you've got something a bit like Chris' picture, but you've only got five tubes to represent the core --

MR. FLETCHER: Yes.

CO-CHAIRMAN WALLIS: -- instead of the however many there are.

MR. FLETCHER: Right. We also have an eddy flow in the upper plenum. We have a flow that goes through the upper plenum towards the hot leg, and then another one that returns backwards in the lower part of the upper plenum.

Moving on to the loops, we've modeled the split hot legs as completely separate hydraulically. There's no communication between the two hydraulically as you go down the length of the hot leg.

The only place we're really forcing the solution is based upon the CFD results over at the steam generator inlet plenum, and by forcing the solution we're doing it using what's called C sub V values, also know as flow coefficient methods, where the flow through the junction is defined as a function of the delta P across the junction.

So we're in essence saying that if I have this delta P, I'm going to force the flow to be this, other than allow the code to calculate what the flow might be through there. So by doing this and matching, tuning these numbers, tuning these C sub Vs until we agree with the recirculation ratio mixing fractions and steam generator powers that we have, we can mimic, if you will, the CFD results for the behavior that's actually going on there.

But other than that, RELAP 5 is doing its job as far as calculating things. So RELAP 5 is being used to calculate the buoyancy driving head associated with the different temperature fluids in the upper and lower hot legs, and the buoyancy driving heads associated with the steam generator tubes, one flowing in the forward direction and one flowing in the reverse direction.

DR. RANSOM: The number of tubes that you've said is from the CFD calculation, I gather.

MR. FLETCHER: That's correct.

DR. RANSOM: So you pick so many in up flow and so many in down flow.

MR. FLETCHER: And the selection is 50-50. Previously --

DR. RANSOM: Fifty-50?

MR. FLETCHER: Fifty-50. Previously, it was 53-47, I believe, up flow/down flow.

DR. RANSOM: I thought the results we saw indicated a much smaller fraction in up flow.

MR. BOYD: That number changes with the heat transfer rate. I showed you some with the high heat transfer rate. It was 38 percent, and the heat transfer rates that we feel are more appropriate, we got 46, 47, and 48 percent. The data showed 50 percent, and we had to stay in that range. We chose the 50. In the end we were close to it with the CFD, and then we're doing sensitivity studies to show that it's not all that important in these kind of differences anyway.

CO-CHAIRMAN WALLIS: Well, what's important are the temperatures. Now, we saw for the steam generator you had -- what is it? -- you had maybe 1,000 degrees there and maybe 1,200 coming out of the core or something?

MR. FLETCHER: Yes.

CO-CHAIRMAN WALLIS: And there was missing in that plenum. Now, if you've got 1,200 coming out into the hot leg, that means that you've got some mixing in the upper plenum. So maybe you've got 1,400 there, and then somewhere in the core you've got other temperatures.

You need to know that temperature in the core presumably because you're beginning to get degradation of the core.

MR. FLETCHER: Yes, absolutely.

CO-CHAIRMAN WALLIS: So you need to be careful about this, that the flow distributions and the mixing right in the core, as in the steam generator so that you don't blindly say that, you know, whatever is coming out of the core in temperature is what's going into the hot leg because it isn't, because it's mixing with some of the --

MR. FLETCHER: It's mixing in the upper plenum, and RELAP 5 will do that.

CO-CHAIRMAN WALLIS: But that will mean that the steam generator is colder than it would have been, and so it's less likely to pop.

MR. FLETCHER: That's true.

CO-CHAIRMAN WALLIS: And the core is more likely to fail.

MR. FLETCHER: So if we had a mixing process going on at the hot leg vessel connection, it would make things better from a steam generator --

CO-CHAIRMAN WALLIS: And I think this is where there has to be a perspective of the whole issue. You're worried about does the steam generator pop before the surge line, but also the question is does the core degrade before either of these.

MR. FLETCHER: Right.

CO-CHAIRMAN WALLIS: And by how much because if it started to lose its geometry, then you have to do something about the heat transfer.

DR. KRESS: I think the chances of it losing its geometry are small compared to --

CO-CHAIRMAN WALLIS: Is it going to release hydrogen?

DR. KRESS: It's going to fail the hot leg in the early tubes first.

CO-CHAIRMAN WALLIS: Well, you're saying that as a statement. Do you know the temperature?

DR. KRESS: I've seen a lot of calculations.

CO-CHAIRMAN WALLIS: So you know the temperatures in the core.

DR. KRESS: You have to get pretty high temperatures.

CO-CHAIRMAN WALLIS: Okay. Thank you.

DR. KRESS: Before they start changing.

MR. FLETCHER: The base case calculation will show you the core does not actually melt.

CO-CHAIRMAN WALLIS: Do you get oxidation of the cladding?

DR. KRESS: You start oxidizing, but you don't really run into the --

CO-CHAIRMAN WALLIS: That's not a significant heat source?

DR. KRESS: It can be, but --

MR. FLETCHER: The oxidation source is significant.

CO-CHAIRMAN WALLIS: Oh, so you do have to get that right.

MR. FLETCHER: Yes, we do.

CO-CHAIRMAN WALLIS: Oh, okay.

MR. FLETCHER: The peak oxidation power is 335 megawatts, roughly ten percent of normal core power and roughly ten times decay heat.

CO-CHAIRMAN WALLIS: So it's dominant.

MR. FLETCHER: It's dominant, yes.

CO-CHAIRMAN WALLIS: Better get it right.

MR. FLETCHER: Got to get it right.

The point I wanted to make on the steam generator tubes is that RELAP 5 is being used to calculate the buoyancy driving head there, the steam temperatures inside the tubes, and you really have two mechanisms going on there. The hot steam is rising into the forward flowing tube and is being cooled as it goes along, and it continually is being cooled all the way over to the outlet plenum.

And then there is a similar cooling process going on from the outlet plenum back to the inlet plenum. So you really have a differential buoyancy going on here where you have a difference in temperatures between the tubes on the up flow side that helps you, and you have a different temperature on the down flow side that actually works against you, and it's the difference of those two terms that really defines how fast this flows.

DR. KRESS: How your heat sync is strictly the metal in the --

MR. FLETCHER: On the secondary side. As you can see, we've modeled the downcomer as one pass on the right-hand side there, one dimensional, and then the boiler is one dimensional up there as well. So there is a steam flow that RELAP 5 calculates around that loop in the secondary side.

We do have heat loss off the outside of the shell, as well, which is a fairly thick component. So there is some ultimate heat sync out there.

DR. KRESS: The natural convection into the --

MR. FLETCHER: Yes, yes. But the essence of what we're looking at here is really very fast heat-up that is driven by the oxidation in the core, and the questions is how does that heat spread out into the components, out into the legs and out into the steam generator, and the heat-up rate is very rapid, and so things like time constants to get heat out there, the mixing that can go on at the inlet plenum can significantly moderate the heat that the steam generator tubes see.

CO-CHAIRMAN WALLIS: The mixing in the

upper part of the reactor and moderate the heat of the hot leg.

MR. FLETCHER: Absolutely, it could, and we're not modeling it.

CO-CHAIRMAN WALLIS: So that's the take-away, I think.

MR. FLETCHER: Yes, right. I hear you.

The next few slides describe the model modifications that were made since the previous base case. I'll hit only the major ones.

We've added reactor coolant system heat loss to the containment from the external surfaces from the primary and secondary coolant system. We've added a 21 gpm pump seal leakage in each of the pumps. We added a counter current limiting model at the pressurizer to surge line tank connection which was not in the previous --

CO-CHAIRMAN WALLIS: What is gpm again? This is that weird unit that means mass flow?

MR. FLETCHER: It means volumetric flow at some --

CO-CHAIRMAN WALLIS: Unspecified condition?

MR. FLETCHER: Right. It is a dilemma, and I ran into the dilemma. What I decided to do is put in a brake size that gave me 21 gpm volumetric flow at the initial point and then left the area the same throughout.

CO-CHAIRMAN WALLIS: This is gpm at room conditions or reactor conditions or gpm or steam or what?

MR. FLETCHER: This would be gpm of water at the time the break opens up, which is early in the event.

CO-CHAIRMAN WALLIS: So it's about half the density of water in that bucket at room temperature or something like that. It's not like gpm that comes out of a faucet.

MR. FLETCHER: No, it's gpm of reactor coolant system temperature water, 550.

CO-CHAIRMAN WALLIS: So it's a lot less dense than cold water.

MR. FLETCHER: Yes.

CO-CHAIRMAN WALLIS: Please do away with this unit. It's so confusing.

MR. FLETCHER: Okay. We've changed the tube plugging assumption from 15 percent to ten percent, which is the middle of the expected range. We've added thermal radiation modeling in the hot legs. The previous model did not have wall-to-wall radiation between the upper hot leg wall and the lower hot leg wall.

CO-CHAIRMAN WALLIS: Steam generator radiation must be important. You've got pretty stagnant steam on the outside. You've got hot tubes, and radiation. I mean, even when we're sitting here the radiation from you is about equivalent to your loss by natural convection in this room. So do you do that in the steam generator? Do you model all radiation between tubes?

MR. FLETCHER: No. Let me specify the --

CO-CHAIRMAN WALLIS: I would think that would matter.

MR. FLETCHER: Well, first of all, we only have a single tube.

CO-CHAIRMAN WALLIS: Oh, okay.

MR. FLETCHER: Or two tubes. So we're not trying to model the details of what's going on there.

What we've done is we've added wall-to-wall radiation for the upper and lower hot legs. We've also added steam-to-wall --

CO-CHAIRMAN WALLIS: Excuse me. If radiation out from the tubes in the steam generator were the dominant heat transfer mechanism, then the middle would be hotter than the outside.

MR. FLETCHER: Absolutely.

CO-CHAIRMAN WALLIS: If they all have the same natural convection heat transfer coefficient, you predict them all to be about the same. So it matters what the mechanism of heat transfer is in that steam generator.

MR. FLETCHER: Well, and one of the studies that we've looked at is what is the heat transfer coefficient on the outside of the tubes. What are the sensitivity of the results to that?

CO-CHAIRMAN WALLIS: If radiation dominates, then you have a different problem. You have radiation from a tube to the tubes around it to the tubes around that in a matrix.

MR. FLETCHER: Right.

DR. RANSOM: Well, if you ignore the radiation that's a more conservative assumption, I believe.

MR. FLETCHER: That's true.

CO-CHAIRMAN WALLIS: Well, let's not get too conservative. Yeah, the more realistic you can be the better. Yeah, I agree that you might be conservative.

MR. FLETCHER: The steam-to-wall radiation we're modeling on the inside of the reactor coolant system, on the inside of the steam generator tubes, but not on the outside of the steam --

CO-CHAIRMAN WALLIS: It doesn't help to be conservative Vic because the question here is which pops first, the steam generator or the hot leg, and then if you arbitrarily don't let the heat get out of the steam generator, you're going to get too hot, and you're going to arbitrarily make it pop first, which is not right. It's a --

DR. RANSOM: Well, from my understanding, the steam generator tubes rupturing first is worse.

CO-CHAIRMAN WALLIS: Yeah, okay.

DR. RANSOM: A bitter source term. So really it's like an error in the direction of I would say a more conservative result.

CO-CHAIRMAN WALLIS: But, again, Chris showed that when you get more heat transfer, you get less circulation. It's a kind of strange thing. So I'm not sure which way it would go. So let's be realistic if you can or as realistic as you can.

MR. FLETCHER: We've changed the forward and reverse flow split from 53-47 to 50-50. We've revised the inlet plenum mixing parameters to those that Chris feels best represent the full scale Westinghouse steam generator.

CO-CHAIRMAN WALLIS: What's this forward-reverse ST tube flow split?

MR. FLETCHER: The model we have has two --

CO-CHAIRMAN WALLIS: The fraction of the tubes that are --

MR. FLETCHER: Exactly, that are forward flowing and reverse flowing.

CO-CHAIRMAN WALLIS: Up and down?

MR. FLETCHER: Yes. We've changed the modeling of the mixing parameter assumptions to agree with the CFD results. We've also added a hot tube to steam generator one, which is the steam generator in the loop containing the pressurizer and also containing the stuck open PORV. So we're doing an on line calculation of a single hottest tube in that steam generator, representing the hottest temperature from the CFT results, which is the .625 normalized temperature.

So we're using the RELAP 5 calculated hot leg temperature.

CO-CHAIRMAN WALLIS: So in the previous slide you put in these numbers like .87, .0 -- that came from the Westinghouse thing, but we know that in something like the CE you get different numbers.

MR. FLETCHER: That's correct, and for the CE model the numbers will be changed.

CO-CHAIRMAN WALLIS: And you know that they are, in fact, somehow influenced by what's going on in the whole system. You've pulled them out of Chris' work, but in fact, if you could incorporate his calculation with your calculation as an interface, you might find that you need to calculate these things rather than just having a target value because I don't know what can happen in a -- you know, he already showed that in the real Westinghouse thing, you don't have a symmetrical. So you get these strange things happening.

MR. FLETCHER: That's correct.

CO-CHAIRMAN WALLIS: You know, it might well be that you have to calculate. You're better off, but we don't know how important this is yet for the PRA and all of that. I think when we know that, we might need to go back and sharpen your pencil on these 87s and 81s.

MR. FLETCHER: Okay. There's a slide that shows the agreement between the calculated values and the target values, which is in good agreement, and another slide that shows the comparison of the plant steady state data and the RELAP 5 calculated data, and that's in excellent agreement.

And there's a sequence of events that I'll hit the high points on. At time zero we have the station blackout event initiation. We lose AC power. We have reactor and turbine trips, reactor coolant pump trips.

CO-CHAIRMAN WALLIS: I'm puzzled by this target value. Didn't you input some of the .81s and things from --

MR. FLETCHER: We're back to the word "input" being confusing. We have a target value for the mixing fractions and the re-circ ratio and the steam generator power, but the code doesn't actually have an input for those values.

What is done is you adjust the flow coefficients.

CO-CHAIRMAN WALLIS: Oh, you fudge the flow coefficients.

MR. FLETCHER: Right, and not only that. It's an iterative process, that if you want to change one of those values, you end up changing others at the same time. So it's a manual operation to come up with the adjustments needed to match the data, and that's why we're off a little bit on some of these.

CO-CHAIRMAN WALLIS: Do you have 60 slides or something? Am I right?

MR. FLETCHER: I do.

CO-CHAIRMAN WALLIS: Well, 60 slides takes you two and a half hours to go through, rule of thumb, two and a half.

MR. FLETCHER: How would you like to proceed?

CO-CHAIRMAN WALLIS: Go ahead.

MR. FLETCHER: Okay. The sequence of events is given here. The steam generators dry out at 1,600 seconds for the generator that has the stuck open valve, at 5,500 seconds for the other three steam generators.

We then have a period of continuing PORV cycling where the valve open and closes and relieves the primary pressure because there's no other heat sync.

At 9,062 seconds, the steam at the core exit begins to super heat. We've uncovered the top of the core, and this is when we change the model to include the split hot leg representation.

Shortly thereafter, at 10,400 seconds, we have the onset of fuel rod oxidation. The pressurizer empties at 10,600 seconds. We have control rod rupture, and then at 12,240 seconds, I have the first creep rupture failure of the steam generator one hottest tube, and probably the best way to say this is this is a tube that's degraded to roughly 15 percent of its original strength, and we're applying the hottest steam temperature expected to that tube.

So that is the worst possible case for a steam generator tube rupture.

CO-CHAIRMAN WALLIS: You don't have any rupture of surge line or anything in here at all?

MR. FLETCHER: The surge line comes a little later.

CO-CHAIRMAN WALLIS: It comes later?

MR. FLETCHER: Comes a little later than the absolute worst degraded tube with the hottest temperature.

The oxidation peak, by the way, is right at 13,000 seconds. It's not shown on the list there.

At 13,165 seconds we have the first creep rupture of the first average tube. In other words, this is a degraded tube to 15 percent of its strength, with the average steam generator tube temperature on the inside. It fails slightly before the surge line, which fails at 13,205.

CO-CHAIRMAN WALLIS: Pretty close.

MR. FLETCHER: Pretty close.

CO-CHAIRMAN FORD: Excuse me. When you say "degraded to 50 percent" of its strength?

MR. FLETCHER: Fifteen percent, yes.

CO-CHAIRMAN FORD: Fifteen percent of its strength. Do you mean --

MR. MUSCARA: He's using a stress concentration factor of seven.

MR. FLETCHER: Yes, stress concentration of 7.5.

MR. MUSCARA: You have to put that in context. An M sub P value of 2.3 is equivalent to a tube with a flaw that would fail at three times normal delta P.

CO-CHAIRMAN FORD: Okay.

MR. MUSCARA: So none of those tubes should be in the generator because their legends (phonetic) require that tubes should meet three delta P any time you're in operation.

CO-CHAIRMAN FORD: Right.

MR. MUSCARA: But there's a probability it's there because of inspection reliability, et cetera. So all of that to be taken into account when doing the PRA.

CO-CHAIRMAN FORD: Okay.

MR. MUSCARA: But, I mean, this is a tube that really should not be in the generator if it's that degraded, and if it is there, it shouldn't occur very often.

CO-CHAIRMAN FORD: Okay. I understand. Okay.

MR. FLETCHER: The intent of this is just to scope where we are with respect to failure.

The hot legs fail shortly thereafter.

CO-CHAIRMAN WALLIS: I have a question. These pump seals leak instantly?

MR. FLETCHER: Yes. There were some experiments run at Westinghouse, and it was determined that in a station blackout event, due to the loss of the --

CO-CHAIRMAN WALLIS: Loss of the cooling water.

MR. FLETCHER: -- the cooling flow, yes, that it was almost a certainty that the pumps would leak immediately at 21 gpm was the expected value.

CO-CHAIRMAN WALLIS: You lost your service water, too, in this?

MR. FLETCHER: Yes, you've lost everything that's AC powered.

CO-CHAIRMAN WALLIS: So there's no containment cooling or anything like that.

MR. FLETCHER: No, no. This is very severe accident.

MR. ROSENTHAUL: The 21 gpm is just the normal flow rate. There's no additional failure.

MR. FLETCHER: We will later look at other failures of the pump seals to look at higher pump seal leakage rates.

If you look at the process in time, slide 24 shows that the surge line fails at 13,205 seconds, and if you look at the results by stress multiplier for the average and hottest tubes, you can see for the average tube it requires a stress multiplier of two to fail it before the surge line fails and for the hottest tube, it requires a -- I'm sorry. I said it backwards.

For the average tube it takes a multiplier of five, and for the hottest tube it takes a multiplier of two to fail before the surge line.

DR. KRESS: Can we go back to slide 22 a second?

MR. FLETCHER: Yes.

DR. KRESS: In between the first control rod cladding failure and the first creep up to failure of the hottest tube, is that when you're releasing all of the cesium and iodine?

MR. FLETCHER: No. This is the first control rod failure. That's a control rod. That's not a fuel rod. So you wouldn't be releasing at that --

DR. KRESS: No, but your own set of fuel rod oxidation is 10,406 seconds, and it takes what, about 30 minutes from there to release all of the cesium and iodine?

MR. FLETCHER: I don't immediately have the answer to your question. The peak oxidation was at 13,004, I believe.

DR. KRESS: Oh, oh, okay. So this is a low level.

MR. FLETCHER: This is the beginning of the oxidation. Below that you don't have any oxidation at all.

DR. KRESS: You haven't gone into the run-away oxidation.

MR. FLETCHER: Right. IT's slowly increasing starting at 10,039 and the peak is at 13,000.

DR. KRESS: I was interpreting that wrong. Okay.

MR. FLETCHER: I have a number of slides that show the transient results. I'll hit only the high points. On the reactor coolant system pressure, on slide 25, we originally have a slight depressurization of the RCS as we have steam generator cooling when we still have water in the steam generators, and then late in the event we also have a depressurization that's caused by the pump seal leakage that we're assuming.

Steam generator secondary pressures, we have one that's blow down. The other three remain at pressure. Steam generator masses, you can see how we've lost the water mass from the steam generators fairly early in the event.

PORV flow cycling is continuous after we get out to about 9,000 seconds or so.

The pressurizer level stays elevated as we continue to blow water and steam out of the PORVs on the top of the pressurizer, but then eventually we expel sufficient liquid that the water slumps back down into the hot legs, and we end up draining the pressurizer shortly after 10,000 seconds, which is before we end up with the main heat-up process here.

Looking at the circulations that we have on slide 30, we're looking at the hot and cold average tube flows in steam generator one, which is the affected steam generator, and you can see we have a mass flow rate of maybe ten kilograms per second through those tubes. I'm showing both the hot flow and the cold down flow sides there.

On slide 31, we're looking at the hot leg circulations. We have a mass flow rate of about five kilograms a second through the upper and lower hot leg sections on steam generator one.

And then slide 32 shows the vessel circulation. The black line is the central channel flow, which is upward at roughly it looks like ten kilograms a second or so, and then the red line is the downward flow in the peripheral channel at ten kilograms per second.

Velocities associated with all of these are on the order of a half a meter per second. So it's not a very rapidly flowing system, but we are exchanging mass at about this rate.

Slide 33 shows the oxidation process. The number in the table is when it begins, and you can see the peak is out at 13,000 seconds.

DR. KRESS: So that's about when you releasing the iodine and cesium?

MR. FLETCHER: That is when the release from the fuel rod to the coolant would happen, yes.

DR. KRESS: And at that time, you've only failed -- well, you failed the -- where are the fission products going at that time? That's 13,000. Do you have one steam generator tube rupture that you've --

MR. FLETCHER: But only the most degraded tube and only with the hottest steam temperature.

DR. KRESS: The surge line is failing about that time also.

MR. FLETCHER: Yes, the surge line fails slightly after that.

DR. KRESS: So you've got dual pass in the fission product, but the surge line is probably the easiest path to go in?

MR. FLETCHER: That's correct.

In our model, we're not actually stimulating the rupture of the surge line other than to say when it would happen. We're not looking at the depressurization.

DR. KRESS: You're not looking for a take on depressurization.

MR. FLETCHER: That's correct. We're allowing depressurization to continue to see what the effect on the other tube degradations might be.

MR. MUSCARA: Let me also mention quickly that in the surge line evaluation, it really only uses the pressure stress. In what we'll hear about this afternoon, we're doing a finite element analysis of the entire line.

DR. KRESS: I see.

MR. MUSCARA: So what are the stresses that are taken into account because of thermal stresses.

DR. KRESS: So it may have failed earlier than this.

MR. MUSCARA: Right.

CO-CHAIRMAN WALLIS: So you've burnt off all of the zirconium then after this blip?

DR. KRESS: Basically.

CO-CHAIRMAN WALLIS: You've turned it into oxygen.

MR. FLETCHER: Yes, that's correct.

The essence of the thermal transience shown on Slide 34, these are structural temperatures in loop one. The black line is the surge line. The red line is the hot leg, and then the green and blue lines are the average and hot tube responses.

Now, you can see the temperatures all start up together back there. The hot leg temperature starts up. The surge line is delayed for a short period of time until we lose the last bit of water out of the pressurizer as it's draining.

But then once that water is gone, the surge line temperature rises very rapidly. Of course, the surge line is thinner than the hot leg. So the rate it rises is going to be faster.

CO-CHAIRMAN WALLIS: So it is it dropped when it falls down again? What does it fall down?

MR. FLETCHER: Why does? Oh, at the top? Well, first of all, we go past the oxidation peak and power. That --

CO-CHAIRMAN WALLIS: The other temperatures are still going up.

MR. FLETCHER: No, the other thing is we have heat loss off the outside of the hot legs and on the outside of the surge line, and so the surge line is relatively thin and the heat loss is more effective at cooling it down. These are average structure temperatures.

CO-CHAIRMAN WALLIS: So if it survives the hottest temperature, it's going to survive later? When does the surge line pop?

MR. FLETCHER: The surge line fails at -- I can't give you the temperature it failed at.

CO-CHAIRMAN WALLIS: But it failed, but hasn't it failed by the time its temperature is dropping or not?

MR. FLETCHER: Oh, yes.

CO-CHAIRMAN WALLIS: Yes. Okay.

MR. FLETCHER: Yes, the surge line has failed on the way up here on the steep part of the ramp there.

CO-CHAIRMAN WALLIS: That makes more sense now.

MR. FLETCHER: And if we look at the creep rupture damage indices on the next couple of slides, it compares -- first of all, what this is is the useful life that's been expended going from zero to one. When the curves reach one, that means that the code assumes that this structure has failed. The dashed line is the surge line. The red line is hot leg one, and the other three hot legs are shown together on the trace that follows them.

And if we look at the average tubes, the dashed line, again, is the surge line and the colored curves represent the multipliers from three to five and intervals of one-half. So the red line is a stress multiplier of three, in other words, a degradation to only one-third of its original strength, if I'm saying that correctly.

CO-CHAIRMAN WALLIS: Now, these things

like a surge line and hot leg, they have insulation on them?

MR. FLETCHER: They have insulation on the outside. What we're modeling is a constant H, heat transfer coefficient, on the outside of it, representative of the heat loss at normal operation, and we're just leaving them constant throughout the event.

We also haven't adjusted those heat transfer coefficients based upon insulation being different at different locations. So it's an average look at it.

CO-CHAIRMAN WALLIS: Insulation doesn't deteriorate or fall off or anything before they fail?

MR. FLETCHER: I'm sure it could.

MR. SIEBER: It's metal insulation.

CO-CHAIRMAN WALLIS: It's foil metal.

MR. SIEBER: It's mirror type.

CO-CHAIRMAN WALLIS: Mirror type, but it's a metal.

MR. SIEBER: Sheetmetal.

CO-CHAIRMAN WALLIS: Sheetmetal. So it gets pretty hot, too.

MR. SIEBER: It snaps. Pretty sturdy stuff.

MR. FLETCHER: So slide 36 shows that the surge line fails, the surge line which is the dashed curve, fails between the results for a multiplier of 4.5 and five, the finding being that if you had a tube with a multiple of five or somewhere between four and a half and five, it would fail before the surge line, but other tubes would not.

And if we look at the hot leg we have similar results for multipliers of one, one and a half, and two, and here it shows that the surge line fails before the multiplier tube fails.

MR. SIEBER: How certain are you? You know, you're talking 13,000 seconds to 13,200 seconds. You know, it could go the other way, right?

MR. FLETCHER: Well, the real problem is the heat-up is very rapid, and the question is how are these heat transfer processes going to affect the spread of that heat?

MR. ROSENTHAUL: Can I make a couple of comments, if nothing else because it's a public meeting with a transcript? So I want to get a little perspective going here.

We're looking at a station blackout scenario here. Of course, the PRA will look at a broader scope of events. The station blackout rule had a goal of three times ten to the minus five for a core damage frequency due to all station blackouts, and here I'm talking about a perverse one with just the right set of failure bouts.

So I'm talking about a subset of that three minus five. So I'm talking about a reasonably low probability event.

Then when I'm talking about stress intensity factors that go above two, three, I'm really talking about tubes that should have been removed from service, you know, assuming that the inspection program really does identify them. So, again, I'm talking about a reasonably low probability event, and we shouldn't lose sight of that.

When we see numbers, you know, obviously nothing happens for the first two hours while you're boiling off, and then things get exciting over a relatively short period of time, and we all smile when we see the differences in time because none of us would believe the Larson-Miller model as being able -- and the RELAP -- as being definitive on something is going to go 200 seconds before something else.

And that's exactly what prompted us to do the finite element analysis and hopefully the work from engineering will show bigger differences in time that you can start to believe.

But, no, we're smiling at these.

MR. SIEBER: Well, actually it takes three days from the onset of the accident to get to the point where you start failing these pressure boundaries.

MR. ROSENTHAUL: Hours.

MR. SIEBER: Hours. Okay.

CO-CHAIRMAN FORD: Joe, could I ask a question of you? We should really stop at the very latest within ten minutes regardless of whether we finish this presentation or not. Is it your wish that we just compact the rest of this presentation into ten minutes or it depends on what follows?

Are the next presentations going to be full time?

MR. MUSCARA: My feeling is I don't mind staying late, but if we do this in its entirety, we'll wind up being late this evening.

CO-CHAIRMAN WALLIS: Well, will this PRA really take so long?

MR. MUSCARA: They're all complex, and everybody has more slides than they have time.

CO-CHAIRMAN WALLIS: Okay. They've all got more slides than time.

DR. KRESS: If Bill doesn't mind staying late, I don't think we should mind either.

CO-CHAIRMAN FORD: I agree with you.

DR. KRESS: Why don't we just get it all?

CO-CHAIRMAN FORD: Now we have a noose to the question. Graham has another meeting he has to go to. Do you wish to stop cold now and resume or is there something you want to finish?

MR. ROSENTHAUL: If we're going to stop, this would be a good time to stop. If you would like me to continue, we could do that, too.

CO-CHAIRMAN FORD: Okay. Let us recess until 1:15, which is the time allocated for us to start. So we've got a slightly longer lunch break. One, fifteen, we are in recess until then.

(Whereupon, at 12:01 p.m., the meeting was recessed for lunch, to reconvene at 1:15 p.m., the same day.)

AFTERNOON SESSION

(1:17 p.m.)

CO-CHAIRMAN FORD: I'd like to come back into session, and we'll continue.

Sorry for interrupting you to start with.

MR. FLETCHER: Thank you.

I'm at slide 38, a summary of the base case results and what we've learned so far from them.

Steam generator tube failure margins have improved from what we've seen in previous base case calculations. I'd like to make a comment regarding the RELAP calculation of the creep rupture failure. We're doing this strictly to look at it in a crude way, and we're also looking at multipliers as high as seven, which are tubes degraded so much that they could barely exist at normal operating conditions.

So I wanted to correct perhaps the perception that has been given here, that the first tube failures occur very early with respect to the surge line failure.

The actual stress calculations and tube failure calculations will be done elsewhere with better tools using the RELAP 5 pressures and temperatures as boundary conditions to do those calculations in a much more detailed way than is being done here.

On the other hand, we did want to put in something that would give us some feel for where we are with the thermal hydraulic results. If we just showed you the events and their times, the question would be, well, what does this mean for rupture, and so that's what we're trying to do here, is gain at least a rudimentary understanding of where we are.

CO-CHAIRMAN WALLIS: And we discussed with Chris the business of the maximum temperature and the hottest tube and the steam generator not being the same as the average.

MR. FLETCHER: That's correct.

CO-CHAIRMAN WALLIS: And that it might be some effort to predict that. SCDAP/RELAP doesn't really do that, does it? It gives you an average temperature in the steam generator.

MR. FLETCHER: Well, we actually have an average tube and we have a hot tube that we're modeling. The average tube is just that. It's the average of all of the tubes. For the hot tube, we're taking advantage of the CFD and the Westinghouse one-seventh scale data to give us an idea of what the inlet temperature might be.

CO-CHAIRMAN WALLIS: Okay.

MR. FLETCHER: That's correct, and we have modeled that, but we are modeling only one hot tube. We're not modeling a distribution of hot tubes and so forth.

On the other hand, if we did have good data about what the distribution inlet temperatures might be, we could put in a number of hot tubes with different inlet temperatures.

We have made --

MR. SIEBER: The hot tube changes from minute to minute as the flow distribution changes.

MR. FLETCHER: In the real steam generator that is the case. My model is so crude I only have one hot tube, and I don't know where it is on the tube sheet. I'm just making a worst case calculation.

In fact, all of the creep rupture calculations I'm doing are for the worst case situations. For the tubes I'm looking at the inlet temperature where the steam temperature is the hottest. For the hot leg I'm looking closest to the vessel where the temperature is the highest, and for the surge line I'm looking closest to the hot leg where the temperature is highest.

A major factor in the improvement that we've seen in the tube failure margins has been that we've made changes in the target recirculation ratio and mixing fractions, but that the target steam generator power fraction has not changed.

So what we have is steam generators being more effective than they were before in the original base case because we've tried to make -- we have made mixing fraction changes to make things hotter, and yet because of that we've had to slow down the steam flow to the steam generators to keep the power fraction where it was.

And as a result of that, the hot legs and the surge line tend to fail slightly sooner with respect to the tubes, and therefore, we gain some margin.

And I believe I've covered the information on that.

The last part of the work here is task two, which is the sensitivity studies that we've done to date. We run a series of calculations as variations on the base case to evaluate the sensitivity of the tube failure margin results to various problem variables, including plant configuration and operating parameters, natural circulation process parameters.

And we're going to use the output of this study to decide which parameters are most important to be looked at in the uncertainty study.

And slide 41 shows the full list of what we've done, what we have done and where we are today. The results I'll present are for all except for the last two, which are still in process.

Regarding the sensitivity of results to the steam generator power fraction, the base case is done at a 30 percent value. That's 30 percent of the power being removed to the four steam generators. We will --

CO-CHAIRMAN WALLIS: Doesn't this come out of analysis rather than being used or isn't it --

MR. FLETCHER: No, if you remember, this is the target value that we try to achieve as a result of changing the flow coefficient.

CO-CHAIRMAN WALLIS: So 30 percent of the power goes to the steam generators. The rest of it goes to heat up the core?

MR. FLETCHER: Heat up the core and the hot legs and everywhere else.

CO-CHAIRMAN WALLIS: Doesn't this all depend upon all of these flows and things? You can't sort of impose something. You have to calculate it. If you have better heat transfer in the steam generators, you're going to get more heat out of there. If you have no heat transfer, you get nothing, and this rate should be zero.

So there has got to be something here that's calculated.

MR. FLETCHER: The steam generator power fraction is one of the variables that define the mixing process, and the data indicate that we have a spread from about 25 percent to 40 percent in that value.

CO-CHAIRMAN WALLIS: Is this because you're not modeling what I was talking to Chris about, the way in which the flow in the hot leg really is dependent on the buoyancy effect at the entrance?

I think it may be that you have to invent something because there's a little piece of physics missing about what determines the flow there.

MR. FLETCHER: Well, we talked about that at lunch and what we might do, and in fact, I think we'll add a sensitivity study looking at some mixing that goes on at the hot leg to reactor vessel connection just to see what the effect there might be.

CO-CHAIRMAN WALLIS: Well, I think it's more than that though. Again, this is something where maybe you need to work it out because it seems to me you can't just take this ratio. It depends on the whole thing. It ought to be calculated.

And if you're trying to think about how to do it, maybe it's out of place to get the solution to my question now. Just remember that I think it is an important thing to resolve.

MR. FLETCHER: Okay. We adjusted the loss coefficients or the flow coefficients to provide 25 and 40 percent steam generator power fractions and sensitivities. We found the tube failure margin results are moderately sensitive to this. The results are shown on the bottom of the slide there.

For the base case, the tube stress multiplier required to fail the tube prior to the time the surge line failed was five for the average tube and two for the hottest tube, and you can see the results there for the 25 percent and the 40 percent cases.

CO-CHAIRMAN WALLIS: Let me go back to this thing now. If there were no heat transfer from the steam generator, what would happen would be you would be heating up those tubes more.

MR. FLETCHER: No heat transfer from the steam -- you mean you have no heat across the tubes?

CO-CHAIRMAN WALLIS: There's no heat

coming out of the tubes into the outside part, the secondary side.

MR. FLETCHER: Well, then the tubes are not a problem then.

CO-CHAIRMAN WALLIS: They'd heat up. No, on the outside there's no heat leaving them.

MR. FLETCHER: No heat leaving; adiabatic on the outside.

CO-CHAIRMAN WALLIS: Right, because you've just got stagnant steam in there and it's not doing very much. Then that's going to be changing as a heat transfer ratio. You're not going to be getting anything out of that.

MR. FLETCHER: I think the answer is the core melts in place and the tubes don't melt because it takes --

CO-CHAIRMAN WALLIS: What would happen would be that the gases from the core go up into the steam generator. The steam generator temperature is more like the temperature in the hot plenum, which you don't want.

MR. FLETCHER: And the steam is going to get up there how?

CO-CHAIRMAN WALLIS: By counter current from the hot leg.

MR. FLETCHER: Well, the counter current flow in the hot leg will take it to the inlet plenum of the steam generator, but if you have no heat transfer --

CO-CHAIRMAN WALLIS: Then it goes up into the steam generator.

MR. FLETCHER: But there's no heat transfer off the outside of the tubes. You say --

CO-CHAIRMAN WALLIS: But you have hotter stuff in the bottom; you have cold stuff in the tubes. The cold stuff drains out, and the hot stuff goes up into the tube. The cold stuff then goes back to the core.

MR. SIEBER: You have to remove heat in order to get that to flow.

MR. FLETCHER: Yeah, that was my point.

CO-CHAIRMAN WALLIS: You don't have to remove heat. If you have the core hotter than the steam generator --

MR. SIEBER: You do.

CO-CHAIRMAN WALLIS: -- the hot gas --

MR. FLETCHER: You do, yes.

CO-CHAIRMAN WALLIS: You don't have to remove heat to get the circulation. No, you don't. Think about it.

You're heating up the core. You get a high temperature above the core. The steam generator is still cold. That high temperature steam plus along the hot leg goes up around the steam generator and heats it up. In heating it up, it cools down, comes back, goes back to the core.

The heat loss is essentially just in heating up the steam tubes, what you call the heat loss. It's still got natural circulation, which is how the steam generator tubes get heated up, and I say if you're not cooling them on the outside, they're going to tend to want to approach the temperature at the top in the upper plenum, which is hotter than -- they'll be about the same temperature as the hot leg.

MR. FLETCHER: What you're saying is you'll still have tube circulation, but it would only be there because in a transient sense you're heating up the tube wall.

CO-CHAIRMAN WALLIS: But you've got it for that anyway. That's part of why you get it anyway.

MR. FLETCHER: Right.

DR. RANSOM: Well, it would be an easy calculation for them to make. Just make the heat structures of the tube adiabatic and --

MR. FLETCHER: Right, we can do that.

CO-CHAIRMAN WALLIS: Right, but then I think you can't impose this parameter here, can you? You'd have to have a zero, wouldn't you, for the ratio?

So I think you can't impose this. It could be zero, and it could even be 50 percent depending on how --

MR. BOYD: But this parameter includes the heat-up of the tube. So it wouldn't be zero. It would be that --

CO-CHAIRMAN WALLIS: But it would just be going into the tubes. Okay. So this isn't the ratio of the heat loss from the tubes. It's the heat to the steam generator. Okay.

MR. FLETCHER: It's the ratio of the heat being removed to the steam generator to the total heat, oxidation and core decay heat.

CO-CHAIRMAN WALLIS: Okay, okay. The heat is not being -- oh, okay, okay. It's just being removed, and whatever fluid is going in there is recirculating through the steam generator. That's what you mean.

MR. FLETCHER: That's correct, and included in the steam generator heat here is the heating of all steam generator that enters the steam generator, into the plenum, into the plenum walls, into the tube walls, anything that's delivered through --

CO-CHAIRMAN WALLIS: And so anything that is being heated up.

MR. FLETCHER: Yes. What we found is the tube failure margin results were moderately sensitive to this. As you would expect with a higher steam generator power fraction, the tubes receive more heat, and so they're more likely to fail.

We did a sensitivity calculation to a number of reactor coolant pump shaft seal leakage assumptions. In the base case, we've assumed the 21 gpm for pump leakage starting at the beginning of the transient, which represents a leakage rate that's expected because of the loss of the seal cooling flow.

We also made four calculations looking at larger leakages that occur at two hours and 13 minutes, at a two hour period and at a 13 minute period into the accident. These are the times when larger pump seal leakage failures were seen in tests. The rates we're using are the expected rates during those tests with 61 gpm after two hours, 172 gpm after two hours, 182 gpm after 13 minutes, and 300 gpm, which is the maximum expected leakage per pump, after two hours.

CO-CHAIRMAN WALLIS: Now, this failure is a progressive failure of the seal or do you just blow the whole seal out the first time around?

MR. FLETCHER: In our calculation we're blowing it out. We're assuming the 21 gpm flow area for the leakage for the first two hours.

CO-CHAIRMAN WALLIS: Why didn't you assume 300 gpm? You've blown the seal away completely.

MR. FLETCHER: Why did we assume 300 gpm?

CO-CHAIRMAN WALLIS: Why not? In the beginning you had destroyed the seal and blown it away; you've got 300 gpm.

MR. FLETCHER: No, there are a couple of failure modes here. The one mode is the leakage mode resulting in the 21 gpm that's expected. There are also failure modes associated with the popping open of the mechanical seals --

CO-CHAIRMAN WALLIS: That's what I mean.

MR. FLETCHER: -- and some O ring failures as well. And those are more or less instantaneous, and the times when those were observed in the tests were at two hours and also at 13 minutes, and so that's why we selected these times.

CO-CHAIRMAN WALLIS: So it took two hours to blow out the O rings or whatever?

MR. FLETCHER: That's correct.

CO-CHAIRMAN WALLIS: That's a long time.

MR. FLETCHER: That's correct.

This was a set of Westinghouse data that had bene looked at and reviewed. The issue that they were looking at was mainly how long does it take to lose enough water to uncover the top of the core in a station blackout, which is not the same issue we're looking at here., but the data is still applicable.

The results were found to be sensitive to the leakage parameter, and it's a function of the leakage rate. The higher leakage rate leads to less PORV flow, and therefore, lower surge line flows, lower surge line temperatures, and delayed or no surge line failure as a result of that, but the higher leakage rate also leads to generally lower RCS pressures which delays or eliminates the hot leg and the steam generator failures as well.

So the results show that actually the worse possible case was the 61 gpm leakage, reduced our average tube multiple for failure before the surge line from five to three and a half and the hottest tube from two to one and a half, and for that case, the surge line failure was delayed, and that's the reason that those margins were reduced.

For the higher leakage cases, the surge lines did not fail at all. We have so much depressurization there that the surge line is not challenged. The hot legs did fail, and in both of those cases at 172 and 182 gpm.

CO-CHAIRMAN WALLIS: So this pump seal becomes a kind of relief valve for the system.

MR. FLETCHER: That's correct. That's correct, yeah.

We did not calculate any average tube failures for those cases because the pressure was low enough. We did have some hot tube failures, but the margins were increased over the base case.

And for the biggest break, the biggest assumed leakage, 300 gpm, the depressurization is significant enough so that we didn't have any structural failures at all, surge line tubes, regardless of multiplier or tubes regardless of the steam inlet temperature.

CO-CHAIRMAN WALLIS: Do you mean the whole system stays intact forever?

MR. FLETCHER: The whole system stays in the vessel. It doesn't stay intact. It then melts and ends up in the lower plenum.

CO-CHAIRMAN WALLIS: Forced down. Okay.

MR. FLETCHER: Yes.

MR. SIEBER: Or beyond.

MR. FLETCHER: Or beyond, yes.

We evaluated the sensitivity of results to tube plugging. The base case was at ten percent. The sensitivity cases are at zero and 20 percent. We didn't find a big sensitivity of the results to that parameter.

Outer wall heat transfer coefficient on the steam generator tube.

CO-CHAIRMAN WALLIS: You assume the uniform plugging not just in the one place? If you plugged the tubes right above the plume, it might make a difference.

MR. FLETCHER: Our model is so crude that it doesn't know where the plume is. This is just strictly what's the flow area and what's the tube heat structure area.

Outer wall heat transfer coefficient. The base case is calculated using the standard SCDAP/RELAP 5 heat transfer models on the exterior of the tubes. For this the code looks at forced convection using Dittus-Boelter corrected for vertical bundle configuration; laminar convection; and natural convection, and the code selects the maximum heat transfer coefficient based upon those three.

However, all three of those are providing very low heat transfer coefficients, roughly seven watts per meter Kelvin.

CO-CHAIRMAN WALLIS: Now, this Churchill-Chu, you're just assuming that there's like one tube in a big environment?

MR. FLETCHER: That is correct.

CO-CHAIRMAN WALLIS: Which is not the case, is it? These tubes are pretty packed in there, interacting with each other, and there are support plates or things that are in the way?

MR. FLETCHER: Yes, and they're not modeling any of that detail on the secondary side.

The point is that the heat transfer coefficient we are using on the outside of the tube is very small, and as a result of this we looked at sensitivities to increasing it arbitrarily by factors of five and factors of --

CO-CHAIRMAN WALLIS: Make it zero and look at the limiting case.

MR. FLETCHER: We could do that.

CO-CHAIRMAN WALLIS: That would be, I think, quite -- I believe Dr. Ransom suggested that.

That would perhaps be a worst case, wouldn't it?

MR. FLETCHER: Okay. Here we find the results are sensitive to it, and in fact, the base case with a multiplier of one results in the lowest margins of all of those cases, the reason being that the higher heat transfer coefficient more tightly couples the tube to the cooler steam that's on the secondary side.

CO-CHAIRMAN WALLIS: I think when you make the heat transfer coefficient zero on the outside of the tubes and all you're doing is heating up the tubes, what you will find is that your actual heat, if you calculated it, the heat ratio from the core to the steam generator would be much less. There's much less heat going to the steam generator.

Because, you know, if you had no mass at all, no heat could go there.

MR. FLETCHER: Yes, I agree.

CO-CHAIRMAN WALLIS: So your 30 percent wouldn't make any sense. We'd be far overheating the steam generator.

MR. FLETCHER: Right.

CO-CHAIRMAN WALLIS: So you need to fix that 30 percent thicker somehow. If you heat something with no thermal mass, it's going to go over there.

MR. FLETCHER: Okay.

CO-CHAIRMAN WALLIS: It's going to be high. It's going to be hotter than the upper plenum, which makes no sense at all.

MR. FLETCHER: I'm still not sure what we're going to do about the 30 percent value.

CO-CHAIRMAN WALLIS: Well, okay. It solves the whole problem.

MR. FLETCHER: We are forcing the answer here.

Thermal radiation modeling. I explained earlier that we're using steamed wall radiation on the inside of the primary and secondary coolant systems, and we're also using hot leg upper to lower wall wall-to-wall radiation. We made some sensitivity calculations putting multipliers of .5 and two on what the code was calculating for the radiation heat fluxes, and we found no significant effect there, which is a bit of a surprise.

This is something a lot of earlier talks were looking at thermal radiation as being very important to the process here.

The next sensitivity regards surge line depressurizer connection, the CCFL modeling at that point. The base case calculation was modeled as an open pipe configuration on the bottom of the tank using a Kutateladze correlation and a flow area based on a 11 and a half inch surge line diameter.

In a sensitivity calculation we instead looked at a sparger design at that connection point, and we based the sparger design on the AP 600 pressurize sparger which we had some data on. The sparger has a hole diameter of .375 inches, and the sparger flow area through the holes on there is roughly 1.7 times the pipe open flow area, and we changed the counter current flow limiting correlation from the Kutateladze form to the Wallace form based on that geometrical data.

Here we found the results were insensitive to the change in the CCFL model. Changing to the sparger formulation of CCFL we delayed the draining slightly by about 150 seconds, but it still occurred before the time when the heat-up really got significantly going. So there was no major effect there.

Reactor vessel internal circulation. In past analyses of other subjects there's been a number of instances where RELAP 5 calculations were showing circulations that did not appear to be physical. So we wanted to look at this. We did some hand calculations to see whether or not the flow rates in the core were reasonable and they checked very well based upon the buoyancy driving heads and the flow resistances through the loops.

We also want to just force this situation where we went in and arbitrarily increased the loss coefficients. We did so to reduce the flows inside the vessel by 50 percent, and what we found was that in the sensitivity calculation the flow losses in the reactor vessel and the upper plenum regions we increased them by a factor of eight, reduced the flows by 50 percent, and the slower vessel circulation results in earlier and faster heat-up within the reactor vessel and an acceleration of the core melting process.

In other words, if we slow the flow down in the reactor vessel, the reactor vessel ends up being a lot hotter than it would be if the flow were going faster, and so the core melt process proceeds earlier, and we end up melting core and relocating core well before we end up with any surge liner or steam generator failures.

DR. RANSOM: Where is the circulation? Is it down through one channel and up through another one?

MR. FLETCHER: Well, we --

DR. RANSOM: Because the loop seals are not clear.

MR. FLETCHER: No, this is inside the vessel, and we have five channels in the core.

DR. RANSOM: Have what?

MR. FLETCHER: Five channels, five vertical channels. The flow is generally downward in the outer channels that is driven by the cool steam flowing in from the bottom of the hot legs, and upward in the center two channels, and in the middle of the five channels, the flow starts downward at the upper part of the channel and is upward in the lower part of the channel and it then flows inward and upward to the core.

DR. RANSOM: Are they cross-linked so that --

MR. FLETCHER: Yeah, the core channels are cross-linked at every axial level. We also have an axial and transverse grid in the upper plenum with cross-flows modeled there as well, and in addition to the core circulation, there is an eddy flow in the upper part of the vessel towards the center of the vessel and the lower part of the upper plenum and away from the vessel in the upper part of the upper plenum.

And reducing the flow by 50 percent caused this to increase the multiplier needed to fail the average tube from five to greater than the seven and a half, which is the maximum we're looking at, and the hottest tube stayed essentially the same, the reason being that the hottest tube temperature is influenced by what's coming back from the cold steam generator tube recirculation.

I apologize for the way the next slide ended up being in the package. It's overwritten in a couple of places.

On heat loss, containment heat loss modeling, the base case was done at four megawatts. We also did sensitivities at two megawatts and eight megawatts. These numbers are a normal operation.

Results were found to be moderately sensitive to this, which was somewhat of a surprise. We didn't think this was going to be a major effect. The main effect that we're looking at here is that we have heat loss on the outside of the hot legs, heat loss on the outside of the pressurizer surge line, and that tends to keep those structures cooler.

So if you have more heat loss, you end up with less tube failure margin.

We looked at two things on PORV, pressurizer PORV functioning, one where we assume that the PORVs were blocked closed, which would require the pressure to rise up to the pressurizer safety relief valve setting instead, which is approximately 150 psi higher than the PORV setting.

So essentially we have the same process going on, just a slightly higher pressure, and as a result of that we didn't see any change in tube failure margin.

We also looked at an operator intervention in which the operators observed the core exit steam temperatures, realized the situation they're in, and there is an operator instruction to open the PORVs when the steam temperatures reach 1,200 degrees Fahrenheit.

In our calculation we assume the operator opens both PORVs at that time and leaves them open thereafter. That time was 10,798 seconds into the base case calculation.

When we do so, when we open the PORVs, we depressurize the reactor coolant system. We end up with a cumulator flow as a result, and so we interrupt the core heat-up process as the accumulators dump their fluid.

But eventually the accumulator's liquid is expelled and the core heat-up resumes. We have roughly about 80 percent of the core melting and relocating to the reactor vessel lower head a t 25,000 seconds.

So the heat stayed within the reactor vessel, and we did not have any steam generator tube failures indicated, and therefore, the calculation indicates a success of this as an accident mitigation strategy for preventing fission product release to the steam generators.

We also looked at steam generator tube leakage. The base case was done with no leakage and the steam generator tube is assumed. We looked at 50 gpm, 100 gpm, and 200 gpm leakage in steam generator one. The leakage is assumed to be induced by the failing open of the secondary side valve on steam generator one that occurs at 190 seconds.

The results of the calculations, we looked at leakage on the hot side and on the cold side of the tubes, and by that I mean midway between the tube sheet and the U bend on the tubes, on the up-flow side and on the down-flow side; found slightly less margin when the break or when the leakage was assumed on the up flow side, and that's the assumption that we used for the remainder of the calculations.

We found the results of the tube failure margins to be sensitive to the steam generator tube leakage. The results are shown in the table there. We reduce the average tube multiplier required to fail it before the surge line from five to three and the hottest tube from two to one and a half over the range of leakages that we looked at.

CO-CHAIRMAN WALLIS: Now, is this consistent with what you'd expect from Chris' observations of tube leakage? He got something which was not altogether intuitive perhaps about how the flows worked when there was a tube leakage.

Are you allowing some sort of mixing which would not quite duplicate what he observed?

MR. FLETCHER: I don't think our calculations compare directly at all. I'm using a simple representation of the two paths and assuming the leakage is halfway up, and in my calculation it will influence the average tube inlet temperature as a result. It will pull steam up in there because that's the way the model is built, which is counter to what he said.

CO-CHAIRMAN WALLIS: Your leakage is in the cold tube or the hot tube?

MR. FLETCHER: It's in the up flow tube, in the hot tube.

CO-CHAIRMAN WALLIS: It's leakage in the down tube?

MR. FLETCHER: I'm sorry?

CO-CHAIRMAN WALLIS: Was his leakage in the -- no, his leakage was also in the up tube, but it didn't draw more flow into itself. Right, okay.

MR. FLETCHER: but he has a detailed model of the region. I have a very crude model of the region.

CO-CHAIRMAN WALLIS: I was just wondering whether observation that the hot plume was not drawn to the leak -- perhaps your hot plume -- I was thinking your hot plume might be drawn to the leak by the way you modeled that. That's why.

MR. FLETCHER: That's correct. We will see effects of the leak on the tube temperatures.

MR. LONG: This is Steve Long with NRR staff.

There's two different effects here. One is do you draw extra hot fluid from the reactor vessel to the steam generator if you have a leak in the steam generator. The RELAP model includes that, but it doesn't change the mixing as you have more hot fluid and less --

CO-CHAIRMAN WALLIS: Well, I was talking about drawing hot fluid to the leak in the steam generator itself. I mean, one might think that the hot fluid was seek the leak, but in fact, Chris seemed to show that it didn't necessarily do that. They could just go up the tubes anyway.

MR. LONG: Right. What Chris showed was that it doesn't change the location of where the plume comes out of the hot leg and goes through the plenum. It's the tube sheet. Chris allowed it to change the mixing. So there are two different effects, one in each model. It's not clear how they go together yet.

CO-CHAIRMAN WALLIS: Yes.

MR. FLETCHER: We also looked at a sensitivity to the hot leg nozzle core bypass flow, reducing it by 50 percent, and we saw no significant effect of that change.

In summary of the sensitivity calculation results, the tube failure margins were found to be insensitive to the tube plugging assumption, thermal radiation modeling pressurizer to surge line CCFL modeling, blocking closed to the pressurizer PORVs or the core bypass flow, and we found the results are sensitive to steam generator power fraction, recirculation, reactor coolant pump shaft seal leakage, steam generator tube outer wall heat transfer coefficient, the vessel circulation rate, the RCS heat loss, the operator intervention strategy if used and the steam generator tube leakage assumption.

So in conclusion, I would like to leave you with the thought that the updated base case is a good representation of the station blackout event to be used as a basis to look at remaining work. We find that we have moderately increased the steam generator tube failure margins as a result of the changes that have been implemented recently.

The multipliers required to fill those tubes on Larson-Miller prior to the time a surge line fails are five for the average tube and two for the hottest tube, and only steam generator tubes with structural strength degradations that are greater than this would be expected to fail prior to the surge line.

The flow patterns and rates of the SCDAP/RELAP 5 reactor vessel internal circulations appear to be reasonable, and trying to slow that circulations down resulted in increased steam generator tube failure margins because the heat remained more inside the reactor vessel.

The operator intervention strategy shows that it was effective and that for carrying on the uncertainty studies for sure we want to include the five parameters listed at the bottom of the page there as variables in that study.

That includes my talk.

CO-CHAIRMAN WALLIS: Thank you very much indeed. That was very nice. Thank you.

MR. FLETCHER: thank you.

CO-CHAIRMAN FORD: Any comments?

DR. RANSOM: Don, in this accident scenario, what ultimately happens in the long term? I mean what is assumed to happen?

MR. FLETCHER: Well, in the long term without any intervention at all, the core is still producing delay heat and the core will melt is what it amounts to.

DR. RANSOM: Well, in the release assumptions is it assumed that it just continues to melt and then leak out the containment bypass? Is that --

MR. FLETCHER: Well, in the long term if the core melts, it will fall into the lower head of the reactor vessel and then perhaps melt through that into the bottom of the containment, the point being that if that happens, the fission product release would be into containment.

So the key that we're looking at here is might you have steam generator tube failures that would allow that release to be made into the steam generator rather than into the containment.

DR. RANSOM: Which would bypass the containment, I guess, if you assume the main steam line breaks.

MR. FLETCHER: Well, the concept of the containment bypass is a word that I've heard just fairly recently here, but what we've been talking about before were steam generator tube rupture events during severe accidents. The containment bypass concept is that the fission products goes to the steam generator rather than containment. That's the whole intent of that.

If the fission products make it into the secondary side in this particular accident, it's open to atmosphere because the valve is stuck open on the top of the steam generators. If you didn't have that failure on the secondary side, it would still go into the secondary, and then it would be relieved through the safety valves at somewhere around 1,000 psi. In both cases you have the potential for release to the environment.

CO-CHAIRMAN WALLIS: But your release is in the hottest tube, which is probably somewhere in the middle of the tube bank at the bottom. It has got to make it through all of this tube bank and the spacers and everything in order to get to the outside world. I would think the removal of aerosols in that steam generator is going to be tremendous.

MR. FLETCHER: I guess I can't address the fission product aspects of this.

MR. ROSENTHAUL: I discussed some earlier work with Raj Sadal (phonetic) because I would have thought you would have had huge DFs with all of that surface area and an aerosol, and he thought that there was some old EPRI experimental work which would lead DF to ten, which is disappointing. I was thinking 100, 1,000. I mean, you know, a pool scrubbing is 10,000 or 1,000, and that's just because of the slip beams (phonetic), and just the flow and how the aerosol is prepared.

And that's why we're participating in the ARTIST program, so that we'll get some real data and we'll know, but I think that --

CO-CHAIRMAN WALLIS: What is unreal data, by the way?

MR. ROSENTHAUL: Excuse me?

CO-CHAIRMAN WALLIS: What is unreal data?

MR. ROSENTHAUL: Chris' data is, in my mind, more suspect that from a physical experiment. My bias is coming through here.

But in any case, you know, if you had to guess on the outcome, I think you're thinking of that DFs of ten to 100 as distinct from pooled DFs which are like 1,000 or more. But that's still considerable.

CO-CHAIRMAN FORD: Okay. Thank you very much, indeed.

MR. FLETCHER: Thank you.

CO-CHAIRMAN FORD: Would you like to introduce your next speaker, Joe?

MR. MUSCARA: Yes, t he next area is the work on the primary system component failure in severe accident conditions, and Saurin Majumdar from Argonne will provide that presentation.

(Pause in proceedings.)

CO-CHAIRMAN FORD: Maybe you could tell us. did we receive a report on these particular next three items, 34(h)(1) through (3)? I don't have a copy of it. Does Graham? In which case we can always blame the manager at Argonne for noncompliance.

MR. MUSCARA: The report is still under review.

CO-CHAIRMAN WALLIS: That's okay. We can get draft reports, too. I was looking through my notes. I don't think I have any notes on this subject.

MR. MUSCARA: You do not have, but this item, the first part of it, can be closed out. So a report should be sent out with a closure letter soon.

Joel, what's the status of the report?

MR. PAGE: We just received the official peer review comments from NRR, and we're going to be resolving them soon.

CO-CHAIRMAN FORD: Good. Items one and two have been completed. Item three, large scale tests, that's not due to be done until '05; is that right?

MR. PAGE: If we have large-scale tests.

CO-CHAIRMAN FORD: Yeah, that's one of the questions.

MR. PAGE: If needed. Large-scale tests, as you know, are very expensive.

MR. MUSCARA: They're not planned at this point.

MR. MAJUMDAR: My name is Saurin Majumdar from Argonne National Laboratory.

As this is of use to you by now, this is a collaborative study between RES staff and several contractors. You already heard from RES and ISL. I'm going to talk about the structure behavior of pressure boundary and the high temperature and will be followed by the PRA work.

We already know that we are looking at the station blackout scenario with the secondary side depressurized and the primary side still fully pressurized, but that challenges the tubes to the maximum degree.

Now in the NUREG 1570 study, the failure of the pressurized surge line was predicted before the steam generator tubes, as well as the previous speaker mentioned, the RELAP studies from the new base case.

The structure models from the RCA components were highly simplified. It was just like a RELAP 5. They're only considering the internal pressure loadings, and the other mechanical loading and thermal loadings that are not considered in that model, for example, the local geometry, structural boundary condition, thermal stress, dead weight, material variability, these sort of things we will be considering under this study.

DR. WALLIS: Now, material variability, what do you mean by that?

MR. MAJUMDAR: That means we'll be doing an uncertainty analysis of material variability of the rupture strength on --

DR. WALLIS: Do you mean by it that there are different materials in different places, different alloys or do you mean within a certain alloy there are different heats and you don't quite know how it behaves?

MR. MAJUMDAR: For example, we have the average rupture property for a given alloy.

DR. WALLIS: But is that good enough?

MR. MAJUMDAR: We might as well do uncertainty on that to see what kind of variability you're going to get and whether it's important or not.

The objective of the 2:00:44 annual program is to improve prediction of the failure model location, failure modes, and the times to failure of reactor RCS components. This equally serves hot leg piping, manways, PORVs and PSVs under severe accident condition.

CO-CHAIRMAN WALLIS: So what's your pipeline for people like the previous speaker where he's predicting things and you're taking his results for temperatures and things.

MR. MAJUMDAR: Yeah, I'm not sure what I wrote.

CO-CHAIRMAN WALLIS: Do you have to wait until there's an approved report, or is there a pipeline where you can send your stuff right away?

MR. MAJUMDAR: We've already gotten the heat transfer coefficient from --

CO-CHAIRMAN WALLIS: So you have a pipeline of direct transfer, not sort of send it up to management and management goes on vacation and then you wait.

MR. MAJUMDAR: No, no, no.

CO-CHAIRMAN WALLIS: No? Okay. Good.

MR. MUSCARA: That's part of the reason for having this integration team that I work with, to make sure that the information gets released at the right time.

MR. MAJUMDAR: So basically we have two phases in the program. During phase one of this program, we did an engineering review, and we saw the most likely components to fail would be the pressurizer safety valves, bar operator relief valves, PORVs, the manways, and the steam generator and the hot leg and the surge line piping, including the intersections and the nozzles.

These components are identified as the most likely to fail during a typical severe accident.

Now, analysis of the passive component, like the hot leg or the surge line, is relatively straightforward compared to the active components which have moving parts, and the active component failure is rather challenging. So we reviewed the literature of failure history of valves, bolted joints, and gaskets during phase one.

To help determine whether detailed analysis of the active components was a realistic objective or not, we held a workshop at Argonne with participants from two valve manufacturers, one gasket manufacturer, and NRC and EPRI and INEL personnel.

Now, the participants --

CO-CHAIRMAN WALLIS: Did you have foreign representatives or other people are working on this problem It's just --

MR. MAJUMDAR: We tried to get hold of foreign participants, but this was just after 9/11 and everything was canceled.

MR. PAGE: We have to delay the meeting twice.

MR. MAJUMDAR: So we concluded that the

most likely scenario for the PORV, for example, to fail would be galling, but to analyze galling we needed tolerance in tightly fighting parts. Participants felt that the valve manufacturers would not very easily give out those detailed geometric information, and even if he did the analysis and predicted failure, the feeling was it would be very difficult to predict that the PRA would fail in the open position or shut position or half opened, half closed or whatever it is. So it wouldn't be very useful.

Participants were more optimistic about analysis of bolted joints. So during our phase two, our primary has been focus on analysis of passive component failure. We obtained detailed mechanical and structural drawings of the hot leg and the surge line piping of the ZION nuclear station.

We did finite element analysis of the hot leg and the surge line piping, including the nozzles of Loop 4 which had the pressurize, and the analysis was based on thermal hydraulic results provided by ISEL and NRC Research.

We conducted a study of other RCS passive components like the steam generator primary manway, and here we were really looking for the loss of both

--

CO-CHAIRMAN WALLIS: On the hot leg, I mean, in the hot leg you have counter current flow of pretty hot steam and pretty cold steam. Is the heat conduction in the metal from the cold top out to the cold important?

MR. MAJUMDAR: Yeah, we took that into account. Yeah, yeah, I'll show you some results.

CO-CHAIRMAN WALLIS: And what does that do? Does that heat transfer -- that changed the temperature of the streams. I don't know if Chris Boyd has that temperature, that heat transfer in the hot leg.

MR. MAJUMDAR: No, he didn't have that.

CO-CHAIRMAN WALLIS: The hot leg is like a heat exchanger where the metal is sort of like a fin or something. It eventually helps the --

MR. MAJUMDAR: Actually the RELAP 5 analysis shows a stepped up pressure change but on the hot side.

CO-CHAIRMAN WALLIS: Not quite so simple.

MR. MAJUMDAR: No, but I'll show some results from the --

CO-CHAIRMAN WALLIS: So is the metal almost at the same temperature all around or is it much hotter on the top than on the bottom?

MR. MAJUMDAR: No, it's much hotter on the hot side of the --

CO-CHAIRMAN WALLIS: It is?

MR. MAJUMDAR: Yeah.

CO-CHAIRMAN WALLIS: Even though it's a good conductor?

MR. MAJUMDAR: Stainless steel is not such a good conductor, but it still --

CO-CHAIRMAN WALLIS: Well, then steam is not a very good heater either. So --

MR. MAJUMDAR: Well, I'll show the results. It does smooth out the distribution.

CO-CHAIRMAN WALLIS: Okay. Thank you.

MR. MAJUMDAR: Okay. So we looked at the primary manway, and so we were primarily looking for loss of bolt retention when the power cable lift up and we were allowed to see --

CO-CHAIRMAN WALLIS: You have pretentious bolts?

MR. MAJUMDAR: Retention bolts.

(Laughter.)

MR. MAJUMDAR: And allow the steam leakage to occur so it would depressurize the system, and we also cut the resistance to partially detect the RTD rails[unintelligible due to strong foreign accent [UDTSFA]), the socket rail connection of an instrument like to the RTD flange.

We also did some positive impact, NRC's for the PORV. All the work I'm going to discuss were reported in the NUREG CR-6792 and the current NUREG CR which is under PRA review now.

CO-CHAIRMAN FORD: I've never heard of a resistance temperature detector weld. Is this just a bimetallic weld which is using a thermocouple or what? I've never heard of it.

MR. SIEBER: The RTDs are in a well.

CO-CHAIRMAN FORD: Oh, I see.

MR. SIEBER: And the weld is welded into the pipe.

CO-CHAIRMAN FORD: I understand.

MR. MAJUMDAR: There's a two inch hole actually. The idea is that RTD could be expelled from the hot leg and create a two inch diameter hole through which the steam can escape and depressurize.

MR. PAGE: I don't think the drawing you have would show what you're talking about, but that's okay. It will be okay.

MR. MAJUMDAR: This is basically the simplified diagram of the ZION plant, and we are basically looking at this hot leg of this new pressurizer. This element included the pressurizer nozzle The model includes the pressurizer nozzle, the surge line, the nozzle here, the hot leg, the reactor vessel nozzle, the elbow, the steam generator nozzle.

Even though the steam generator was not part of our study, we had to include that, the lower head of the steam generator in order to apply the structural bond reconditioning in a more convenient way.

So we developed this final element model for the whole system, and the hot leg and surge line material, as I said, is 3/16 stainless steel. You've got significant high temperature material properties at the level for that material, even though there is some lacking in the high temperature range.

The nozzle materials are either carbon or low alloy steels, and these materials are generally not used at high temperature. So we had trouble getting mechanical properties at high temperature.

The high temperature weld, all the welds in this piping are 308 stainless steel. Now, the database is incomplete. By that I mean that the 308 generally has its mechanical properties superior to the band material, but sometimes there are heat affected zones that might have properties that are inferior to the element itself.

We also completed sensitivity analysis and certain analyses we are planning to do in the future. To give you an idea, availability of the mechanical properties data, 3/16 stainless steel exerts the properties, tensile properties, and heat properties, and this temperature here means that in the temperature regime we have the mechanical properties unavailable.

So while the stainless steel is pretty well characterized, the hot leg material at the elbow material is a forging material. It's not much data at high temperature. We assume it is the same as stainless steel.

The surge line to hot leg nozzle is a forging material, again. Again, high temperature data are kind of limited so we had to assume they're the same as stainless steel

MR. MUSCARA: CF8M?

MR. MAJUMDAR: CF8M.

MR. MUSCARA: That's a casting steel.

MR. MAJUMDAR: Oh, that's a casting. Okay.

CO-CHAIRMAN WALLIS: Well, I don't

understand this. Oh, I guess yo mean that the tensile strength is evaluated over that range of temperatures. The temperature strength isn't in degrees Centigrade. Okay.

And the rupture time is something which is also just a function of temperature?

MR. MAJUMDAR: Yeah, it's a function of temperature and stress, and that's the temperature range in which the data are available.

The weld middle, as you see, there's also very limited data. The only exception was where data was available was for the A508, Class 2, and this had a very high heat, developed a very high temperature, the reason being that this particular material was tested in an NRC program that was geared toward analyzing the lower head of the --

CO-CHAIRMAN WALLIS: The hot leg elbow is different material from the hot leg?

MR. MAJUMDAR: Oh, yeah, it is.

PARTICIPANTS: Yeah.

CO-CHAIRMAN WALLIS: And there's a weld there of some of sort of --

MR. MAJUMDAR: Yeah, there are welds there, plus the elbows have got some more massive --

CO-CHAIRMAN WALLIS: You've got to look

for leaks in that area

MR. SIEBER: Is this a plant with centrifugal cast stainless steel or forged?

MR. MAJUMDAR: Is that a casting or forged, the CF8M?

PARTICIPANTS: Eight M is cast.

MR. SIEBER: Okay.

CO-CHAIRMAN FORD: Now, on the previous graph, you said you did sensitivity studies. What were the variables that you put into your sensitivity studies?

MR. MAJUMDAR: I'll come to that later on. I will talk about that.

CO-CHAIRMAN FORD: Okay.

MR. MAJUMDAR: Okay. The properties that we really don't have are, for example, this nozzle, the steam generator and the pressurizer nozzle. This is a cast 216, absolutely no data developed from the material.

CO-CHAIRMAN FORD: So in your analysis, when there are no data available, what do you do?

MR. MAJUMDAR: Well, we assumed the same as the A508, which was the last. This material for this cast low alloy steel, there's a lot of property available for that.

CO-CHAIRMAN FORD: But there's no high temperature --

MR. MAJUMDAR: No data available.

CO-CHAIRMAN FORD: -- stretch strength.

MR. MAJUMDAR: That's right.

MR. MUSCARA: So because there's no data, we're assuming some data, and then conducting some experimental work in the next phase.

CO-CHAIRMAN FORD: So this is just a scoping study at the beginning.

MR. MUSCARA: We need to set up the modeling and --

CO-CHAIRMAN FORD: I understand. Okay.

MR. MAJUMDAR: The other property we don't have really that's very critical is the manway bolts, that A193D7 bolts. We didn't find any heat properties corrupted. That's the critical property that we're going to develop in the next phase of the program.

CO-CHAIRMAN FORD: Okay.

MR. MAJUMDAR: Okay. Now, what I want to say is that the way we did the thermal analysis first, now, RELAP 5 gave us the heat transfer coefficient for these five control volumes and these five control volumes. As you know, RELAP 5 has the hot leg is modeled next to independent pipes, but we had a single pipe. So from the top half we used the spare heat transfer coefficient supplied by the RELAP 5 run areas, and the lower for the colder half of the hot leg. These are the heat transfer coefficients for these five control volumes.

The only problem was that in the surge line, the same thing in the surge line. You would have ideally liked to have used the heat transfer coefficient from the RELAP 5 run, but about this program that we used for analyzing the stress and temperature, can accept heat transfer coefficient only as a function of temperature, not as a function of time, and as I will show later on, the heat transfer coefficient on the surface in flux and the interior surface of this hot leg shows pipes because of the fuel oil recycling, and those pipes could not be ignored because if you ignore that, the temperature analysis will give the wrong answer.

So basically you are talking about the old baseline case. So we have to make sure that we don't get confused here. The stuff that Don presented today is the new baseline case. The stuff that I'm going to talk about is based on this old baseline case assumptions for the F5, and that is basically encountered here.

The main thing is that there's on circumferential heat conduction or radiated heat transfer in the hot leg, and the RCP seal leakage is assumed to zero. So there's no significant increase in same temperature.

MR. SIEBER: The number of tubes, that's per steam generator, four times.

MR. MAJUMDAR: Yeah. Yeah, 3388 total steam generator.

MR. SIEBER: For each one, yeah.

CO-CHAIRMAN WALLIS: So it's the old case.

MR. MAJUMDAR: The old case, yeah.

CO-CHAIRMAN WALLIS: You're going to put in some better assumptions.

MR. MUSCARA: Yeah, that's planned.

MR. MAJUMDAR: Basically, as I said, he wanted to put in the heat transfer coefficient in the interior surface, but this will not accept heat transfer coefficient as a function of time. So as a function of time, we have plenty of heat flux and interior surface in the hot leg as a function of time, and there are these spikes that are caused by the surge line we showed you.

The spikes are caused by the PORV cycling, and they could not be ignored. If you ignore them, then the temperature distribution became not reliable.

Initially the first table is that we need a structural thermal conduction analysis based upon ABAQUS file model, and then use these temperature in the distribution and stress analysis in the second state.

Here I'm showing the inner surface temperature in degrees Kelvin at this time, 1,440 seconds, and as you can see, the hot leg outside; this is the upper half. The upper half is pretty hot, 1280 K. The lower half is showed by the blue here. The blue here are pretty cold as you would expect because the hot flow in the top and the cold flow in the bottom.

And the surge line is hot uniformly all around. So all of these temperatures are computed by ABAQUS.

CO-CHAIRMAN FORD: On the table you have there, can you just -- the red is what?

MR. MAJUMDAR: The red is 1,263 degrees Kelvin.

CO-CHAIRMAN FORD: So it's in degrees Kelvin.

MR. MAJUMDAR: Kelvin, yeah, degrees Kelvin. Sometimes I use Kelvin, sometimes Centigrade, sometimes Fahrenheit in one case.

MR. SIEBER: Thanks.

(Laughter.)

CO-CHAIRMAN FORD: It was 1,000 degrees C.

MR. MAJUMDAR: At that time, 14,000.

CO-CHAIRMAN FORD: One thousand degrees C.

MR. MAJUMDAR: Yeah.

MR. SIEBER: Just one.

CO-CHAIRMAN WALLIS: That's why it's shown red.

MR. MAJUMDAR: Okay. This is the temperature variation in the hot leg. The top and outer surface, the top inner surface and bottom outer and bottom inner surface.

The thing I wanted to point out is that this 4,000 seconds will actually have to add 10,000 because the plus 10,000 seconds, nothing happens in it. So we really started analyzing for after 10,000 seconds.

At around 14,000 seconds or a little before that, the temperature drives. There's a big increase in the gradient from about six degrees per minute to 24 degrees per minute.

CO-CHAIRMAN WALLIS: You don't have any conduction between the two?

MR. MAJUMDAR: I have.

CO-CHAIRMAN WALLIS: You do now?

MR. MAJUMDAR: Yeah.

CO-CHAIRMAN WALLIS: But you didn't before, but the old case had no conduction the wall.

MR. MAJUMDAR: In RELAP 5 there's no conduction in the wall, but this is about the heat. Yet the heat in RELAP 5 could transfer and analyzing/reanalyzing the thermal conduction following.

CO-CHAIRMAN FORD: I must have missed something in previous presentations. I never saw steam temperatures on the order of 1,000 degrees C., did I?

CO-CHAIRMAN WALLIS: This is a reactor. This is a reactor. It isn't cool.

MR. SIEBER: You don't take any heat away and just keep putting it in when you get up to --

CO-CHAIRMAN FORD: Fine, okay.

MR. MAJUMDAR: Most other figures [UDTSFA] all around this point.

CO-CHAIRMAN WALLIS: Well, the burning of zirconium is, after a while, really heating it up.

DR. KRESS: Yeah, zirconium is burning when it takes off in a vertical.

MR. MAJUMDAR: Yeah, this is where zirconium starts oxidizing.

CO-CHAIRMAN FORD: Okay.

MR. MAJUMDAR: Anyway, three is about inner surface temperatures over 50 to 150 degrees C. hotter than the outer surface, and the upper half is about 100 to 500 degrees hotter than the lower half. At this point the RAB increases from over six degrees per minute to 24 degrees per minute.

And this is the circumferential temperature variation in the hot leg, the outer surface and the inner surface. So the RELAP 5 numbers were kind of a [UDTSFA] function that has been rounded out by the ABAQUS circumferential conduction.

You see, because the large maximum temperature of the reactor vessel nozzle lags that in the hot leg about 450 degrees Centigrade. The nozzle really doesn't get hot in the RV end.

The thermal conduction makes the circumferential variation much smoother than calculated by RELAP 5, but on the hot leg max temperature is 1,200 degrees C. Inland temperature is 830 C. You see at this time again, 18,400 seconds.

The RELAP 5 calculated hot to on site temperature drop is about 450 degrees C. It's about here, what, 375 degrees now instead of 450.

And now after the terminal analysis, we come to the structural analysis part, and here we put all of the boundary conditions on the surge line. The surge line has a number of supports to carry the load, just the weight of the surge line. The hot leg is not supported. It's supported only by the reactor and by the [UDTSFA] cell. There are no supporting besides the hot leg itself.

Also the steam generator that sits on these four supports that are in the bottom, they are gim bolts so they can rotate around these points.

Basically the point I want to say, bring out here is that we model all the structure boundary conditions that are applied on the --

CO-CHAIRMAN WALLIS: These supports are assumed to be rigid? They don't pull out?

MR. MAJUMDAR: No, they're not rigid. It has been constantly --

CO-CHAIRMAN WALLIS: They can pull out? They can break?

MR. MAJUMDAR: No.

MR. PAGE: No, they do not break.

MR. MAJUMDAR: But there is three constants, as I said.

MR. PAGE: And also the one on the opposite side of the steam generator is very important because that's a steam generator stop, and so basically as it grows under normal conditions, it basically goes up against the stop. So any further growth due to thermal is going to just be pressing these things together.

MR. MAJUMDAR: Yes, I'll come to that.

This is the typical deformation of the hot leg surge line.

CO-CHAIRMAN WALLIS: Is that exaggerated or is that --

MR. MAJUMDAR: It is very highly. This is highly exaggerated, but the green shade is the deformed shape at room temperature, and the unshaded area is the deformed after temperature.

I think you will notice that the surge line deforms quite a bit, and the other thing is that the independent supports, this support moves from there to there. So basically the steam generator can move as a rigid body, heat up from the room temperature to this normal operation at a full power, but as Joel was just saying, what they do is they then put shims against the bumpers so that the steam generator is not about to move any further away from the reactor.

And as I said before, I modeled all of the supports, but not directly.

CO-CHAIRMAN FORD: Now, educate me in terms of the qualification of these deformation codes as they apply to these sort of temperatures. I'm showing my ignorance here because I just don't know the answer.

Have these deformation codes been qualified at these sort of temperatures?

MR. MAJUMDAR: You mean the ABAQUS code?

CO-CHAIRMAN FORD: Yeah. ABAQUS code is an old code.

MR. MAJUMDAR: Yeah, they've done all kinds of creep analysis and validation. They've done validation on simple models. Plus a complex thing like that, there's no way of validating the results. You take it on trust.

CO-CHAIRMAN FORD: That's what worries me. ABAQUS code I seem to remember as being gas turbines, and has it been well qualified under those operating conditions?

I've got a natural reserve about anybody using a code way beyond the conditions under which it has been qualified against observations.

MR. MAJUMDAR: It's not in the code. What is the uncertainties are material properties.

MR. SIEBER: This is first principles.

MR. MAJUMDAR: Yeah, this ABAQUS code, they have validated the results with known analytical results. They can validate it that way, but for a complex thing like this, how do you validate on --

CO-CHAIRMAN WALLIS: Your ABAQUS is an IRC code. It's a universal code used all over the place with all kinds of purposes.

MR. MAJUMDAR: Yeah, yeah, yeah. It's a pretty well known code, especially for non-linear analysis.

CO-CHAIRMAN FORD: I guess I'm being a devil's advocate or being an old Jenny, but I hate to be in a situation in some time in the future if we had a severe accident and something unexpected occurred, and here we are sitting down in front of a public review and someone says, "You never asked the question as to whether this was qualified for these conditions."

I mean, I'd hate to be in that situation, and that's why I'm asking the question, and I'm hearing all of the experts in the room here say, "Don't worry, Peter. This is being qualified." No questions asked.

MR. SIEBER: No, first principles.

CO-CHAIRMAN FORD: I've heard first principles, Jack, coming out of my ears and then something unusual happens like an O ring was quite all right to use on this particular shuttle and something happened.

MR. MAJUMDAR: But the final limit was not the problem. It was the people who --

CO-CHAIRMAN WALLIS: Well, I think if Jack, the guy with all of the experience in the room, has to use this sort of academic argument that it's all from first principle, you ought to believe him. I mean, he's --

(Laughter.)

MR. MUSCARA: I understand, but IMAGINE has been used in situations like this, and whether they have validated the results or not --

CO-CHAIRMAN FORD: Now we're taking this well --

MR. MAJUMDAR: I'll say more. I've seen some experimental work by the Japanese who actually take pipes and heat it up under temperature and then measure the deformation and predict using ABAQUS.

CO-CHAIRMAN FORD: Okay.

MR. MAJUMDAR: Not failure, but the deformation.

MR. MUSCARA: Bill, do you know about the IPIRG? It may have been used there also when you had some large structures that were heated up and tested.

CO-CHAIRMAN WALLIS: Well, the sort of question you might have would be what --

MR. SHACK: As Saurin says, I mean, ABAQUS is the standard finite element structural code for nonlinear situations. It has been benchmarked against all sorts of analytical solutions. So I think as Saurin said, I mean, it solves the equations correctly.

Now, whether the model we're using describes the physics correctly is a different questions, but, you know, to the extent that you want to solve a creep rupture problem, ABAQUS solves the creep rupture problem correctly and has been through many, many rounds of QA, and is highly qualified against benchmarks.

So to that extent I think you would feel very comfortable using ABAQUS.

MR. SIEBER: There are some opportunities for deviation between what you calculate.

MR. MAJUMDAR: Oh, yeah.

MR. SIEBER: Because you don't really know how rigid the supports are for --

MR. MAJUMDAR: There is some uncertainty in that, yeah, yeah.

MR. SIEBER: And material properties have some variability as to what the handbook value is.

MR. MAJUMDAR: Sure, sure. There's all kind of heat to heat variation, welds.

CO-CHAIRMAN FORD: So all of these uncertainties, physical uncertainties can be addressed by this fundamental code.

MR. MAJUMDAR: You have to model it correctly.

MR. PAGE: We're trying to improve dramatically what was previously done in previous work, and we think this does do that.

Perfect? I don't know that we'll ever achieve perfect.

MR. SIEBER: That's why you can't get perfect.

MR. MAJUMDAR: If you put garbage in, garbage out, but do it perfectly.

CO-CHAIRMAN FORD: Sure.

MR. PAGE: But I think these models, we really sat through a couple of sessions of intensive assumptions on where we put the supports, what's allowed to move, what's not allowed to move, and so we looked in great detail at the actual down to the inch --

MR. SIEBER: Well, the fact is there is no such thing as a rigid support.

MR. MAJUMDAR: Yeah, but we are also supposed not really though.

MR. PAGE: No, no, but you can be rigid with respect to something else if this is --

MR. SIEBER: Well, that's why you put in the model and then you get an answer that approximates what really happened.

MR. MAJUMDAR: And that's the best we can do. What else are we, other than doing a test, full scale test, whatever, are we going to do?

MR. PAGE: Yeah, we assumed that the reactor vessel was not going to move. That nozzle was going to stay in place. We assumed that the pressurizer nozzle was not going to move. We went through and we had a group. We had like six or seven people sitting in a room at Oregon that were people very familiar with designs, and we sat down and decided what was this thing going to be like, what were going to be the assumptions.

And actually all of us agreed at the end that those would be good assumptions for this model. Now, we're relying that this is probably as good a code as you're going to get at this point to do this analysis.

MR. SIEBER: You know, they actually do test these things. Part of the testing sequence for starting up the plant is when you heat it up, you measure where everything moves to.

MR. PAGE: Well, actually that's where they do the adjustments on the --

MR. MAJUMDAR: That's a simple calculation. There's no stress. The things move unconstrained. That is proved.

CO-CHAIRMAN FORD: Okay, but, Jack, what you jut said is a very useful statement. Actually when they start out, they measure deformation of those pipes, et cetera.

MR. SIEBER: Yeah, through that limited temperature range. Now you're talking about --

MR. MAJUMDAR: Now the question is --

MR. SIEBER: -- temperature changes here.

MR. PAGE: When they do the measurements you're talking about they go like in the earlier picture a couple of slides back. You'll see some of those seismic supports that aren't really in contact with the pipe, but they go through, and the shims on the end on the stop, they make sure all of those at temperature are in the correct locations.

MR. SIEBER: The plant grows. It gets bigger. It gets hotter and it get wider.

CO-CHAIRMAN WALLIS: That's what this means? NL means normal operation here?

MR. MAJUMDAR: Yeah, it means normal operation, yeah.

DR. KRESS: RT means rupture time?

MR. MAJUMDAR: Where? No, room temperature.

DR. KRESS: Room temperature.

MR. MAJUMDAR: There's no rupture here.

DR. KRESS: So these things would be room temperature?

MR. MAJUMDAR: It does heating it up uniformly.

DR. KRESS: All right. At what point are you heating this thing up to?

MR. MAJUMDAR: Up to normal operation

MR. PAGE: This is just a benchmark. This is just a starting.

DR. KRESS: Normal operation temperatures.

There's no creep involved in this. This is just thermal expansion.

MR. MAJUMDAR: This is thermal expansion plus the mismatched threads.

DR. KRESS: Now I've got you.

CO-CHAIRMAN WALLIS: And there are measurements in this.

MR. MAJUMDAR: -- not be constrained from the supports, I believe. The supports are allowed to move out.

MR. SHACK: He doesn't want to introduce an artificial constraint by locking the steam generator.

MR. MAJUMDAR: Too early.

MR. SHACK: It's too early. So he has to have the realistic thermal expansion up to a certain point, and then he's going to lock it, and it goes into his creep analysis.

DR. KRESS: I understand.

MR. MAJUMDAR: The question is if this type of deformation, once you go beyond normal operation and severe accident remains, then you're going to see more of these deformations, and consent to that type of deformation will cause stress, and these kinds of stress are not included in RELAP 5.

So this, for example, reduce first in the elastic stress. Suppose we said no plasticity or creep, and we did a simple elastic stress at normal operation again, and I'm plotting here the stresses, and as you can see, those stresses here are very low. Blue, blue is pretty low here.

CO-CHAIRMAN WALLIS: What are those units on those stresses there?

MR. MAJUMDAR: These are megapascal.

CO-CHAIRMAN WALLIS: Three hundred?

MR. MAJUMDAR: Yeah, megapascal, yeah.

CO-CHAIRMAN WALLIS: Three hundred? That's all?

MR. MAJUMDAR: Yeah, that's pretty high.

CO-CHAIRMAN WALLIS: It's above the yield strength?

MR. MAJUMDAR: You yield 172 megapascals. So look at the [UDTSFA] located on the junction here, and that's primarily because we are modeling the structure by sheer elements.

CO-CHAIRMAN WALLIS: Does this happen in normal operation? You reach that and it actually yields at that junction?

MR. MAJUMDAR: It's very local. It's not general throughout the structure. Very locally, and that's because secondary stress, but a little deformation will take care of that.

CO-CHAIRMAN WALLIS: So as you heat up and cool down, that thing wiggles and yields.

MR. MAJUMDAR: Yeah, but basically the whole structure is at at pretty low stress.

CO-CHAIRMAN FORD: You've got a small pipe or relatively small pipe going into a large hot leg where there's a large stress concentration. Under normal operations, do you get cracking there, fatigue cracking?

MR. SIEBER: It's a thermal sleeve.

MR. MAJUMDAR: A thermal sleeve in there, yeah. There's thermal sleeve in there.

CO-CHAIRMAN FORD: I wasn't thinking of thermal stresses, Jack. I was thinking of just --

MR. MAJUMDAR: This is a difficult stress concentration area, but I don't think there has ever been a case of cracking there.

MR. SIEBER: I don't remember any.

MR. SHACK: Again, that would be analyzed as part of the stress analysis for the piping. You would, you know, do the thermal stress calculation in a fatigue life, you know. So I'm sure there's a CUF for that joint

CO-CHAIRMAN FORD: My follow-up one question, Bill, was that I asked for what parameters went into the uncertainty analysis during severe accident. So what would happen if you had even a CUF of half and there's a considerable crack in that pipe that wasn't protected?

MR. SHACK: No, no, no. CUF means there's no crack at all. You haven't initiated a crack yet. You design against initiation in the ASME code. It's not a flaw tolerant design. It's a no crack initiation design.

CO-CHAIRMAN FORD: Certain gaps are defined as initiation.

MR. SHACK: No, no, no, no. In this case you're avoiding all initiation as in smooth surface.

MR. MAJUMDAR: No cracks are --

MR. SHACK: No cracks allowed.

MR. MAJUMDAR: Cracks are not observed.

CO-CHAIRMAN FORD: Okay. We'll discuss that later. You've got to do it for the ASME code as initiate, as we understand it, but if you had a crack at that point where you might expect there to be a crack during normal operation for start-up and shutdown, that presence of that preexisting crack input into your severe accident analysis.

MR. MAJUMDAR: No, right now we did not include that, any crack at all. We assume everything is free of cracks.

MR. PAGE: I think when we looked into the crack situation, the flaws, flaws are quite a big thing obviously with tubes because tubes are extremely -- these are very large, massive, robust structures.

DR. KRESS: Keep in mind, Peter, if that thing fails, that's a good thing.

(Laughter.)

MR. PAGE: Yeah.

DR. KRESS: So if they want to be conservative --

MR. PAGE: You have to be backwards of your normal approach. You have to say it's almost pristine. It's almost pristine.

MR. MAJUMDAR: It's under normal thinking you want stuff to fail as late as possible. Now you're trying to make the thing fail as early as possible.

MR. SHACK: So what you have to do is make sure we analyze every assumption to make sure we don't build a conservatism in because we're going to make this thing fail prematurely. So your whole thinking gets reversed. We're looking at every possible conservatism we've introduced in trying to remove it because we don't want to induce an early failure.

Early failure is good.

MR. MUSCARA: When we started out, the presence of flaws was one consideration. Eventually you may include flaws that you might expect from fabrication. From service induced, I think we've decided that these components would not experience very much in the way of service induced flaws.

So if you're looking at fabrication flaws, they probably don't have much of an effect.

MR. SIEBER: Well, the temperature differential from one end of that line to the other is about 100 degrees.

MR. PAGE: No, it's not very much.

MR. SIEBER: And there's flow through it all the time. So there's a gradient.

MR. MAJUMDAR: Now, here you're employing the effective elastic stress after the severe accident has started at 14,400 seconds. So the pipes have really moved, and the stresses are very high, and now the highest stress on this, on this point is more than 1,000 megapascal. So they're way beyond the yield, and therefore --

CO-CHAIRMAN WALLIS: Yeah, that's right,

and how can you get there?

MR. MAJUMDAR: Well, the conclusion is that plasticity will play a significant role. So you cannot get away with elastic analysis.

So to do elastic-plastic analysis, we need to yield the ultimate properties like that, and this is a typical 316 stainless steel yield here and ultimate strength there that are not available beyond 1089 K.; 1,500 would be the best.

Since there's none of that high temperature in the ultimate approach, so the [UDTSFA] information drops very rapidly, and for 304 stainless steel, it drops to within one and five percent at greater than 1,200 K. As you see, the [UDTSFA] in form elongation really drops to almost two percent or one percent, although the [UDTSFA] product elongation stays very high.

This is the key [UDTSFA]. Now, we express [UDTSFA] the function of the power loss to the stress, stress mostly to the power n, and again, the data were available up from 866 to 1089 degrees Kelvin here, and beyond that we didn't have data. So we used this explication to extrapolate the A beyond 1089, and M as shown here.

Now, we are plotting the --

CO-CHAIRMAN WALLIS: That's great precision with which you know log A, isn't it?

CO-CHAIRMAN FORD: And you've got no concern -- this is a rhetorical question -- you've got no concern about changes in the creep mechanism by going that extra amount? There's not much in extrapolation.

Do you have concerns about changes in the creep?

MR. MAJUMDAR: Creep mechanism?

CO-CHAIRMAN FORD: Creep mechanism.

MR. MAJUMDAR: But we actually believe that severe accident is such a short event that long-term creep mechanism that are equated on cavitation and stuff like that are not really applicable here. They're over in a couple of hours. So these are more or less, I guess, slow tensile rupture. What they call creep rupture here is really a very slow strain of creep rupture.

You're not talking about cavitation and long-term creep rupture there.

CO-CHAIRMAN WALLIS: It's interesting to see a factor of E to the minus 31 in anything other than a PRA.

(Laughter.)

MR. SHACK: We can change that with units.

MR. MAJUMDAR: So the elastic stress distribution, now that stress, maximum stress, is to be 1,000 megapascals, now is down to 253 because we have produced plasticity and creep. Here we see elastic stresses, and if you look at the bottom half, the bottom half is colder and higher stress than the top half, which is hotter as you would expect where the end stress goes down with the temperature.

CO-CHAIRMAN FORD: I'm sorry. Just going back to your previous graph 21, boy, those stress components are really high, aren't they? So you had better know what your stresses are.

MR. MAJUMDAR: Creep is not used for that, but stress has to be really accurate.

CO-CHAIRMAN FORD: And so that would be fed into your uncertainty analysis, which would be fed to the --

MR. MAJUMDAR: Well, we varied the creep rate by a factor of two, I think, and then seen the effect.

CO-CHAIRMAN WALLIS: Is that normal?

MR. MAJUMDAR: Under the creep rupture that we collected from the literature, this is what 316 stainless steel and we've treated it with the

Larson-Miller parameter that Don was talking about earlier. You've got a Larson-Miller parameter as defined here, and the fit is pretty good actually, and with the C, the constant is equal to 14 to get the best fit together.

But the only caveat is that if the creep damage was considered only if the in plan principal stress is tensile. If the stresses are compressive, you don't considered creep damage to be active.

CO-CHAIRMAN FORD: Now, I seem to remember that the creep equations are also dependent on the environment. I'm just talking now from gas turbine technology, as well as the applied strain weight. Do you take into account those changes?

MR. MAJUMDAR: With this stress, this test has applied stress, applied load, hanging load so that there's a constant load.

CO-CHAIRMAN FORD: Right.

MR. MAJUMDAR: So there's two stress changes to the test, but --

CO-CHAIRMAN FORD: Now, you're changing the temperature?

MR. MAJUMDAR: No, this is not. This is a constant isothermal temperature.

CO-CHAIRMAN FORD: but if you change the

temperature.

MR. MAJUMDAR: Yeah.

CO-CHAIRMAN FORD: You also will obviously change the creep. It is not necessarily by that formulation, is it, by changing --

MR. MAJUMDAR: Well, this is what -- that's a good point. We actually ran it several years back. We had a severe accident test done on steam generator tubes with constant internal pressure and at temperature ramp, and then we used this linear time fraction damage to predict rupture of that similar tube. Using this loss similar parameter for Alloy 600 tubes going up to 16, and we were able to predict the failure rupture of those tubes quite successfully. That was a condition of constant stress with the ramping temperature.

CO-CHAIRMAN FORD: So you have done separate studies of the effects of known isothermal creep conditions.

MR. MAJUMDAR: That's right. Alloy 600 tubes.

MR. SHACK: An, again, that might not be true if we had a true creep case, you know, of a real design situation where you're talking about thousands and thousands of hours, but again, we're talking about situations in which the time of interest is an hour at most sort of thing, that, you know, you're really in the creep regime.

Once this thing starts heating up and you start creeping, the temperature is ramping up and everything is going very rapidly.

CO-CHAIRMAN FORD: Well, I think that stuff that Soji (phonetic) does and other people have done, you take these exhaustion theories of creep, and now you start to change things in terms of it's non-isothermal or it is changing stress conditions, and you just cannot add --

MR. MAJUMDAR: Well, there's a big debate, I mean, if time fraction is good or what, and that's a different argument, but we have used the linear time fraction rule for Alloy 600 tubes under a constant hoop stress with a rising temperature and predicted the rupture of both flawed and non-flawed tubes quite successfully.

CO-CHAIRMAN FORD: Okay. So prototypical conditions have been used.

MR. MAJUMDAR: Then we're talking about pipes, big pipes here.

CO-CHAIRMAN FORD: Yeah.

MR. MAJUMDAR: Okay.

CO-CHAIRMAN WALLIS: Something failed in the quality control of pioneering science and technology on your vertical axis there. You've got two ones and two twos and two threes. There's no way that can be.

MR. MAJUMDAR: That's really 2.5, 3.5.

Okay. Now we covered our life prediction, creep rupture, failure prediction. Creep failure of exhaustion of material creep ductility, all by the accumulation of creep damage. Either way, we develop these historically either the exhaustion of ductility or damages [UDTSFA].

Failure by exhaustion of creed [UDTSFA] is when the affected heat strain is in some critical value which we call the creep ductility. While the time to failure is insensitive to the actual value of the creep ductility, I'm not sure why, because the [UDTSFA] it doesn't matter whether creep [UDTSFA] is 20 percent of [UDTSFA]. Time to rupture is [UDTSFA].

The [UDTSFA] damage rule is linear time fraction damage [UDTSFA]. This is what is used in the A-74 in the Subsection [UDTSFA]. What we are finding is time to failure predicted by either method, either by the [UDTSFA] exhaustion or the damage rule is a pretty similar feature. There's not much difference, 20 to 25 percent [UDTSFA] and damage [UDTSFA] prediction.

So in our analysis we really attempt to predict [UDTSFA] satisfied in the average member and stress that must be tensile for a significant portion of the structure, and if there is compression, then we don't consider it as a creep failure. Thus, it would be tensile, and the whole thickness of the -- so there cannot be one point that is the damage which is one, and we don't consider that the failure unless the whole section reaches a value of one.

Now, the question in the piping analysis, the driving force was stress, is expansion of the pipe due to temperature rise that creates the stress, but as your temperature rises, it tends to relax all of the stress. So there are two competing mechanisms. One is driving the stress up. The other is driving to try to relax the stress.

Now, if the creep deformation is not fast enough to relax the stress, then failure can curb a tensile rupture. That means there could be tensile [UDTSFA].

At high temperature stainless steel [UDTSFA]. As I said earlier, two percent beyond which [UDTSFA] localization occur. So what we said that if true thickness average temperature tensile plus the strain issues a value of two percent or more before creep damage is just a value of one, then the section is considered to have failed by tensile rupture.

So the failure can have either tensile rupture or [UDTSFA] rupture depending on which one is involved.

Here plotting the tensile and creep damage accumulation of the [UDTSFA] bid surface at this time [UDTSFA] to 580. If you're wondering what's magical about this number, this is the number at which the ABAQUS prints out the output. So that's where it started. There's nothing magical about this time here.

CO-CHAIRMAN FORD: I'm sorry. I didn't hear you. What was magical about 14?

MR. MAJUMDAR: There's nothing magical about --

CO-CHAIRMAN FORD: Nothing.

MR. MAJUMDAR: -- this time here. It's just that point ABAQUS printed out the data.

Now, the effective plastic strain I'm plotting on this side and on the mid-surface, as you can see, the very high plastic strain right near the reactor nozzle, not in the nozzle itself, but in the hot leg next to the nozzle, the nozzle stays very cold. So there's not really much deformation at this stage.

And this maximum of four percent here, and in the surge line, the maximum key damage occurs near the bend, 17 percent damage [UDTSFA], but the inside damage is highest in the hot leg near the reactor vessel nozzle here. The key damage [UDTSFA] surge line bend area.

[UDTSFA]in elastic strain accumulation, that means -- by that I mean both plastic and creep strain accumulation. In the stop [UDTSFA] circle here, that's the [UDTSFA] creep in the hot leg. And the hot leg is an expansion of time. This is, again, [UDTSFA]. So that's 14,000. That's 14,200, and so on.

This is the variation of the [UDTSFA] plastic strain maximum [UDTSFA] plastic strain hot leg, around 14,400 it starts going up, and two percent is reached around 14,500. So the two percent tensile membrane stress is accumulated in hot leg after 14,500 seconds.

At that point the creep strain is pretty low. It's not yet --

CO-CHAIRMAN WALLIS: How does this 14.5

appear on this graph?

MR. MAJUMDAR: It is [UDTSFA] five.

CO-CHAIRMAN WALLIS: You mean there's a one in front of those fours?

MR. MAJUMDAR: Pardon?

CO-CHAIRMAN WALLIS: There's a one in front of all of those fours?

MR. MAJUMDAR: Yeah, this 4,000 here.

CO-CHAIRMAN WALLIS: It should be 14,000?

MR. MAJUMDAR: Fourteen. They add 10,000.

CO-CHAIRMAN WALLIS: This is another one of those quality control things.

MR. MUSCARA: No, no. He started the analysis at 10,000 seconds.

MR. MAJUMDAR: At 10,000.

CO-CHAIRMAN WALLIS: Well, but you've got to be consistent with your two.

MR. MAJUMDAR: Yeah. So the hot leg fails at -- is predicted to fail at 14,500 degrees at 500 seconds. At that same point, the hot leg creep damage, if you notice, that it is pretty small, pretty low.

CO-CHAIRMAN WALLIS: It goes so rapidly that moving things around doesn't really change it very much.

MR. MAJUMDAR: That's right. It starts to pick up really rapidly here.

If you look at the surge line, the surge line, plastic strain, that's the blue line here. That was just two percent here, around 14,550. It's only 50 seconds later the surge line is predicted to fail at the end area.

CO-CHAIRMAN FORD: So just to make sure I understand, at 14,000 seconds, the temperature has not increased that much at least as far as the exponential creep.

MR. MAJUMDAR: That's right. At 14,000 there is a break in the temperature ramp. Remember I showed you the ramp, slow, eight degrees per minute to 24 degrees per minute.

CO-CHAIRMAN FORD: Okay.

MR. MAJUMDAR: Six degrees per minute to 24 degrees per minute. So this is where the temperature really starts taking off.

CO-CHAIRMAN FORD: Okay.

MR. MAJUMDAR: And that's where the creep starts [UDTSFA] actually moving and plastic starts actually moving at that point.

CO-CHAIRMAN WALLIS: So this is where the temperature starts taking off everywhere.

MR. MAJUMDAR: Yes.

CO-CHAIRMAN WALLIS: So this is sort of a race between this is how long it takes to creep and how long it takes to --

MR. MAJUMDAR: That's right. It's a race.

CO-CHAIRMAN WALLIS: -- something else at the steam generator.

MR. MAJUMDAR: How long this temperature is going up is the driving force is going up because the pipes are expanding pre-load. So there is stress developed, and the creep and plastic is trying to relax the stress out. So there's competition between the stressing and the relaxing, and whoever wins out gets to --

CO-CHAIRMAN WALLIS: Now, when it breaks, does it just open up a fish mouth thing or does it snap?

MR. MAJUMDAR: It's going to be locally --

CO-CHAIRMAN WALLIS: Does it separate and bounce so far because of the --

MR. MAJUMDAR: That's a hard thing to predict. What we are predicting, does it locally -- not a point division, but some volume area, the damage is [UDTSFA], and we predict that locally there will be some kind of rupture in the [UDTSFA] and they open up a gaping hole to which the steam will escape.

CO-CHAIRMAN FORD: So essentially your mitigation strategy in this whole thing, without being flippant, is that you want everything to last okay out to at least 14,500 seconds, and then you're going to rely on this to be your safety relief valve.

I'm trying not to be flippant.

MR. PAGE: I think to say it more precisely, we don't expect anything to happen before you enter this window here. So this is just a snapshot when all of the action takes place. There's no reasonable thoughts of a loss, a rupture of anything prior to that, at least of these components.

CO-CHAIRMAN FORD: Yes, okay.

MR. PAGE: Now, the reactor coolant pump seals, maybe, but not something like this or even the manway might open up a little bit. That's not necessarily a creep type failure, but I'm saying the actual --

CO-CHAIRMAN FORD: I notice that second sentence. Containment isn't bypassed, is it?

MR. PAGE: The containment isn't bypassed, but I'm saying up until the beginning of this window here where we started that there really is no activity that to draw it out this long. This is really where all of the action is for the piping, for the piping.

MR. SIEBER: Well, you end up with an interesting thing on the manways. You know, those are flexitalic gaskets which are --

MR. MAJUMDAR: They cover the manway. [UDTSFA] on the manway.

MR. SIEBER: And you get that hot enough and they will melt, and then you get a leak. It's not a rupture, but it's a pretty good size leak, which reduces the stress throughout the system.

MR. PAGE: Well, not only that, but even if it wasn't a huge leak, we'll get to it in a little while, but we were also wondering about the possible disturbance of the flow in the mixing in that chamber area, which could be affected and could affect how fast the tube heats.

MR. SIEBER: That's right. It would change that flow because the manway is right there, and that looks like a pretty delicate --

CO-CHAIRMAN WALLIS: But if you are really concerned with this problem and you weren't sure which would break first, then you could conceivably put in some device like this feasible thing made out of some other material, which at 1,200 degrees K. would separate.

MR. MAJUMDAR: Sure.

MR. PAGE: You could build a rupture disk out of the electrosleeve material that's two inches in diameter and back it up with a block valve like PORV has got a --

CO-CHAIRMAN WALLIS: This might not be all that complicated.

MR. MAJUMDAR: If we have electricity --

MR. MUSCARA: A number of us have been recommending that for years, but it's not something --

CO-CHAIRMAN WALLIS: Okay.

MR. MUSCARA: The utility might decide to use some indication. This could be one of them. It has been suggested. I'm not sure how serious it has been taken.

DR. KRESS: It probably won't pass the [UDTSFA].

CO-CHAIRMAN WALLIS: Well, it's going to be --

MR. PAGE: No, you're probably right because of the probability picture. The probability picture is so low. However, in generic safety issues, which you probably have seen several of those in the past, when you did the regulatory analysis and you did the cost benefit, at the end of the analysis you also had this thing called "other considerations."

Usually that method -- this is almost impossible, but if it does happen, you're really going to -- when the wing really does fall off the plane, you know, you do want a parachute.

CO-CHAIRMAN WALLIS: It might be cheaper than continuing to do all of this analysis.

MR. PAGE: You mean to put in the rupture disk?

CO-CHAIRMAN WALLIS: Your cost benefit should include the cost of continuing to do a lot of expensive research.

MR. PAGE: Yeah, but we're doing that, not the utilities.

CO-CHAIRMAN WALLIS: Maybe that's not our point of view.

MR. SIEBER: The same view.

MR. MAJUMDAR: Okay.

CO-CHAIRMAN FORD: I got you off the track. Sorry.

MR. MAJUMDAR: Just to show the damage, [UDTSFA] looks at that. It's still 17 percent. So it's not anywhere near rupture, but it's starting to take off in the hot leg and the surge line. They're beginning to take off. So if the tensile rupture didn't [UDTSFA], the [UDTSFA] rupture would fall off pretty soon.

CO-CHAIRMAN WALLIS: We should put fins on this thing to cool it. The heat plug has a big defect. Take off the insulation.

MR. MAJUMDAR: In some sensitivity analysis, first of all, we reduced the thermal conductivity of stainless by 20 percent.

CO-CHAIRMAN WALLIS: Well, surely the insulation has a factor of two on heat flux at least. Is there insulation on the surge line?

MR. MAJUMDAR: No, it's [UDTSFA] fully adiabatic. There's no heat transfer now on the outside surface.

CO-CHAIRMAN WALLIS: But if you took off the insulation. The surface heat flux on the surge line? Is that what you mean by that?

MR. SHACK: You want this to heat up and fail.

CO-CHAIRMAN WALLIS: The second bullet?

MR. MAJUMDAR: In the case of – this is what I'm doing on the inside, interior. What we'd really like to do is to increase the heat transfer coefficient just to see all --

CO-CHAIRMAN WALLIS: Oh, this is the

inside heat transfer.

MR. MAJUMDAR: Yeah, yeah. We wanted to see what the effect of changing the heat transfer --

CO-CHAIRMAN WALLIS: Well, that's harder to do, I think.

MR. MAJUMDAR: Yeah, very hard. But I would say in ABAQUS we couldn't input the heat transfer coefficient directly. So we are developing increased surface heat flux that was given to us by a factor of two, and that is a bigger face than that because that changes the temperature history significantly as you can see in the flux here.

CO-CHAIRMAN WALLIS: I wonder how well we know heat flux in these situations where there's a lot of temperature variation.

MR. MAJUMDAR: That's why I'm in a discussion with Chris on them. We decided a factor of two would be --

CO-CHAIRMAN WALLIS: This is where you could do some more fluent stuff because you can't just blindly use some standard Dennis-Bolter or some kind of semi-correlation. It doesn't work. You've got --

MR. MAJUMDAR: Hopefully in the future we'll get uncertainty in the heat flux from Don, from the round that he does.

CO-CHAIRMAN WALLIS: Okay.

MR. MAJUMDAR: Okay. The next item that we looked at is the manway. The manway, this is a hot leg manway, and we included the lower half of the steam generator so that it made the application of the heat as a special bonding condition simpler, but we included the insert of the cover, the cover plate of 16 bolts and the gasket in the final analysis.

Actually we did not include the gasket because the gasket is so soft it does not affect the stress that much, but the gasket would affect the leakage area once it has [UDTSFA] and depending on how much spring-back there is.

Now, we modeled the pretensioning at room temperature and the manway was uniformly heating. The gasket, as I said, was negligible. Failure was defined as the creation of floor [UDTSFA] two inch diameter hole, lifting of the collar plate.

At some point the bolts would lose all of their tensions, the tension in the bolt, and then the cover plate would start lifting up and allow the steam to escape, and when the leakage area would accumulate the two inch diameters hole, call that a failure of the gasket or of the manway.

CO-CHAIRMAN FORD: I take it these never

leak?

MR. MAJUMDAR: Pardon me?

CO-CHAIRMAN FORD: These gaskets never leak?

MR. SIEBER: Yes, they do.

CO-CHAIRMAN FORD: They leak, boric acid corrosion?

MR. SIEBER: Well, usually when they leak it's right after refueling. Somebody is bolting it on, and there’s damage to it or they didn’t get it in there right, and as soon as you try to do the hydro or design pressure test, it leaks and you know it.

MR. MUSCARA: It's the secondary water.

MR. SIEBER: No, it's on the primary side.

MR. MAJUMDAR: This is the primary side.

MR. PAGE: In that picture of the hot leg it’s coming in at the other 45 degree angle. It's coming in hitting the separation plate.

MR. SIEBER: There, the secondary side.

CO-CHAIRMAN WALLIS: No, I think the concern is --

MR. SIEBER: One on top and then there's the handles.

CO-CHAIRMAN WALLIS: Jack, do you get slow leaks in these that would give you boron, boric acid, corrosion of the bolts?

MR. SIEBER: Theoretically, yes. I've never seen it.

CO-CHAIRMAN WALLIS: You've never seen rusty bolts on these things?

MR. SIEBER: Not on the manways. It's something you go in every outage, and so because of all the steam generator inspections, the people who work on those manways really know what they're doing. There's, you know, a reg. that places it in place and, you know, new gaskets all the time.

I've seen rusty looking bolts, but I've never seen the deterioration to the extent that it would cause me to believe that it would be subject to an early failure.

MR. MAJUMDAR: Our primary concern was the bolt relaxation, bolt load relaxation. Here I'm showing the bolt load relaxation without creep because there's no creep in the bolt. You don't allow creep to occur, and there is some relaxation due to the change in the modulus elasticity of the bolt material.

I'm plotting temperature with the bolt load here. On the other hand, if you allow creep in the top right here, then the bolt load relaxes by about 14,000 seconds again, which corresponds to about

435 degrees Centigrade. At pretty low temperature the bolt --

CO-CHAIRMAN WALLIS: Now, when the bolt relaxes and creeps, presumably the first thing that happens is the gasket leaks.

MR. MAJUMDAR: Well, once this -- it doesn't go down to zero, as you notice that, because the steel has to support the pressure acting out of power. Beyond this point the cover plate starts lifting off, and you start getting --

MR. SIEBER: And the gasket leaks.

MR. MAJUMDAR: The gasket would leak. You might even get blow out of the --

MR. SIEBER: Well, the gasket is a spiral wound metal --

PARTICIPANT: Flexitallic.

MR. SIEBER: It's a Flexitallic. There's a big backing ring which gets us to about this big that holds it all together so that it won't boil out.

MR. MAJUMDAR: Now, in this figure I show that all of the 16 bolts are preloaded to exactly the same preload. In other words, this lower figure, what I've said is that after the bolts are preloaded to 85 percent of the design preload and the others are 100 percent, then the bolt relaxation follows these two curves. Bolts one and five can lower the load. It will start relaxing here, but both sets of bolts relax to zero or to the final value at about the same time, 14,000 seconds.

So that means they adjust the variability in the bolt preload will not change the relaxation point significantly.

Now, here, plotting the left figure here, I'm plotting the contact pressure on the junction of the plate and the bolts around the circumference, and this is at room temperature. Once the bolts are tightened, it gets a contact pressure distribution, something like that, and as you increase the temperature, the contact pressure reduces, as you can expect, and by about 450 degrees C. the contact pressure is reduced to zero. That's been the junction starts opening up.

On the right side I'm plotting contact opening versus the opening displacement here.

CO-CHAIRMAN WALLIS: It opens up a lot.

MR. MAJUMDAR: And so by 450, it starts opening and --

CO-CHAIRMAN WALLIS: It's a huge amount.

MR. MAJUMDAR: -- because we start getting a pretty large --

CO-CHAIRMAN WALLIS: And a quarter of an inch opening all around?

MR. MAJUMDAR: That's right, yeah. It's predicted to be that much. That's 640 C., 650 C. It's a pretty high temperature.

CO-CHAIRMAN WALLIS: What's the gasket doing when it is opened up a quarter of an inch?

MR. MAJUMDAR: Anybody's guess. The gasket probably gets blown out, but the main thing is that there's a big leakage there.

CO-CHAIRMAN WALLIS: There's an enormous leakage presumably. That's to be avoided, isn't it?

MR. MAJUMDAR: One thing is certain is the bolt properties, as I said, the bolt creep properties we really don't know that good. So we're going to do some tests and nail it down.

MR. MUSCARA: But they're not high temperature materials.

MR. MAJUMDAR: Yeah, they're not.

CO-CHAIRMAN WALLIS: So the temperature of this plate is determined by Chris Boyd's recirculation pattern in the bottom of that steam generator.

MR. MAJUMDAR: Actually it doesn't take much of a plastic strain to relax the bolt load out. All you have to do is relax the elastic strain, and that takes very little plastic strain.

DR. KRESS: Where's your rupture disk?

CO-CHAIRMAN WALLIS: It may be, but it's in the wrong place.

MR. PAGE: No, this will be a great place.

CO-CHAIRMAN WALLIS: There's a good place here?

MR. MAJUMDAR: Oh, yeah.

MR. PAGE: Because if you can take a 19 inch hole and lift it up enough to equate to a two inch hold in a reactor coolant system, you've blown down the whole system.

CO-CHAIRMAN WALLIS: Oh, yeah, this is still in the containment. Okay, good.

MR. PAGE: You're talking about something this big around, you know.

CO-CHAIRMAN WALLIS: Oh, I guess you're right.

MR. SIEBER: It would blow it down pretty fast, but the chances of it failing and unzipping are pretty low compared to leaking.

MR. PAGE: Yeah, we're just talking about liftoff. We're not talking about --

CO-CHAIRMAN WALLIS: Liftoff would be something else.

MR. PAGE: No, no. I mean, I'm just talking about --

DR. KRESS: We would have a whole new containment.

MR. PAGE: These are not rupture bolts like in a rocket ship, but I mean, if you can just give a space in there and start blowing out, it shouldn't take a lot.

MR. SIEBER: It's sort of a delicate balance anyway because the pre-tension of the bolt is designed to withstand the force of 2,500 pounds of RCS pressure, which is the design pressure limit, and still keep the gasket preloaded, but you know, as you heat up the plant, you know, some of that balance of force is thrown away.

CO-CHAIRMAN WALLIS: So when does this happen? At what seconds?

MR. MAJUMDAR: This is at a time. It develops the temperature. I don't have it right now, but it's around 14,000, slightly --

CO-CHAIRMAN WALLIS: Everything happens around the same time.

(Laughter.)

CO-CHAIRMAN WALLIS: So this is like sort of the final five seconds of the Super Bowl.

DR. KRESS: More like half time.

MR. SIEBER: This is half time, yeah.

CO-CHAIRMAN WALLIS: Oh, I don't know. This is more like the end. Which team wins is all decided in a few seconds.

MR. MAJUMDAR: The next thing we looked at is this registered [UDTSFA] detector, and the welds I'm talking about, this is RTD. The scope sits here on the hot leg, and the welds, full transition welds on the water load, OD and the ID surface, and this is the OD weld and that’s the ID weld, final element model. That's the RTD.

So we modeled both the RTD. We include the whole inside, and the welds and the hot leg. Now, remember the upper half is hotter than the lower half. So we put in the heat transfer coefficient for the upper half and the corresponding heat transfer coefficient for the lower half and did a thermal conduction analysis first, then used that temperature and pressure failing the stress analysis.

CO-CHAIRMAN WALLIS: Have these RTDs always been in these hot legs?

MR. MAJUMDAR: Well, yeah, there are three of them actually.

CO-CHAIRMAN WALLIS: These are the ones

that excited the staff at TMI when they got too hot, presumably? I didn't know they were there.

MR. MAJUMDAR: Yeah, it was there in the elbow.

MR. SIEBER: Yeah, they were there in the very earliest plants, before commercial.

CO-CHAIRMAN WALLIS: So when the staff got all excited about super heated steam in the hot leg, this is what was reading it?

MR. SIEBER: Well, the RTD, everything else is thermocouples, and the RTD is the only accurate instrument you have. If you want to know what the outlet temperature is because it's the hottest temperature other than in the pressure.

MR. MAJUMDAR: They say that the concern here is that the pressure is acting on this hope and trying to force this out of the --

CO-CHAIRMAN WALLIS: Trying to blow out the RTD?

MR. MAJUMDAR: The whole RTD. Once it blows it out, then there's a two inch diameter hole right there.

CO-CHAIRMAN WALLIS: Which is desirable.

MR. MAJUMDAR: Okay, and the next item I'm going to discuss later on is there's a socket weld around here that’s also volatile to failure.

CO-CHAIRMAN WALLIS: And these never leak with boron either?

MR. MAJUMDAR: Liquid?

MR. SIEBER: I have never seen it happen.

MR. MAJUMDAR: Again, I define failure. Now, the failure we're talking about is the failure of the interface within the weld and the RTD. That failure would cause it to blow out, and the failure is either --

DR. KRESS: Sheer failure.

MR. MAJUMDAR: Sheer failure, but what we do is the average effective plastic strength, two percent or 40 percent average creep strain, [UDTSFA], and then we say it's failed.

CO-CHAIRMAN FORD: But, again, this is a small tube welded into a large body.

MR. MAJUMDAR: That's right.

CO-CHAIRMAN FORD: With high [UDTSFA] residual stresses presumably. The analysis doesn't take into account they may be defected.

MR. MAJUMDAR: No defects, no defects, no.

CO-CHAIRMAN FORD: No, no. You're saying no defects, but what would the uncertainty analysis indicate if there were a defect?

MR. MUSCARA: That would make it fail even sooner. So if this fails, that's the end of the story. You don't need to know who the fail --

MR. MAJUMDAR: That wouldn't be the conservative assumption in this context.

MR. SIEBER: That would be a good deal.

CO-CHAIRMAN FORD: Well, this is the first time I've heard a cracked body is a good thing.

CO-CHAIRMAN WALLIS: Oh, it is in this case, very much.

MR. MAJUMDAR: In this context it is.

DR. KRESS: Well, you get a small break LOCA. It's not as bad as this.

CO-CHAIRMAN FORD: Okay. I learn something every day.

MR. MAJUMDAR: Okay. So that's the temperature profile in RTD at 14,000 seconds, the magic number. Now, perhaps it's hotter than the lower half.

The RTD tip actually heats up pretty rapidly because there's more mass and approaches that other tube as it approaches the hot leg.

MR. SIEBER: Actually, the RTD is modeling the fluid streams.

MR. MAJUMDAR: The tip is in the fluid

[UDTSFA].

MR. SIEBER: When you take the RTD out, you don't get a leak.

CO-CHAIRMAN WALLIS: You've got to answer my question.

MR. MAJUMDAR: You don't get a leak?

MR. SIEBER: No. It's in a weld. It's a thimble, and the thimble -- otherwise you would never be able to replace it.

MR. PAGE: Well, the RTD we got drawings of, the thimble, which is a cone, came down into the flow stream, but it had like five holes drilled into it.

MR. SIEBER: Oh, I've never seen that.

MR. PAGE: Well, I'd be willing to show you the drawing. That's the one we got.

MR. SIEBER: All right. [UDTSFA].

MR. PAGE: No, no. I mean, I wondered, too, but it seemed --

MR. SIEBER: I've never seen one made like that.

MR. MAJUMDAR: I guess the scope sits -- this is what we are calling RTD. It's really the scope, right?

MR. PAGE: Yeah, this is called the scoop.

MR. MAJUMDAR: Scoop.

MR. PAGE: It's like a fairly substantial metal thing, but it had five holes drilled in it that were what, quarter inch diameter? It was about four --

MR. SIEBER: -- inch?

MR. PAGE: It was about five inches down in the flow stream.

MR. SIEBER: Oh, quarter inch.

MR. MAJUMDAR: It's sticking into the flow stream about four or five inches, yeah.

We also got a drawing for the generic RTD for Westinghouse plants which are quite different from this design. This one was provided specifically for ZION plant.

MR. SIEBER: There might be something unique about that plant, but you could take the RTD out of the plants I worked in and it would not leak.

MR. PAGE: I think we're talking about three different things here. I think one is the scoop, which is what we had in mind, and then the thimble sticks down, and then the RTD, I think, sticks down in the thimble.

The thimble is actually quite thin, the one you're talking about. It's a fairly thin surface, and they have had failures of some of those, and so, I mean, I --

MR. SIEBER: Well, they may have.

MR. PAGE: I talked to the RTD guru, I guess, and we still haven't literally figured out the details of the innards of this thing, but this was a first cut of looking at the welds themselves.

MR. MAJUMDAR: But the welds are clearly defined on the drawing though. These two welds and whatever it's called. I don't know the RTD scoop. If those welds fail, then this thing is going to be --

MR. SIEBER: Yeah, it is welded in place.

MR. PAGE: That would be a two inch hold.

MR. SIEBER: Yeah, right.

MR. LONG: Just to clarify the structure there, that used to be a scoop. There are three of them, and it was actually sampling and taking flow out to a ring header that went to an RTD bypass manifold.

MR. SIEBER: Oh, yeah. They eliminated that.

MR. LONG: They eliminated the manifolds, but they then used these things as RTD welds, but the point was they wanted fast, you know, heat transfers. So they needed to put holes in there to get the fluid to touch the RTD more directly than through that weld.

MR. SIEBER: Strangely enough, those RTD manifolds were slow responding to temperature change.

MR. LONG: That's why they went to this.

MR. SIEBER: Correct. That's why you couldn't rely on them for protection.

MR. LONG: Well, it's too bad that they don't have them now if you really want something to fail because scooping the hot flow out into the thin pipe and taking it down by force load to the reactor coolant pump seal leak would have been treat at the moment, but --

MR. SIEBER: Yeah, right. You refreshed my memory. That was a strange design.

MR. MAJUMDAR: The average temperature of both the welds actually follow almost the same profile with time. This is typical stress distribution in the ID weld and RTD interface, and the stresses are not really that large so large scale plastic ending is not predicted.

CO-CHAIRMAN FORD: Sorry. Just to make sure I understand, on that previous plant, these are the stresses associated with a constant displacement weld; is that correct?

So you're looking at the changes -- the stresses at that particular time.

MR. MAJUMDAR: This is at that time on the ID weld.

CO-CHAIRMAN FORD: Is this the residual stress?

MR. MAJUMDAR: Oh, no. This is the stress due to the temperature, pressure, everything.

CO-CHAIRMAN FORD: And the residual stress.

MR. MAJUMDAR: Well, no, not the residual stress. Welding in the -- we did not assume any welding in these residual stresses.

CO-CHAIRMAN WALLIS: So what's the bottom line here?

MR. MAJUMDAR: Well, the next figure shows the stresses in the ID weld starts out high, compared to the OD rails, but we did creep, relaxes faster because the ID is slightly hotter, and the OD welds will follow this pattern.

There is a peak there in the stress, and this point is that 14,000 again. There is a change in the rate from six degrees per minute to 25 degrees per minute, and right before that, the creep trend takes off. You can have very effective creep strain versus time. Pretty low up to that point, and then it really explodes.

CO-CHAIRMAN FORD: And that's purely because the very high activation enthalpy for creep?

MR. MAJUMDAR: Well, plus the temperature is going up rapidly.

CO-CHAIRMAN FORD: Now, on your left-hand side you show a high dependency of stress, but you've also got a high exposure to stress on the creep rate.

MR. MAJUMDAR: Yeah, there's a high --

CO-CHAIRMAN FORD: So if there's any uncertainties in either the stress, calculated stress or the calculated temperature, you could be way to the left or right of that.

MR. MAJUMDAR: Well, that's a good point, and we have to do the uncertainty analysis to see what we've done.

CO-CHAIRMAN FORD: And can you bring down the thing to 500 seconds?

MR. MAJUMDAR: I'm sure you could make the heat large enough. I would show some of the heat rate.

CO-CHAIRMAN FORD: Okay.

CO-CHAIRMAN WALLIS: What you're going to find here because this is just the law that things never work out too well is when you put all of the uncertainties and all of these things; they all overlap; and you can't really tell which is going to happen first.

MR. PAGE: Unless you find the silver bullet that is 500 --

CO-CHAIRMAN FORD: This could be the silver bullet.

CO-CHAIRMAN WALLIS: Make it out of silver and it will probably pop out.

DR. KRESS: I think the proper, good uncertainty analysis that shows you that overlap would be extremely useful because then you could factor that into the probability of the failure and then check the consequences and see if you -- per a significant number of these plants, whether or not you exceed the safety goals. I suppose that would be the approach on how to deal with this issue.

You might not be able to confidently say that it's going to fail RCS before it fails in the steam generators, but you can get some sort of idea of the probabilities.

MR. MAJUMDAR: That's what the PRA does, and I think that's their responsibility, not ours.

MR. MUSCARA: We need to keep in mind that this is the old base case, and the temperatures are changing. They're getting hotter. So these numbers

I'm confident will drop. So we have the input. We just don't have a program in place yet to get the work started, but very soon we should be able to get the work started, use a new base case to rerun these things. Then I think we'll see more separation, and at that time with the new base case, we can do the sensitivity analysis.

This is the other instrument line I talked about before. It sits on the total RTD flange, this weld. Again, the effective -- if this weld fails, then this line will expel and there will be a one inch diameter hole, and the creep strain along those two interfaces are, again, pretty low up to 14,000 and then takes off.

So I made a summary of the failure times summary. The first row is a reference case. That is the reference old baseline case. This is the hot leg will fail by tensor rupture at 14,506 seconds. The surge line bend, again, tensile rupture, 14,550 seconds. The hot leg to surge line nozzle, slightly earlier, 14,250 seconds.

You don't predict any failure in the elbow because the elbow is under compression all the time. Now, this RTD to hot leg weld, that's predicted to fail at 13,890 seconds. That's the earliest failure we predict, followed by the instrument line socket weld here.

The manways is the last actually, 16,726 seconds. That's when it lifts up and [UDTSFA] weld into a two inch diameter hole.

Now, the bottom two rows of the variability check, uncertainty check, we first increased the creep rate by a factor of ten. What will it do? The failure of these two or these three are the creep rate dominated, and in that case the failure time would be reduced from 3,890 to 3,710, and so the headline would fail 100 seconds earlier, whereas the manway would be failing a lot earlier, about 1,000 seconds earlier.

CO-CHAIRMAN WALLIS: Where does the steam generator tube fail?

PARTICIPANT: Thirteen thousand --

CO-CHAIRMAN WALLIS: Thirteen, five hundred?

MR. MAJUMDAR: Well, we still don't know the exact failure point of the steam generator.

CO-CHAIRMAN WALLIS: Yeah, but it's in the same range as these numbers.

MR. MAJUMDAR: The same range, yeah. It will be near the area, yea.

PARTICIPANT: But there, again, we're comparing the old case and new case.

MR. MAJUMDAR: Yeah, we have to look at the tube failure in more detail.

CO-CHAIRMAN WALLIS: So the lowest thing you mention here that's possible is the hot leg nozzle failure.

MR. MAJUMDAR: No, the lowest is RTD.

CO-CHAIRMAN WALLIS: The earliest is 12,750 at the bottom with a sensitivity study.

MR. MAJUMDAR: Which one? Oh, this one, yeah. This is a the heat flux plate, too.

CO-CHAIRMAN WALLIS: So you're making occur the double ended guillotine break, which is impossible? No, it isn't impossible yet.

MR. MAJUMDAR: The single ended --

CO-CHAIRMAN WALLIS: Not under severe accidents, yes. So that would be interesting if you did that, as to what actually would happen. How would it break?

MR. MAJUMDAR: That's different. This is the initiation of the failure.

CO-CHAIRMAN WALLIS: Right. Does it just make a little hole that moves over a little bit?

MR. MAJUMDAR: Well, the temperature, high enough under -- there's enough load acting load so they'll probably open up.

CO-CHAIRMAN WALLIS: We're almost at the end, I think.

MR. MAJUMDAR: So that's where I said the discussion that all of the failure stops at close to 14,000 seconds. That's the time where the steam temperature ramp actually goes from .3 to 3Ds per second, and the failure time of the component will always be closed no matter how detailed the analysis and in forming more than 15 minutes apart.

Failure to focus on failure temperature or the relative failure time between the tube and the component.

MR. SHACK: Fifteen minutes is forever.

MR. MAJUMDAR: Fifteen minutes would be 900. That's 2,700 degrees heat. I think this would be less. I think maybe ten minutes would be best, five to ten.

MR. SHACK: We're being optimistic.

MR. SIEBER: Of course, if one thing fails, then [UDTSFA] that, right? It stops.

DR. KRESS: It changes everything.

CO-CHAIRMAN WALLIS: What's this hot inlet plenum?

MR. MAJUMDAR: This is still one of 500 degree wrap that was mixing. Whatever is done here is done.

CO-CHAIRMAN WALLIS: Where is that?

MR. MAJUMDAR: That was --

MR. SIEBER: It's in the steam generator.

CO-CHAIRMAN WALLIS: Well, it just seemed to be a much lower time, everything else.

MR. MAJUMDAR: One, oh, five, this is 105 here.

MR. SIEBER: Where? Oh, okay.

CO-CHAIRMAN WALLIS: So it's the hot leg going into the steam generator.

MR. MAJUMDAR: But without mixing. I think before mixing.

CO-CHAIRMAN WALLIS: So that's the one that could fail before anything else, significantly before anything else.

MR. MAJUMDAR: Yeah, actually Don's recommendation was to use the 106 because that's -- the initial level is using that line. We have an early failure.

CO-CHAIRMAN WALLIS: Why does that fail so early? It's not the hottest part.

MR. MAJUMDAR: But this mixed mean inlet

plenum, that's the cell he wanted us to use for the lower head. Actually the CFD calculations show a little less than this.

This conclusion is, again, the RTD weld that failed first, the difference case, and connecting following instruments, socket welds, the surge line, hot leg nozzle, the hot leg itself, the surge line then, manway, elbows. There was no failure. It's under compression.

Completed some sensitivity analysis that was showed the major factors controlling the failure of surface [UDTSFA].

[UDTSFA] on the tensile properties.

I have one slide of planned future work. During the next phase of the program, we are proposing to do some tests on the bolt material, some gaskets and some nozzle material, and we'll do analysis, the final analysis of the hot leg to the new baseline case. We try to treat some here a little more rigorously, and we try to estimate leak rate versus time through the manway once it lifts up.

Also there's an RCP leakage analysis to evaluate the three RCS piping.

CO-CHAIRMAN WALLIS: You don't plan to analyze the CE system?

MR. MAJUMDAR: Yeah, the last one is the CE.

CO-CHAIRMAN WALLIS: Oh, you do. Okay.

MR. MAJUMDAR: Not in the same detail, finite element, but some average.

MR. MUSCARA: Yeah, I should clarify. There is work going on to address the CE issue. Of course, the CFD indicated that that's a much different situation, but the general idea of the work is to develop a methodology and an infrastructure on how one would do a good PRA for this severe accident situation.

So we don't intend to do the CE in detail, but we're going to do qualitative analysis both from a thermal hydraulics point of view and the materials point of view and compare that to the one where we're doing the detail. So with the Westinghouse Model 51 and what we get there with respect to the failures.

CO-CHAIRMAN WALLIS: Well, this looks like a case where the model uncertainty is very, very important in the PRA.

MR. SIEBER: Is there anything unique about B&W plants that would make this kind of analysis, the thermal hydraulic analysis, more difficult?

MR. LONG: If you do get the right size seal, we make a coolant pump seal leak. You tend to start drawing up fluid down through the tube when you start leaking the tube. The big leak (speaking from an unmiked position). It doesn't make the tube very hot. So you have just the right size leak as part of the detail, and it has a lower probability.

CO-CHAIRMAN WALLIS: You need to be talking into a microphone.

MR. LONG: Oh, I'm sorry.

CO-CHAIRMAN WALLIS: Did the recorder get what he said?

CO-CHAIRMAN FORD: Okay. You have one last slide?

MR. MAJUMDAR: No, that's it.

CO-CHAIRMAN FORD: Joel, I'd like to take a break at this time for 15 minutes. So if we can come back here -- it's just after 22 -- we'd appreciate it, and then we'll have the last talk on the PRA and then general comments.

CO-CHAIRMAN WALLIS: Is it okay to say that was also a nice presentation? Thank you.

MR. MAJUMDAR: Yes, yes, yes. Thank you.

(Whereupon, the foregoing matter went off the record at 3:24 p.m. and went back on the record at 3:44 p.m.)

CO-CHAIRMAN FORD: Okay. We're back in session.

I pass it on to you.

MR. MUSCARA: Okay. I don't know if we should say we saved the best for last, but at least this is what everybody has been waiting for.

CO-CHAIRMAN FORD: That's exactly right. We've been saying we need the PRA now.

MR. MUSCARA: Actually we considered having this presentation at the beginning, and I decided it would be best at the end because by this time we will have heard about all of the inputs that need to go into this. Now you will see how the inputs get integrated.

So the last presentation for today's session is on the PRA, and Dave Bradley from SAIC will make the presentation.

MR. WOODS: Okay. I wanted to start as say just a very few words. I'm Roy Woods of the PRA Branch in Research, and I was going to just briefly introduce the people I have with me. I did that yesterday morning.

But on my immediate left here is Dave Bradley from SAIC. He's a subcontractor to Dave

Kunsman, who is the next person to my left, who is with Sandia National Laboratory.

And then finally down at the end is Paul Amico, also of SAIC. The two SAIC guys are based up in Aberdeen, which is convenient because one or both of them have been particularly -- Dave Bradley has been down here a number of times -- particularly helping us a great deal with that plan for bringing everything together onto one Microsoft projects schedule, which was an extremely useful exercise. He's also been doing some of the preliminary modeling, not just PRA, but materials failure type things that we're building into our own model.

Dave Kunsman is holding it all together from Sandia, and Paul Amico has been primarily concerned, I think, with getting together the PRA that we have obtained from the plant which we'll go into and getting it up and running so we can actually use it.

Unless you have any questions for me, I'm going to turn it over.

CO-CHAIRMAN FORD: I've got an overall question. Informally amongst us, we've been making a comparison between this particular project and the PTS project, and it involves certainty measurements and uncertainties and materials degradation, thermal hydraulics, et cetera. Is that a good analogy?

MR. WOODS: Absolutely. In fact, I was wondering whether to say this or not. The whole idea, I think, of assigning me to do this particular PRA coordinating function is not because I'm a PRA expert, which I'm not, but because I did the same or am doing the same function for the PTS project, and that was a tremendous learning experience for the contractors and for the staff in how you do a multi-discipline effort like this.

In this case, it's very similar, only maybe a little more so. We have got two different materials aspects on this one. We've got the steam generator tubes, and we've got everything else that Joel was talking about, you know, all of the other components that might fail before the tubes.

In the case of PTS, of course, you're just worrying about the vessel failing.

CO-CHAIRMAN FORD: So drawing on your experience of the very successful PTS program, how do you view this particular program in terms of the order in which things are done?

You have a never ending back --

MR. WOODS: There isn't any order. We've

learned that you can't draw it as a linear thing. You can start anywhere you want in the circle, but it's a continual feedback, and we'll actually get into a little bit of that.

CO-CHAIRMAN FORD: Good.

MR. WOODS: So if that's okay --

CO-CHAIRMAN FORD: Yes.

MR. WOODS: -- I'll turn it over to David.

MR. BRADLEY: Good afternoon. I'm Dave Bradley from SAIC.

Three objectives today for the presentation refers to kind of describe to you how we plan to approach the PRA; second, to provide a status of where we are right now; and actually we're fairly new at this effort. Clearly, if you look at the viewgraphs, there aren't a lot of results that are included. So we're just beginning the effort, and we can tell you where we are and where we plan to go.

And then also -- and Roy allude to this -- I want to describe a little bit how we plan to interact with the other elements of the program, the thermal hydraulic folks, the materials response folks, et cetera.

So let me move on to the next slide.

The scope of the study is limited to

severe accident induced containment bypass scenarios only, that is, driven by steam generator tube failures. The initial efforts in this area were to develop a methodology that was part of our original scope.

We developed a draft methodology and produced that methodology in draft form in June of 2003. Of course, without an application of the methodology, it's kind of difficult to know that you've actually described a methodology that's workable.

So at this point we're undertaking an application of the methodology that we provided in draft form to full power internal events. The sample plant that we've selected for this analysis at least the first go-round is a Westinghouse --

CO-CHAIRMAN WALLIS: Well, can I ask you about this? You developed a methodology or sort of a way of going about the problem, and now you're going to apply it to Westinghouse four loop. Maybe PRA is a little different from other areas, but thinking about what, say, Chris Boyd told us, he could probably sit down in an evening and sketch out his methodology and how he's going to approach the problem, and then it takes him a year to do all of the work.

Is PRA somehow different from that?

MR. BRADLEY: No. I mean, it's very similar to that. In fact, what we're finding is that the issues are more complicated than we had thought initially when we drafted the methodology. So I know right now the methodology is going to change drastically, which is why as you'll see we plan on updating that report when we produce the application. This is actually the way we did it.

So I've indicated here in the last bullet on this slide that we do plan to extend the methodology to other plant types, external events, lower power and shutdown states as well. That's downstream, quite a ways downstream. The initial efforts will be devoted towards that Westinghouse four loop sample plant.

CO-CHAIRMAN FORD: I'm sorry. I'm going to ask you a simple question on the first sub-bullet. "No steam generator containment by part before core damage begins. Coming into this on the DPO issue, I assume that the sequence of events was a main steam line break, depressurization, secondary side, rupture the tube, and then subsequent events after that. That is not the only thing we're talking about.

MR. BRADLEY: No, in fact, the main steam line break --

CO-CHAIRMAN WALLIS: You mix it up with something.

CO-CHAIRMAN FORD: Yeah, that's what I'm -- carry on.

MR. BRADLEY: So this is just severe accident initiated.

CO-CHAIRMAN FORD: Okay.

CO-CHAIRMAN WALLIS: This is a station blackout.

MR. BRADLEY: Well, station blackouts are similar.

CO-CHAIRMAN WALLIS: It stops and then it heats up. This isn't a LOCA or anything like that.

MR. WOODS: The intent is to hopefully expand this to other aspects of steam generator tube problems, but the initial effort that we were able to fund and staff or whatever at the start here was the severe accident induced steam generator tube rupture. So that's just where we are at the moment.

MR. BRADLEY: Okay. This chart shows a simple schematic of kind of the project flow, at least the way we initially envisioned it. The first step was to clearly define the issue. What we've assumed --

CO-CHAIRMAN WALLIS: This looks like a generic chart, apart from a few specifics.

MR. BRADLEY: Yeah, it's a fairly generic flow.

What we've assumed is that the severe accident is containment bypass would be a risk informed application, and what that means is that that implies that you need to look at something like the ASME standard to determine what capability requirements you have for a PRA and look at the PRA that's available to determine whether it's capable to do the job.

Clearly there are specific needs of the steam generator tube failure type scenarios that will require enhancements to existing PRAs, and so we want to also identify what those enhancements would be as well.

Now, to do that, we've drawn heavily on the work that has come before, the NUREG 1570 analysis that was done, the thermal hydraulic analyses some of which were reported earlier, the materials response analyses, the tube integrity analyses, et cetera, that were done before to try to identify what we thought when we drafted the methodology report, things that would be important to include in the PRA.

Again, I'm sure that those things will change and probably grow in scope as we go through the methodology itself.

Shown in the yellow box which fortunately does appear on the overhead is where we are now. We've got an existing PRA which we consider capable of doing the job or at least a good starting point. We're looking at improving that PRA as needed for this application. We want to apply the PRA.

Also, the other aspect of this analysis that we're looking at is developing the conditional probability of tube failure before failure of other RCS components for a given accident sequence. So that's also part of the application, the methodology. It's a big part of the methodology.

Well, then after we've applied the methodology, as I've indicated, we'll revise the methodology document. We'll produce a draft and a final document with the application included so that the reader can see exactly what we did.

I wanted to point out the interaction that we see at the bottom of the chart. As Roy alluded to and I mentioned earlier, there's a lot of interaction with the other elements of the program. We need the tube integrity analyses to tell us what pressure and temperature conditions can threaten the tubes. We need the thermal hydraulic analysis to tell us what sorts of systems and human failures or human errors can get us to those conditions, and of course, we need the analysis of the other RCS components to know when those failures might happen before the tubes would fail.

There is a continuous loop, a continuous interaction that we envision throughout the life of the PRA, and we've initiated that effort, but we've got a long way to go.

As I indicated, that draft methodology report was issued in June of last year. The methodology was based on Sebraxton (phonetic) induced steam generator --

CO-CHAIRMAN WALLIS: I thought SAI was Science Applications International.

PARTICIPANT: Used to be.

MR. BRADLEY: Well, SAIC. We've assumed that this would be a risk informed application and that caused us to look towards the ASME standard for the capability requirements for a PRA and when enhancements would be needed for this particular application.

Some of the enhancements that I've listed are such things as partial failures. Maybe it's got a partially stuck open relief valve or something of that nature that isn't traditionally considered in a PRA.

You may have state changes where you've got a relief valve that's stuck open and then it heats up and it starts to -- it recloses at some point. It's something outside of what a human -- what an operator might do to initiate a reclosure.

We've also got errors of commission, things that an operator might do that could make the accident worse, could make it better. Those aren't traditionally included in risk assessments. So we've referred to those as enhancements.

Of course, we also want to incorporate the results from studies of phenomena that are unique to severe accident induced steam generator tube failures and RCS failures. For example, we want to look at failures that could prevent containment bypass, failure of the manway, for example, or hot leg surge line failure.

So those are also aspects of the methodology.

Now, there's nothing very too earthshaking with the PRA approach the way we've outlined it here, and actually the way we envision it is going to draw very heavily on what was successful PTS program. We've got a first step, which is defining the sequences of interest.

A very important second step is bending those sequences. We've got a lot of quantification that has to happen. We've got a lot of thermal hydraulic analyses that may have to be done. We want to only analyze those sequences that really need to be analyzed. So we want to do a lot of sequence bending if possible, and the bending would be done based on, for example, accident scenarios that might get you to similar sorts of threats to the tubes or similar sort of threats to the tube integrity.

Once we've identified and bend the sequences to the subset that we really need to track, we want to do quantification to determine accident sequence frequencies, and then in addition to that, the probabilities that the tubes would fail before failure of other RCS components. That's another aspect of the quantification.

The PRA itself will tell us the probability of accident sequences. We then will couple that to a secondary analysis which will look at the conditional probability that the tubes will fail before any of the other RCS components fail.

As far as the first step in the process, sequence definition, again, we've indicated that we're going to assume that the starting point is a capable Level 1 PRA. We feel like we found the capable Level 1 PRA that we're going to use as our starting point. I'll talk about that in just a second.

We then would like to use some what we call high level or scoping tube integrity analysis to define the pressure and temperature regimes of interest; use high level or scoping thermal hydraulic analysis to determine what conditions would get us to those pressure and temperature regimes, and then from that we could define the combination of events that we need to consider in the risk assessment, and I've indicated to the extent possible we'd love to screen sequences that would give us prior RCS failures. This is a very difficult thing to do, but if we can, we'd like to be able to screen out those sequences for which a tube failure would not occur.

The second step, sequence bidding, I have indicated -- I discussed this a little bit earlier -- the objectives to bin sequences have produced similar challenges to steam generator tube integrity. The objective here is to reduce the size of the Pier A (phonetic) model, but we don't want to adversely affect either the model accuracy or its completeness. So we need to be very careful in how we bend the sequences. We don't want to bend a sequence that could give us a very high probability of containment bypass with the sequences that give us low probability of containment bypass.

CO-CHAIRMAN WALLIS: When I heard these other presentations, I got the impression that there was more or less one sequence that they were concerned with. They seemed to be a linear thing.

MR. BRADLEY: Well, it was one sequence that they were concerned with because that was, I think the dominant sequence in NUREG 1570. Now, we're going to look at what the Comanche Peak PRA which is the PRA that we're going to be using as our basis, what sequences are dominant in that, and I would imagine that we'll have additional thermal hydraulic calculations that will need to be done, and one of the things we're going to do in the very near future is to take a look at the Comanche Peak PRA and identify the additional important accident sequence.

CO-CHAIRMAN WALLIS: This is the Comanche Peak PRA that was prepared by Comanche Peak?

MR. BRADLEY: Prepared by Comanche Peak.

So they've actually been very helpful in getting that to us.

MR. KUNSMAN: This is Dave Kunsman, Sandia.

I'd like to say it's not one sequence they've been looking at. They've been looking at one variation of one sequence.

CO-CHAIRMAN WALLIS: Well, it seemed to be very much restricted to one story.

MR. KUNSMAN: But one of the things we have been taking advantage of during the breaks and that we have been talking a lot about are the things that we may be requesting of them, which we will be coming out with to them very quickly.

MR. LONG: This is Steve Long, too.

We've been through a few cycles of this. So back in the 1990s when we were doing the 1570 PRA work, the thermal hydraulic model at that time came up with somewhat different results, and at that time we had a lot of input from the sequences where the RCS blew down because the reactor coolant pump seal leaks, and the current model makes those look much less important. So maybe we'll actually get some simplification for the current model and have fewer sequences.

but we do have to look at a bunch of things that could be depressurizing the RCS at the same time that the core is melting. The pressure rises earlier were okay. If it depressurizes well, the core is melting. For whatever reason, the dynamics gets fairly hairy.

MR. BRADLEY: And before moving on, I did want to point out that the sequence binning is something that the PTS folks told us would be a very key aspect of our analysis because they had similar sorts of issues with analyzing more accident sequences than were needed because, again, they have computationally difficult problems that they're analyzing.

Well, the next step after you've got your fault trees and event trees together, you need to assign probabilities to different events. We've got typical failures that are handled in traditional PRAs and for those who would use the standard databases that are available, and in fact, those databases were, of course, used in Comanche Peak PRA.

We've also, as I indicated, have a number of data enhancements for which we'll have to develop probability data. We've got, as I indicated, partial failures, such as a valve leakage. We'll have to try to develop something for that. State changes, again something for that will have to be developed.

Another very important area of the analysis is analysis of human actions. This, again, for the PTS program was very critical, and they developed some very useful procedures in that program.

We hope to use those same procedures to the extent possible. What they found was that it was critical to have a good cooperation with the utility staff, and they've been cooperative so far. We'll see if they're cooperative when we get to this step.

What we'll do is we'll review the severe accident management guidelines which are guidelines and aren't very prescriptive. So we'll have to kind of interpret what we think the operators might do under certain severe accident conditions, try to assign probabilities to those different actions.

And then the other major aspect of the quantification step is this probabilistic analysis of tube failures before failures of other RCS components. That particular aspect is something that I'm going to be responsible for, and I'm finding out as days go by that it's a lot more complicated than I thought it was to start with.

Well, where do we stand as far as the PRA is concerned. Well, we've got a PRA model I've indicated that Texas Utilities was kind enough to provide to us. I believe it's the 2002 update of the Comanche Peak IPE model.

CO-CHAIRMAN WALLIS: IPE?

MR. BRADLEY: It's the updated version of their earlier IPE model. It's much better in our opinion than what they had before.

We felt like it was probably the most capable of the available PRAs. Now, we've got two terms here, capable and available. We don't have the full spectrum of all PRAs that were produced or have been produced that would be available to us. This is one that was available to us and was always capable; it was also capable.

I wanted to point out that our application is only a test to the methodology. The results of the application will not apply strictly to Comanche Peak. One of the main reasons is that we're using TH results in RCS component failure analyses that are based on design plant.

Simply I think there are a number of reasons for that. Those models existed. The work was well underway. The data had been collected, and so we decided that it would probably be more worthwhile to do this sort of a pseudo plant rather than to try to focus specifically on Comanche Peak and try to gather data and prepare new models for the Comanche Peak components.

So clearly we've got a potential mismatch here between components and we'll have to deal with that when we come to those issues later.

MR. WOODS: We looked very seriously at that. The alternative was to get the materials folks to start over on Comanche Peak, but they had been working on the ZION for years. We couldn't get a ZION PRA because ZION hasn't been operating in quite a number of years. There's no up to date PRA available. There would be no staff to interact with, you know, to incorporate the human factors or any of the interactions that we would like to have, that we did successfully have on pressurized thermal shock, and it just look, and it just looked like it was the only viable alternative that we had was to do sort of a hybrid. We didn't like that, but we didn't see a better alternative.

CO-CHAIRMAN FORD: Is there a possibility because of the mismatch between the PRA and the data source that would go into that PRA that at some future date someone is going to turn around and say this is not viable?

MR. WOODS: Well, we're trying to demonstrate a methodology, to fill up a method that could be used for a particular plant, and in fact, that's almost an advantage. Well, it is a compensating advantage, and you know, it doesn't really apply to any plant, and no plant is stuck with the licensing issue when we get finished.

But, yes, you know, we're not going to try to say this is the result for any plan. We're going to try to try to say this is the kind of result you would get. We hope it's typical, but you would have to apply it to several plants to see if it's typical.

CO-CHAIRMAN FORD: Maybe I could turn the question around. The PRA probably --

DR. BONACA: How different are the plants? How different is Comanche Peak from ZION?

MR. SIEBER: Twenty year.

DR. BONACA: No, just in --

MR. AMICO: This is Paul Amico from SAIC.

Basically they're both for a loop Westinghouse plants. The differences are valve sizes that are a little bit different and, you know, pump sizes that are a little bit different, but you know, it's not that significant. They're approximately the same power level, and the same number of components and that type.

So I don't see a significant issue with that.

DR. BONACA: So you would expect, for example, certain transient analysis to be similar to what you would get for Comanche Peak?

MR. AMICO: Right.

MR. ROSEN: How about the reactor coolant pump seals?

MR. KUNSMAN: Dave Kunsman, Sandia.

To the best of my knowledge, I'll put about 95 percent on this. They are the same. I'm not going to put, say, 100 percent.

MR. ROSEN: No, I'll just say that the reactor coolant pump seal design has evolved considerably since the days when ZION operated, and the new seals are more robust.

MR. AMICO: Yeah. Actually, our plan would be to use the probabilities of leakage and amounts of leakage from Comanche Peak and simply tell the thermal hydraulic people, "Assume these leakages when you're running the thermal hydraulics."

MR. LONG: Okay. The kinds of things that may be different are where the surge line attaches to the hot leg, you know, the stop locations and that sort of thing. So some of the detailed analysis from components would probably have to be redone for a particular plant each time you used the methodology, but in general, it should give you an idea of roughly what's going to look important.

MR. BRADLEY: As I've indicated, we've got the Comanche Peak PRA model in house. We've run it. We've compared the results to what Texas Utilities reported, and we can duplicate their result, which is good.

We're currently reviewing the Comanche Peak model against the ASME standard to see what enhancements will be needed to apply to severe accident induced steam generator containing bypass scenarios.

We're also initiating work on HRA related enhancements that will be needed and also something else I wanted to add to this. We're currently developing a list of accident scenarios that will need thermal hydraulic analysis. I think I mentioned that earlier, but that's another activity that we have ongoing.

Now, I wanted to describe briefly the probabilistic approach that we envision for determining the conditional probability of tube failure before or actually conditional probability of containment bypass for these accident sequences. I wanted to indicate its conceptual approach. As I learn more, the approach keeps evolving in my mind, and so it's conceptual right now, but likely to change as we learn more.

The problem keeps getting more and more complicated. I'm hoping at some point we can make some simplifications, but right now it just seems to be growing in complexity.

For a given pressure and temperature set of results from the thermal hydraulic conditions which we will determine for a particular accident sequence that comes out of the PRA, we will do the analysis assuming a given pressure set of results. We're doing it for a particular plant. So there will be assumed steam generator flaw characteristics. Here we're looking at not only the size of the flaws, the location of the flaws because we saw earlier that whether they're located -- the position that they're located in the tube sheet, to one side or another of the hot tube, is important. What position axially along the tube is also important because the temperatures that those flaws would see would be drastically different.

MR. ROSEN: How are you going to pick the flaws for the plant? Just from what they found in an inspection?

MR. BRADLEY: What they found, that is at this point something that we're assuming will be provided to us to do the analysis. I think my discussions with Steve along with that say yes. Probably a little bit of a weakness.

MR. ROSEN: Well, Comanche Peak is two plants actually. Both units are different. The units are different. One has one kind of steam generator, and one has another. So the question is: which unit are you going to use?

MR. BRADLEY: Well, for this application, we may, in fact, choose just a generic flaw distribution. So, again, we get away from the Comanche Peak specific.

But what we'd like to do is start with the flaw distribution that looks like something that a real plant would see. We don't want to create something out of the blue.

MR. ROSEN: I don't think going back to flaw distribution that the plant recorded in its last inspection makes any particular sense. First off, the two units at Comanche Peak are different. So you're immediately presented with a question of which unit to use if you take that approach.

Instead of that, I would recommend that you find some typical distribution for a plant that has been in service for some time. Don't say this is necessarily a Comanche Peak Unit 1 or 2 distribution.

MR. BRADLEY: Yes.

MR. MUSCARA: Let me address that a little bit. You know, prior work, we developed three generic flaw distributions based on field inspection data. These generic distributions relate to a plant that has a mild level of degradation, an intermediate level of degradation, a heavy degraded plant, and we've used that in past work. We intend to use this again.

In addition, we've developed methodology for predicting the flaw distribution from in-service inspection results and the POD kind of results that you've seen over the last day.

So there's a statistical method that's developed, combining in-service inspection results with the probability of detection curves for those results and generating the flaw distribution essentially in the plant.

So these are two areas we will be looking at, the generic flaw distributions and then how does one determine a specific flaw distribution from inspection results.

MR. ROSEN: Will the result depend critically on whether or not you find that a plant has lots of degradation or little degradation or will you have to do this parametrically?

MR. MUSCARA: I think it will make a difference because --

MR. BRADLEY: Potentially.

MR. MUSCARA: -- a mildly degraded plant may also mean that the flaws are not very deep versus an intermediate where you have more flaws and larger flaws.

MR. ROSEN: So you may come out with results for a plant with severely degraded generators that are not good, and the results for plants or generators that are not very badly degraded that are okay, and it could be different.

MR. MUSCARA: So I think we need to look at those three --

MR. ROSEN: The plant is also here going to be different because all of these plants with severely degraded generators are being replaced with new generators. All of that stuff you know, but I just don't know how you're going to handle it all.

MR. BRADLEY: I would envision that we would try to bracket the realistic range of plants, as Joe said, severely degraded, not much degradation.

DR. KRESS: I suspect that if you do the one without any degradation first, that that may answer your question for you.

PARTICIPANT: May?

DR. KRESS: You already get too much overlap for the curves probably, and so it's not going to help you to go to the -- at least that's the approach I would take. That's the approach I would take, you see.

MR. BRADLEY: We would take a severely degraded plant and find out the probabilities are low, not necessarily a likely outcome, but --

DR. KRESS: Well, that's the other approach, but my guess is you've got to go the other route first.

MR. WOODS: Well, the frequency of these things may be sufficiently low to compensate for what you're talking about. You know, a really severe flaw will pretty likely fail in some of these transients, which are probably infrequent.

DR. KRESS: Yeah, but my point was I think the pristine tubes are going to give you a probability overlap that's already too big.

MR. MUSCARA: Yes, but we pretty much know how the pristine tubes are going to behave already. So that I guess another comment, if you really want to tailor the flaw distribution to the Comanche Peak, we need to look at service experience, and these flaw distributions were developed in the past. A flaw distribution for different kinds of degradation processes at different locations in the plants. So if we really want to match it to Comanche Peak, we could see what its history is and then choose the closest flaw distribution for that.

DR. KRESS: That would be another route, yeah.

MR. KUNSMAN: I caution everybody about things like that the number might be too high. We are developing a methodology. We are having great cooperation unofficially from a utility. We are not calculating a risk from this. If they think we are, we lose that cooperation.

DR. KRESS: Okay. You may not be calculating it, but I am.

(Laughter.)

MR. KUNSMAN: Right.

MR. AMICO: I guess fundamentally I guess the point you were really making is we could do different distributions. It could turn out that the results are not significantly different for your different flaw distributions.

DR. KRESS: That was my point.

MR. AMICO: That was your point, yeah, and time will tell.

DR. KRESS: Yeah. I'm just speculating, of course.

MR. BRADLEY: Well, the real crux of the analysis is a Monte Carlo type of approach that factors in or attempts to factor in all of the different uncertainties that we've heard about yesterday and today into an estimate of an uncertainty distribution for the time at which the leakage rate would reach a condition that would constitute a large release.

Again, we're interested in a high rate of leakage that would be viewed as a LERF.

CO-CHAIRMAN WALLIS: Now, this is more a technical analysis than a PRA, isn't it?

MR. BRADLEY: Yes. This is something that we've tackled because it's probabilistic, but it's really kind of in addition to the analysis of accident sequences.

MR. AMICO: Yeah. I mean, we need to get a probability somehow. So what we do with the Monte Carlo is, you know, we have distributions on various parameters and that gives you a distribution, a probability distribution on failure time, and you get that for the tubes. You get that for the other RCS components, and to the extent, as you mentioned, the way they overlap gives you the conditional probability that the tubes will precede the RCS.

CO-CHAIRMAN WALLIS: Many PRAs are rather simplistic in the way that they muddle what happens. They just put in probabilities and advanced PRA so that it has a complicated model of certain key things going on, which is somehow incorporated into it, and that's what seems to be happening here.

MR. KUNSMAN: Along the lines of, if you will the old axial progression of entries after you've got a frequency of core damage, now you go through what's happening inside the containment, balancing the containment failure probability versus the containment loading and that will overlap and whatnot, our accident progression in this case is challenging the tubes so that steam generators.

MR. BRADLEY: Okay. The approach would be to calculate initially the failure time for each flaw that is in the distribution. When I first looked at this problem, I thought, well, that would be where we would stop. We would have a flaw. It would proceed to failure. We would say that that was a tube rupture.

Well, then we decided that, you know, it could be a flaw that's small and produces a leak. So you've got a leak. It's not a rupture. It's not a large release yet. So you need to keep calculating.

So what we plan to do is calculate the failure type for each flaw as the additional flaws happen, accumulate the leakage and calculate the crack opening and the leakage rate, accumulate the leakage until we get to a time at which the leak rate would be substantial and would constitute a large release.

MR. MUSCARA: The reason we made this change, in the past we looked at the first tube that burst and then the analysis was done and it was over. To address the DPO issue, for example, and they're concerned about thousands of tubes leaking small amounts, and so that we do need to track the failure of each tube, how much it leaks and track it with time and accumulate the leakage, and when we get to a certain leakage, then one makes a decision whether we've had enough leakage to cause a bypass or not.

MR. ROSEN: You have another conceptual difficulty in the definition of a large early release in that early release is defined as a release that occurs before substantial evacuation measures have been undertaken. So it's not a number. It's related to emergency response.

So you have to have some sort of nominal emergency response in mind.

MR. AMICO: And this is definitely an open issue. It's something that we just recently discussed, and we haven't settled on exactly how we're going to approach it.

DR. KRESS: The station blackout sequence, for example, proceeds rapidly enough that if you fail enough of these tubes, you had a large early release.

MR. AMICO: Well, and the Comanche Peak PRA has a definition of large early release, and they've created essentially a number of LERF plant damage states and that they've defined them, and you k now, our initial going in position is going to be if it was good enough for their IPE, it is good enough for us.

MR. ROSEN: It may not be generic though because other sites may have a more challenging definition of large early release than a site in the rural area of north Texas. I mean, I'm thinking of a close insight to an urban area. It would be a more challenging definition.

MR. LONG: I think we're going to have to be careful not to get hung up on a sort of legal definition of large early release because what we're really talking about is whether or not it's a contained accident or it's an uncontained accident with some level of release, and you know, nine-tenths of a LERF is probably just about as bad as LERF.

Unless you're really saying kill somebody with an acute dose or not, there may be a boundary there.

MR. ROSEN: Just pointing out the conceptual difficulties you've got, and you're going to have to solve them with some sort of meaningful generic approach.

MR. LONG: Well, we can use sort of a Level 3 approach as opposed to a LERF/non-LERF approach to make sure it's not a hard edge on the thought process.

MR. MUSCARA: That's an issue we struggled with, and in fact, I wanted to stay away from LERF, to begin with. I would like to have a definition of what is leakages of interest so we can say we have contained bypass or we have avoided a contained bypass. And at this point we don't know exactly what that is, but any input you can give us on that would be useful.

DR. KRESS: Well, let me ask you a leading question then. Suppose I took some sort of generic set of plants to do an analysis and forget all of this calculation and say that when I automatically get a containment bypass for this sequence, for this set of sequences; just forget whether it fails first or something else fails first. Just say, okay, it's going to fail first.

You can do the risk calculation and then compare that risk with some acceptance criteria which in my guess would be something like one-tenth of a prompt fatality safety goal, would be a good start because that's what's used in PTS, right?

And if you met that goal already, why do this? Without going to all of this trouble, you could already decide with some uncertainty analysis whether or not you've met an acceptance criteria.

MR. WOODS: I don't think we can use PTS. We were still in the process of determining what acceptance criteria --

DR. KRESS: Well, you know, a good acceptance criteria would be one-tenth of the prompt fatality safety goal. I think you could sell that to most people.

MR. LONG: Well, we've sort of tried that, and --

DR. KRESS: Oh, you've tried that already?

MR. LONG: And sort of what we're going to need then to do with a good PRA is figure out what the frequency of the sequences are that look like they could be a challenge.

MR. BRADLEY: that's what's done in the PRA.

MR. LONG: That's right, but it hasn't been done very well. I mean, Bob Paulo (phonetic) and I tried to do it, and then we tried to get some better PRAs than the 1150 work that we started with, and we were getting widely different answers because the licensees were doing it with their own PRAs, and we checked and we could easily find additional things.

DR. KRESS: I think that would be the first thing that I --

MR. LONG: That's one main question.

DR. KRESS: Yeah, I think that would be the first thing.

MR. LONG: The second though is there are a few things that aren't tracked in the usual PRAs that are important here, like the probability that the secondary side becomes depressurized by a valve sticking open. They leak down by operator error of commission or intentional action under the SAMGs. So these are things that they need to put into the PRA now to start asking what's the frequency with which the thermal hydraulic challenges need to be considered.

Right now it looks like we are a couple of orders of magnitude higher than we could say is clearly where we could stop. Now, if we can reduce the frequencies with these other considerations from what we know the station blackout frequencies are, well, yeah, but the secondary side doesn't depressurize.

You know, if you can get it down low enough with just the PRA work will stop.

DR. KRESS: Okay. You'll do that part.

MR. LONG: We've tried before and we couldn't stop. So if we stop this time, we will.

DR. KRESS: I didn't realize you had done that, yeah.

MR. BRADLEY: Well, the other important

aspect of this is something we heard just a short time ago, was about the probability of failure of other RCS components. What Saurin presented were failure times or specific failure times, and we talked about the uncertainty in the models, the uncertainty in the thermal physical properties of the materials.

What you're going to end up with is a probability distribution, not a single time, and it's possible that those distributions will be wide enough so that there will be a significant probability that the tubes will fail first, even though the mean of the distribution may indicate that the failure would occur after.

DR. KRESS: Even if it's .5, you've still got a problem.

MR. BRADLEY: Oh, yeah, a lot of problems if it's .5.

So if we roll the two sets of distributions together, we end up with a conditional probability that the tubes would fail first, and you'd have containment bypass for a given accident sequence because the accident sequence will, of course, determine the pressure and temperature conditions with the tubes and the other RCS components we'll face.

One of the major uncertainties we view as the thermal hydraulic input into all of these analyses, I think it's important that you cannot consider the pressure temperature curve that you get out of the thermal hydraulic analysis as the real deal and that you actually look at the uncertainty in that.

And it may actually extend to looking at other thermal hydraulic models. For example, the MAAP code gives you different results. We're not sure why the MAAP gives you different results, but it does, and it's an accepted industry tool.

So we need to understand the sensitivity of the predictions to the uncertainty in the thermal hydraulic inputs. So that's something else that we need to do as well.

CO-CHAIRMAN WALLIS: Well, there are probably some physics that the MAAP code does not model very well.

MR. BRADLEY: That would be something that would be important to determine, but I think in some early comparisons of MAAP and SCDAP/RELAP, we found out that there was some physics in SCDAP/RELAP that one thing handled well and so the --

CO-CHAIRMAN WALLIS: There are some funny things about mixing that maybe SCDAP/RELAP does as well, but I think MAAP does some weird things about mixing phenomena in places where flows come in and mix.

MR. MUSCARA: Chris has left, but I know he has a program in place to do an evaluation of MAAP versus RELAP. So we hope to learn from that and update our code if it needs to be updated.

MR. BRADLEY: Or get them to update MAAP if it needs to be updated. It would be nice to get some convergence.

DR. RANSOM: Certainly I think the uncertainty in this analysis is huge. You know, when you look at it from the standpoint of going from the one dimensional hydraulic transient codes through even non-severe accidents and getting into the point of core heat-up, core damage, multidimensional flow through the system.

Then when I listen to the structural calculation or presentations, as well, as far as how it would behave, uncertainty in some of the structural properties, it just seems like there's a huge uncertainty as to which way you go. You know, do the tubes fail or does some other part of the system fail?

And I don't know how you plan to incorporate that, but I sort of support Dr. Kress' feeling that that uncertainty may dominate the whole thing and, you know, what really governs risk is just whether or not you have an event that leads to this or not.

MR. BRADLEY: I mean, if we end up with .5 for the conditional probability that you get containment bypass almost regardless of the scenario, then clearly you need to focus on the accident sequences and try to do something there. At this point we don't know, but that's certainly an outcome that's possible.

CO-CHAIRMAN WALLIS: Point, five is sort of the guesstimate when everything is overlapped so much that you can't sort it out?

MR. BRADLEY: We don't know. Flip a coin.

As far as the modeling of tube failure and leakage, I think Saurin discussed a little bit about the creep rupture models that Argonne developed for crack pop-through, that is, failure of the remaining ligament for part through-wall cracks. There have been previous studies that Argonne has done to look at the various tube failure models, and they developed their model, and it appears to be the best of the available models. Their model compares very well to test data, and so it's the model we've adopted for use in our probabilistic analysis.

It's also fairly simple and amenable to the kinds of things that we need to do. It predicts a failure time based on the creep damage index of one, the same sort of thing that we heard earlier.

There are also tube leakage models that Argonne has developed that we're going to use for the second phase where we try to accumulate the leakage from the failed tubes. These models have also been benchmarked against test data.

Now, those models apply primarily to tubes that have part-through wall failures. For through-wall cracks you can do a limit load analysis to predict burst of tubes, and that's the sort of analysis that we'll use for tubes that have through-wall cracks.

What we would like to do is consider the full range of uncertainties. I've identified some of the key ones on this slide. As far as flaw characteristics, we want to know the distribution for the length and depth of the flaws. We want to know the distributions for the number and locations of the flaws.

CO-CHAIRMAN WALLIS: Isn't this one of the areas of greater uncertainty?

MR. BRADLEY: It is. It definitely is.

The inspections provide some information, but they're not 100 percent accurate. So we need to do some extrapolations.

CO-CHAIRMAN WALLIS: At least you have inspections. It's not like PTS where you have to make more assumptions about where the flaws are an dhow big they are.

MR. BRADLEY: That's true.

A parameter that has turned out to be very important in my initial studies is the Larson-Miller creep rupture parameter. There's a distribution that Argonne provides --

CO-CHAIRMAN WALLIS: That's the one that has powers of ten and things like that and is very sensitive?

MR. BRADLEY: Yes, very sensitive, and Argonne provided a distribution that they used. I think that seems appropriate.

CO-CHAIRMAN WALLIS: Is this something which is a standard n the materials area? Everybody knows where it is and --

CO-CHAIRMAN FORD: Larson-Miller? Yeah.

CO-CHAIRMAN WALLIS: It's not something that has just been invented for a new year.

CO-CHAIRMAN FORD: Oh, no. They've run a

long time.

MR. BRADLEY: Another parameter that's used in the Argonne model is the stress multiplier. That's the M sub P. There's some uncertainty in that value based on I guess it's the uncertainty in the flaw characteristics or what produces that, Bill?

MR. SHACK: Assuming we know the flaw characteristics, it's not a perfect correlation. So it would be some --

MR. SIEBER: Can't hear you.

DR. KRESS: Would you use the microphone, please?

CO-CHAIRMAN WALLIS: Would you identify yourself?

DR. KRESS: Identify yourself.

(Laughter.)

MR. SHACK: Bill Shack.

Even when you have well characterized flaws, you know, it's not a perfect model. So there's some uncertainty, but that is, in fact, characterized in an Argonne report, a distribution for that inherent error that has to be, again, added on top of the uncertainty you have when you're dealing with real flaws and you have uncertainties in the depths and shapes of those.

MR. BRADLEY: There's also, of course, some variation in the temperature that the tubes see. We've got radial variations that Chris talked about this morning, and of course, there's also an axial variation as you move up the tube. The temperature tends to drop. So we need to factor those into the analysis.

CO-CHAIRMAN WALLIS: Well, the whole temperature distribution in the steam generator is rather incomplete because you don't know much about what's happening on the secondary slide. We mentioned that this morning.

I think that's an area where somebody has got to go away and figure out better what's happening on the secondary side.

MR. BRADLEY: Yes. There are also some uncertainties related to tube burst and tube leakage. We haven't pinned those down yet, which is why it's shown as to be determined, but again, we want to make sure that we consider all of the important uncertainties. So we'll address those as well.

I mentioned the pressure, the thermal hydraulic conditions are uncertain. The variations in thermal hydraulic parameters, such as those that Don talked about this morning; variations caused by use of different computer codes, something else I alluded to earlier.

CO-CHAIRMAN WALLIS: Tricky. You're going to run a whole lot of different computer codes?

MR. BRADLEY: Well, I think what we envision is trying to get the TH experts to say, "Okay. This is our median estimate of the pressure temperature history. We think it could be this or this, you know, based on their experience running their models, and we'll attempt to reflect that uncertainty in the model.

CO-CHAIRMAN WALLIS: I think you've got to be careful here. If you run TRACE and RELAP and some Westinghouse code and all of that, you may be surprised at the difference you get.

MR. BRADLEY: I suspect that there will be large differences, but again, it's model uncertainty that is there, and we need to try to consider that. It may make the distributions extremely wide, but so be it.

And then, of course, the models for failures of other RCS components were subject to a lot of the same uncertainties that tube failure are subject to and quite a bit of additional ones, I'm sure. So we need to make sure that those are covered.

And what we would envision there is trying to get the experts, again, to tell us what they view as the uncertainty in the time of failure.

Now, it's always difficult to do that with experts. They tend to want to think that their models are accurate, but we'll do our best to try to get them to be realistic in representing the uncertainty in those times to failure.

CO-CHAIRMAN WALLIS: The experts go through a kind of life span when they start out and they become first experts, and they think they know everything, and then as they get more and more expert, their uncertainties tend to increase, to widen.

MR. SIEBER: Until they're totally humiliated.

(Laughter.)

CO-CHAIRMAN WALLIS: I'm really impressed by the breadth of stuff you're undertaking here.

CO-CHAIRMAN FORD: And to be completed by the end of 2005, as I understand it.

MR. BRADLEY: That's why I said I'm hoping that we can make some simplifications because right now it just looks fairly overwhelming.

CO-CHAIRMAN FORD: Challenging

.MR. BRADLEY: Challenging, very

challenging.

MR. MUSCARA: But also, a lot of the inputs and building blocks are there.

CO-CHAIRMAN FORD: Yes.

MR. BRADLEY: Well, we have actually done some work in modeling tube fairly. I've put the Argonne creep rupture models into Excel. I've benchmarked the Excel model against the Argonne test results and against the model predictions that Argonne has reported, matched to both of the test results and their model predictions.

The reason why we've selected Excel for this is that there's an Excel add-in called Crystal Ball that can be used for Monte Carlo simulations. You can input uncertainty distributions for any input parameter of the model. There's a streamline way for doing that within Crystal Ball.

Crystal Ball then does the leg work and does the statistical analysis and reports nice plots of probability distributions for the output parameters that you select.

So I've used it in the past. It does a very good job. You can either do light Hyper Cube and Monte Carlo at your selection. I've done some of that already, and I've gotten some distributions for time to failure. Unfortunately I don't have any of that information that I brought with me. I think I've got it on a laptop if anybody would be interested.

The model calculates the time of pop-through failure for each flaw, and you can input uncertainty distributions for the flaw depth, the flaw length, the temperature, the location, and it will produce an uncertainty distribution for the time of pop-through failure. But, again, that's just the first step.

Next we need to try to incorporate verse failure for those flaws that are through-wall initially and to incorporate models for tube leakage into the spreadsheet. Now, we need to build a framework for aggregating the leakage as consecutive tubes or tubes fail in sequence and for somehow identifying the time at which you've reached that critical leakage rate, which is yet to be determined.

We'll then use Crystal Ball to produce the uncertainty distribution for the time at which that critical leakage level has been reached, and then what we'll do is then, as I've indicated, run a series of calculations to determine the sensitivity of those predictions to those uncertainty in the thermal hydraulic input conditions

So this is my summary slide. We developed a probabilistic approach for assessing severe accident induced steam generator containment bypass scenarios. The underlying assumption again is that the analyses will be part of a risk informed application so that the starting point of the PRA needs to be a capable PRA with capabilities that we've attempted to define based on the ASME standard, along with enhancements that would be required for this particular one.

We've prepared a graph methodology and an application of methodology is currently underway. We fully expect the methodology to change as we proceed through our application.

The methodology uses traditional PRA methods. There's nothing too exotic. We draw heavily on the experience of the PTS group and use a lot of the techniques that they developed.

CO-CHAIRMAN WALLIS: How could it not be a risk informed application? How else would you make a decision on something like this?

MR. BRADLEY: I don't know.

MR. AMICO: I mean, it's just the construct of where we decided to come from since the ASME standard had been issued and there was a framework for doing a risk informed application, meaning, you know, an application to the NRC that's risk informed.

CO-CHAIRMAN WALLIS: It's really questionable stuff. How else could you make a decision on this issue except some risk informed basis? You don't have a standard criteria for this kind of an event.

MR. LONG: Well, you really can't do it without being risk informed because the design basis for the reactor coolant system didn't include a high pressure core melt. You know, the ECCS is to prevent that. When you go the containment where core melt is part of the design basis, it was unfortunately a low pressure core melt. So the only thing that challenges the tubes in the design basis is, you know, the iodine spike given the main steam line break, which isn't really from a risk standpoint anywhere near as important as a core damage sequence.

CO-CHAIRMAN WALLIS: If you didn't want to be risk informed, you have to write a new regulation with deterministic regulations in it somewhere.

MR. LONG: Exactly, and you need a backfit analysis to do it and we need this analysis to justify the back fit. So we have to do this to get anywhere.

MR. BRADLEY: We've got an updated

Comanche Peak PRA. We're using it to do the initial application of the methodology. We're going to enhance it to meet the needs of this particular application.

We will use the enhanced PRA to determine the frequency of conditions that could lead to severe accident induced steam generator containment bypass scenarios.

Work, as I've indicated, is also underway on an approach to estimating the probability of steam generator containment bypass for a given accident sequence. It involves a Monte Carlo analysis that will reflect the full range of modeling uncertainties and parameter uncertainties, and will give us an estimate of the uncertainty or the probability of --

CO-CHAIRMAN WALLIS: That's difficult. Excuse me. That full spectrum modeling uncertainties, I mean, you touched upon it, but there are basic uncertainties in predictions of a code like RELAP having to do with the assumptions in the code and all sorts of the ways it's structured and so on. And they're not universal. I mean, they should depend on the application.

For certain problems it does a good job. For other problems, lots of uncertainties. And answering the question about how uncertain is RELAP for this particular problem is really a very difficult question to answer.

MR. BRADLEY: And we're going to do our best to try to capture it, but you're right. It's very, very difficult.

MR. AMICO: I mean, to a large extent, we have to do -- it's going to be an elicitation process of the uncertainties as people view them, not unlike the way it has been done in seismic analysis. I think we're probably in a problem that has got about as much or as complicated an uncertainty structure as a seismic one, and I mean, our intent will be to use expert elicitation to help determine the uncertainties we need to address.

CO-CHAIRMAN WALLIS: Well, ask the experts who have never actually run a code to solve this particular problem and to guess what might be the uncertainty. I think that's a very risky business.

MR. KUNSMAN: I'm sorry. Could you --

CO-CHAIRMAN WALLIS: You can take -- well, maybe my colleague Vic Ransom could answer -- but if he were an expert asked to estimate the uncertainties in this kind of a prediction, I think unless he had actually run the code for the kind of conditions we're talking about here and found out what kind of problems he got into, he would have a great difficulty giving you any kind of a figure for uncertainty.

DR. RANSOM: Well, my uncertainty would be one, I think.

CO-CHAIRMAN WALLIS: It would be as big as possible?

DR. RANSOM: I'd assume the worst situation and take the best.

CO-CHAIRMAN WALLIS: Well, that's too much.

DR. RANSOM: When I say that I'm including the calculation beyond, you know, the dry-out and severe damage and heat-up and this natural circulation through the steam generators that we've been talking about today.

When you couple all of that together, just it would boggle my mind to put any kind of uncertainty estimate on that.

DR. KRESS: Well, you know, there's a lot of uncertainty in how the core heats up and melts down and stuff, but I think all of that uncertainty gets wrapped into both parts of the thing, and you can almost ignore that and look at, well, now I've got things uncovered and I've got steam going by and I'm lighting off the zirconium fire.

It's from there on, the flow rates you get and the temperature excursions, you know, the certainties that are important because everything before that is going to --

MR. BRADLEY: It gets you to a point in time.

DR. KRESS: It gives you a point in time, is all it does, and you don't care about that really. It's the difference in the time from there on.

So, you know, I have some hope that they could get an uncertainty out of this, and it involves this counter current flow crap that -- not crap, but I think tha's where the uncertainties are going to lie.

CO-CHAIRMAN WALLIS: It's much easier than many of these calculations because it's single phase steam flow. It's not as if you've got two phased phenomena, which really screw up a lot of these problems.

DR. KRESS: Yeah, and that cuts down on your --

CO-CHAIRMAN WALLIS: So that gives you a good basis, but then these mixing patterns and circulations and so --

DR. KRESS: Yeah, well, that's where the uncertainty is.

CO-CHAIRMAN WALLIS: That's why you need, I think, really good CFD, which has, I think, probably much less uncertainty than just a RELAP model with some guess at mixing. That's where I think really CFD has helped us a great deal.

DR. KRESS: But I have some hope that you could come up with a fairly reasonable uncertainty.

CO-CHAIRMAN WALLIS: Yeah. Chris Boyd can model the turbulence different ways and so on and get some range of uncertainty. Don't ask the expert who hasn't done that. I think one expert like Chris, who is believable, is better than ten guys who have run RELAP and are guessing.

MR. LONG: One thing we need to do with this to help us use the result is to ask ourselves what's the sensitivity to the level of uncertainty in certain things because if we just take an uncertainty distribution and fold it into the answer, you know, if it was a guess at the uncertainty distribution, it would have been just a lot cheaper to guess the answer instead.

And so we need to get something out of there that will work, and that would be to say that if you can be this certain about it, then you can make this decision, but if you have a much broader uncertainty, then it would maybe change your decision.

CO-CHAIRMAN WALLIS: Does NRR operate that way? I mean take ten experts to guess the answer.

MR. LONG: Well, there's a lot of summaries of experts guessing the answers in NUREG 1150, which is what we work a lot from right now. We're hoping to get something that goes beyond that with this effort.

MR. BRADLEY: The only other thing I wanted to say before closing was that the last bullet on this slide is clearly the work that we're doing will require very close interaction with the other aspects of the program, which is why we've set up these fairly regular meetings, to get together and have technical information exchange.

So again, that's something that we draw on the experience from the PTS folks where that sort of interaction was necessary.

CO-CHAIRMAN WALLIS: So someone is in the manager's seat. There's the chief engineer making all of this happen and all of the interactions and making sure that the progress is being made.

MR. MUSCARA: That's been a function of

the integrating all of the work in the Research Office. I plan to have meetings every two months with the team and contractors as needed.

CO-CHAIRMAN WALLIS: Every two months? This must be happening every day on this.

MR. MUSCARA: But between the individual people, but when the whole group gets together and make sure things are going on the way they should be going on.

CO-CHAIRMAN WALLIS: Well, it's very important to get a kind of morale going where people talk to each other very quickly as soon as they find something.

MR. MUSCARA: Sure, and that's already going on.

CO-CHAIRMAN FORD: And that was lessons learned from the PTS program, another multi-technical thing which worked very well.

Are there any more questions on this particular talk?

(No response.)

CO-CHAIRMAN FORD: Joe, would you like to make any ending statements?

MR. MUSCARA: Well, simply I've enjoyed interaction over the last two days. I think in looking at the DPO and whether the issue is close, in effect, formally the issue is closed because we have this activity and because the ACRS and the staff has concluded that it's not a safety concern.

I would recommend that we have this kind of meeting annually so that we can keep you updated on the progress of the work if that's what you would like to have.

CO-CHAIRMAN FORD: Yes, i think that would be a very good idea.

MR. ROSEN: Did you plan to go around and ask us questions?

CO-CHAIRMAN FORD: I planned to do that, Steve.

Normally at this time at these subcommittee meetings we go around the table. I'd just like to remind us that this was billed as an informational meeting. No letter has been requested. The information was to address more specifically the progress being made on our recommendations in NUREG 1740 on the DPO issues, where it was going, what was nearing completion, what was completed.

So I'd like to ask the members to address two questions, please. First of all, do you see the need for a letter? And if so, what topics should be covered?

And the second request is to give the staff a guidance as to how to most efficiently run their two-hour session tomorrow on what has been gone through in the two-day item.

MR. SIEBER: Talk real fast.

CO-CHAIRMAN FORD: So, Jack, we'll start with you and go around the table.

MR. SIEBER: I'm not sure I can answer your first question first, which is do you need a letter., but I thought all of the presentations and the work done so far was very good with one exception, and that's the iodine spiking issue, which basically I don't know if we're at the stage of a disagreement or not, but apparently we have an opinion about how that should be treated that differs from the staff, and to me it's unresolved at this point in time.

But otherwise, I think the work that has been done so far is good work. There's a couple of things I need to think about a little bit just to make sure that I understand it properly, and I'm sure that if I come to some adverse conclusion, I will make that conclusion known, but right now I don't have that feeling.

CO-CHAIRMAN FORD: Okay. In terms of the

advice to the staff for tomorrow's meeting, it's my understanding, Joe, that you are going to essentially confine yourself to the summary slides. You're going to confine the number of presenters, and that you are going to have back-up information on the iodine spiking and on the PRA.

Since the members -- you just arrived, Steve and Mario, but also George Apostolakis is not here today. So he hasn't heard this presentation, but that was, I think, the going plan that you had at this time. So if you could give them further advice on that basis, it would be appreciated, I'm sure.

Mario.

DR. BONACA: Well, with regard to that first question, should we have a letter or not, at some point we will need to have a letter. I mean, clearly, the ACRS raised a number of issues on the DPO, and I think the work we have seen here, I mean, I only participated yesterday and then somewhat this afternoon, but the work I saw yesterday had incredibly addressed some of the issues that were raised by the ACRS.

I think that there were some convincing cases made for the kind of delta Ps across the plates. I mean, there were issues there of concern regarding what the consequences of a steam line break would be or the steam generator. I think those have been addressed, and I think that I cannot comment on that at this point because I missed that portion of the presentation, but I think at some point we will have to address how this work is satisfactorily addressed in the issue before the ACRS.

I think we have already sufficient information to address some of that.

Regarding the PRA, clearly, it's a work in progress. I mean I think it's a challenging issue. I think it's a very interesting endeavor. I think that just the issue of address failure of passive components is intriguing to me now and how you're going to treat it.

But, again, there is no need for commenting on that. We can just note that there's work in progress.

On this issue of the competing facts of either -- I mean, which will fail first, steam generator tubes for the bypass (phonetic) or not? That's again a work in progress. We don't need to comment on the outcome except for whatever insights we have.

So a letter could be developed at this

stage that may close some of these issues that we raised.

Insofar as the presentation tomorrow, it seems to me that for those members who are not here, particularly Dana Powers, I would expect that this focus of attention is going to be those issues that we raised in the report and how they've been addressed. So it would be more focusing on the results and how they address those questions or issues that we raised on the ACRS.

I mean, yesterday is a lot of information on details of how the calculations were done and what results. I would focus on those results because two hours is not much of a time for presentation.

CO-CHAIRMAN FORD: Is it possible in your summary slides -- I mean, your summary slides, if it's based on today, is not just on the issues raised in the NUREG 1740, but, for instance, the use of the POD of .6, the database for seven-eighths tubes, the spiking factor for iodine. These are all issues that were quite clearly either concluded or recommended in the final section of NUREG.

So maybe when you go through your summary slides you could emphasize those particular items. For instance, PRA does not appear in NUREG 1740.

That's what essentially you're recommending, is it?

DR. BONACA: Well, POD is a good example. I mean, except the statement was made, and I think an answer has been provided regarding POD and the dependency of POD on a number of parameters, and I think you've made a convincing case.

I'm only saying what I expect to see. I realize that the presentation covers more ground than the observations we made. I'm only saying that for the presentation to the ACRS you probably will see some focus on those issues that were raised in our report.

MR. MUSCARA: My thought had been that I would simply mention that, you know, there was a concern about the fixed value of POD, and that we've done work to characterize the entire POD curves and a number of parameters, but I wasn't planning on showing any of the data.

DR. BONACA: No. In fact, I mean, you won't have the time anyway because, you know, in two hours that would include also discussion on the part of the ACRS. You won't have the time to show how they work.

MR. SIEBER: I think there is some interesting outcomes from the round robin on the probability of detection, you know. Not only do we learn that it's not a fixed number, but a distribution, but the distribution is a function of flaw size which gives confidence that if you have something significant out there, you're going to find it.

I think that's important, and I thought that was a pretty good effort, too.

DR. BONACA: You can always pull out slides as needed if you get additional questions.

CO-CHAIRMAN FORD: Steve?

MR. ROSEN: Yes. I'm Steve Rosen, an ACRS member.

As far as a letter tomorrow is concerned, I really don't have any comment on that. I wasn't here yesterday. So I heard 50 percent of what you did today. I was in and out all day today. So I heard nothing more than about 25 percent plus or minus ten percent of what you've done. So I really have no view on that.

And so I have no guidance for you on tomorrow's session either, except to say that there will be some of us who really haven't heard much of this at all. So you need to put a framework about it. It's not on the ACRS when the NUREG 1740, is it, was written? So I have background there either.

I do have one technical question which comes back to the matter I raised earlier, which was on the assumption of instantaneous failure of the RCP seals at time zero. I asked that question and was told, oh, yeah, that's what it showed. That's what the Westinghouse analysis shows.

But I wonder about that because what does operating experience on the behavior of reactor coolant pump seals given a reactor coolant pump trip tell us. Every time we have tripped a reactor coolant pump have we lost the seals?

MR. PAGE: No.

MR. ROSEN: I rather doubt that.

MR. PAGE: This is Joel Page.

The 21 gpm is not a seal failure. That's just flowing in the other direction. In other words, it came from GSI 23 basically where you lose seal cooling and somebody finally realized that without failing the seals, the delta P associated with that will flow in the reverse direction.

So it's not really the failure of the seal.

CO-CHAIRMAN WALLIS: Or flow through the seal without failing it?

MR. PAGE: Without failing the seal.

The other flow rates --

DR. KRESS: These are elaborate seals?

MR. PAGE: They're actually the three-level seals, and they actually have three different levels that they go to. Some go up.

But I'm saying that the 21 gpm, the lowest level, is not actually a seal failure. It's just actually flowing in the other direction.

MR. ROSEN: Back through the seals into the component cooling water system?

MR. PAGE: There's two or three different directions they go in. They're actually a very, very complicated seal package on those things, and so I don't have the drawing right in front of me, but like I said, the 21 gpm does not constitute a failure per se. It's just because of the large delta P normally you're pumping into the seals at about five or six gpm, but now the delta P situation is much larger, and so all you're doing is flowing back in --

MR. ROSEN: So you're losing reactor coolant out through the seal package.

MR. PAGE: That's correct.

MR. SIEBER: And you're getting the seal package up.

MR. KUNSMAN: This is Dave Kunsman.

I thank you for bringing this back up because I do want to correct something. Paul reminded me when I responded to your question, I was only thinking of the 21 gallons per minute one. I did not think about the 163 or the 183 that's in their presentations earlier, and I do not know if they applied the Comanche Peak at all. The 21 gallon per minute one I'm fairly certain does.

MR. ROSEN: Does it matter, all of this discussion of 21 versus 163? Do we know whether it sends the final result, which is the horse race, between failure of the RCS versus failure of the steam generator tube? Does this seal leakage behavior early in the transient matter?

MR. KUNSMAN: Yes.

MR. AMICO: You missed the earlier presentation that ISL did this morning, and they did a sensitivity on that and they actually did show that the margin to the tubes failing before the surge line changed based on that.

CO-CHAIRMAN WALLIS: With a big enough leak, the problem goes away.

MR. PAGE: That's correct.

CO-CHAIRMAN WALLIS: It becomes a LOCA.

MR. ROSEN: So what you want to do is just exactly the opposite of what the utilities have done, which is build more robust seals.

MR. PAGE: Actually we could ask them to take the Log 2000 seals out and put the old ones back in.

CO-CHAIRMAN WALLIS: No, but there are other more likely events for which you need a good seal.

MR. ROSEN: Well, I think what all of this says is that I'd like to see some really good analysis, mechanistic analysis. Forget about probability. Just tell me what you think is really going on with leakage early in this transient because at least there I don't have to think about a whole lot of things that are indeterminant and uncertain.

I know what the delta Ps are. I know what the seal designs are. I can pretty well tell where the water is going to go.

MR. PAGE: Actually the seal investigation we're doing, which we're launching now, soon, unfortunately was delayed because originally the original assumption we went with were zero leakage, and when we were picking components to investigate, we said, "What are the time temperatures at the seal area?" and they weren't that high. They weren't that high when we looked at the Log 2000, you know, report in generic safety issue 23 resolution.

So we didn't pursue them then. Subsequent to that time, it looked like they were going to be at least 21 gpm. It started changing the picture. It looked like a route now of hot gases into the seals coming from the cold leg side actually which we had not investigated. We had really concentrated on the hot leg, but the cold leg side that looks like access coming directly to the seals rather early in the scenario.

So we do want to pursue that. Unfortunately we're just now really getting into it mechanistically.

CO-CHAIRMAN FORD: Graham.

CO-CHAIRMAN WALLIS: Well, I was pleased with what I heard today. I've already say that in a few instances.

And the question is: how do we best add value to this operation, these tasks? Should we write a letter?

Well, why would we write a letter? I can think that in the letter we might give the Commission and the NRC management some assurance that the work is on track if they want to know that, if they need some assurance of that type.

We might wish to evaluate the work, various pieces of the work, make suggestions for improving the analysis or changes in direction and so on.

I think at the end that we would want to emphasize that what's very important is what we just heard here, and what we said at the beginning of this whole show was it all has to come together somehow, and that's a lot of work.

When you try to bring it together, then you may find out the relative importance of all of these things, and then what it was that you needed to know better and what other things you spent a lot of time on and you didn't need to know so well.

Now, my inclination is to say I think that the presenters from the staff and contractors listened to us very well and responded to us very well. I don't want to belabor the things we didn't like about the work in a letter. I think we have given the message to the staff that we didn't like the rather -- how shall I say? -- not very complete or whatever arguments about iodine spiking or the seven-eighths tube correlation and so on. That message we already got across.

I had some points for Chris Boyd. I think there are certain parts of his analysis that he needs to look at and do differently. I think he has got the message.

Now, do we need to put that in a letter specifically? I'd like to feel we didn't have to. It's all in the transcript anyway. If people are serious about interaction with the ACRS, they've heard what we've said. It's in the transcript, and writing something which praises some and faults others or appears to do so in a letter, I'm not sure I really particularly want to do at this stage.

I'd rather say you have a difficult job to bring it all together, and when you've brought it all together, I'd really like to see it. Then we write a letter.

My colleagues may feel differently. Often we do write letters simply to say we put something in the record so that we can come back to it and say, "Yeah, we made this point and you didn't pay attention to it."

I'd like to feel that in lots of these cases the staff and the contractors listen to what we say and take it into account and do a professional job and we don't need to say, "We asked you to do something," because then we get into what set this whole thing going, is the ACRS sort of saying, "We don't like this. We don't like that. We don't like --you ought to go do some work," and off you go on this tremendous program because of just what we said.

So I'm inclined to say I'd rather not write a letter, but if we did, I think there are certain things we could put into it.

DR. BONACA: That's why, by the way, I was focusing purely on the comments we have made before and not on the whole actual plan. We did critique what we have done today and till then by the staff, and they may be interested at the level of the Commission to know what we think of the work that is being done to address that. That would be the focus of what I would write.

CO-CHAIRMAN FORD: Okay. Tom.

DR. KRESS: I'm inclined to -- are you through? Did you want to say some more?

CO-CHAIRMAN WALLIS: No.

DR. KRESS: Okay. I'm inclined to agree with Mario that a letter might be appropriate at this time for the same reasons.

I also agree with Jack on the iodine spiking issue. I'm sure Dana will be anxious to hear about that, and he'll be anxious to hear about how we dealt with all of the issues.

So you know, at some point in your summary you will want to say, "Here's an ACRS issue in the 1740. Here's how we dealt with it," and then only go into detail later. So I think that has to be part of the presentation.

With respect to the steam generator bypass stuff, I may have a different view than most of the committee. I view it as somewhat akin to the allowance of containment over pressure in the net positive suction head problems. We're allowing the progression of a severe accident to get us out of trouble or to be sure our systems work right.

To me that's a principle that bothers me somewhat, and I suspect if we go that route, which it looks like we're going that route, we'll get grief from intervenors, from outsiders. They won't like this at all.

What? You're going to allow the primary system to melt through first, to depressurize?

You know, we're going to get some grief from that, I think, and with respect to the very nice outline of the work that I see on the PRA, I encourage you to continue in that direction, but personally I think I would start out by assuming I have a large early release, that these sequences, a certain number of these sequences are going to lead to failure of the steam generator tube, and I would make my refinements on the frequency of these and the consequences of these, and see if they don't already meet some sort of acceptance standards.

And my choice for acceptance standards would be one-tenth of the prompt fatality safety goal, which if that didn't work, then proceed on refining to see if you can do better by getting the actual probabilities that this is a large release.

But I would do the other first. But even then I have a suspicion that you're going to get overlapping probabilities that are too high already. You might as well forget about the probability of failing the primary system prior to failing the steam generator tubes. That's just a personal -- you know, it's a bias I have already because I have a bias against using severe accident progression to get me out of trouble.

So, you know, that's the only --

MR. ROSEN: Perhaps even without that bias one can draw the conclusion that the uncertainties are so large on so many sides of this problem.

DR. KRESS: That you shouldn't rely on it. Yeah, you could do that probably.

DR. BONACA: Although I agree with that, I still am -- I mean, the project is very interesting.

DR. KRESS: Oh, yeah. I don't want them to stop on the project.

DR. BONACA: No.

DR. KRESS: Because I think it's very useful stuff that's going to useful just to get the overall risk contribution of these sequences, period. I think it would be very useful for that.

So I think it has multiple uses.

CO-CHAIRMAN FORD: Vic.

DR. RANSOM: Well, this issue predates me. So I really am a little bit at a loss to know what to say about it, but I would have found it very interesting to have known what the big picture looked like, you know, what sort of thing potentially does this sequence present, and I would hope, like Dr. Kress has mentioned, that the probability of that occurring would be small enough that the risk of the overall situation, even if you do bypass the containment, wouldn't be a great threat to the public.

And so the PRA effort that was presented at the end really to me would have been better right at the front, you know, and maybe some numbers put to what the risks are.

I thought the technical work was very interesting, of course, and we saw some CFD work, which is a step forward in terms of looking at some of the multi-dimensional effects that can occur in these situations, but at the same time, I think it clearly showed you that CFD is not the total answer yet sine you can't represent the entire system.

And so you still have to depend on these approximate methods for boundary conditions, and all of this kind of leads me to like looking at a mathematical problem that's ill posed. You know, a little perturbation can push it this way or that, and you have this huge uncertainty, which is the perturbation, and I would just hope that it doesn't matter if I go in the worst direction.

As far as the letter is concerned, I really don't have any comment as far as whether it would be needed or not, except it might provide an "atta boy" for, you know, certainly a lot of good work that's going on, progress report.

And as far as tomorrow is concerned, if people were like myself, of course, I'd like to hear the big picture first and then work down into the details, whereas this one was pretty much -- and yesterday the other way around. We started out with the details and kind of worked up to the end.

CO-CHAIRMAN FORD: What I propose to do is -- I thank you for all of your comments -- what i propose to do is I will write a draft letter which we may or may not use, essentially making the observation that all of the issues that we raised in NUREG 1740 are being addressed or in some cases have been finished, but most of them are being addressed. Some of them have not been finished.

We are satisfied in the main with the progress and the approaches that are being taken, but all of those issues are being melded into the current steam generator action plan for severe accidents, the integrated methodology that we made the analogy to the PTS program.

But I think all of us have also been concerned that the response to our issue on the spiking factor is not adequate, and so with Tom's help I'll draft up something to follow up on that concern mainly because it is a non-conservative safety issue, the approach that they seem to be taking.

And it will be a short letter. It will be addressing those issues. The detailed advice that has been given through these last two days are in the transcript, and I think they've been all well heard and hopefully gratefully received, and I think maybe rather than make a long letter with all of these suggestions, we can rely on the transcript to have that as a communication tool.

That's my proposal at this stage. I will draft that tonight and give it to you all so you can mull it over before we get to the actual letter writing.

DR. KRESS: Sounds good.

CO-CHAIRMAN FORD: Nut those are the salient notes.

DR. BONACA: If I could make one more comment.

CO-CHAIRMAN FORD: Sure, yes.

DR. BONACA: Just simply, you know, one thing that we already wrote up, and I think Vic Ransom discussed this issue of starting with details and now getting more of the big picture, when I look at the work you presented, it's a huge amount of work, and some of it, it's impressive insofar as the thoroughness, the treatment, results you're getting, information you're gathering from it.

And I realize between today and tomorrow it's impossible for you to develop that, but certainly if one had some kind of presentation on what is called the big picture, I would also that almost a decision tree that leads you to each one of the pieces, it would be a much stronger sales job.

I mean, it took us two days or a day and a half or whatever to realize how much around you'd cover, and I think if you had just at the beginning ten minutes of review of the thought process behind all of this, it would be really impressive.

It's just a suggestion.

MR. ROSEN: Perhaps a little history also on how we got to needing this effort.

CO-CHAIRMAN WALLIS: That would be something Joe would present presumably.

DR. BONACA: Yeah, and it would be impressive, and most of all, it would be also useful because at times, you know, in my mind it was always the question of are they covering all of the ground. Is there anything they're missing there? And so you go back to what are they trying to do.

And maybe it is because we have a limited view of the steam generator action plan, and that I think our involvement has been mostly with the DPO that was more limited on a number of issue, not all of them.

But, again, I mean, it seems to me that you're addressing the issue of the ability of that barrier to withstand challenges during design basis events and non-design basis events, and you have a lot of cascading work that you're leveraging there, and I think that it would be useful to have that perspective.

As I said, by tomorrow I think it's impossible to do that, but --

MR. SIEBER: One of the things that could be done to make it a little more systematic is the conclusions and recommendations in 1740 are about two or three pages at the end of the book. Now, Dana wrote a letter based on meetings that he had with the staff that would come out about October 2003 that gave a status report that's not a lot different than the status that was presented here over the last two days, and I think comparing that status or what we've seen in the last two days versus what we concluded and recommended would tell us really where we are, because, you know, this is sort of a building block kind of an exercise, and they aren't to the bottom line yet.

And so there's more to go, and part of the building blocks may change shape a little bit in the process, the iterative process of coming to a final conclusion.

So I honestly think with the exception of the iodine spiking issue it would be premature to give our final blessing for some of these building blocks.

CO-CHAIRMAN FORD: I'm sorry. One item I didn't mention. All we're saying is that we think that the progress that has been made is impressive, but we can't judge the adequacy of what's been done because we don't have the input from the PRA and the uncertainty analysis as to how good has this got to be.

So we don't have a way of metricizing our adequacy.

MR. SIEBER: Well, you can't judge whether you like the answer or not because you don't have the answer.

On the other hand, I think that you can make an informed judgment about whether the approach and the methods are adequate, which I think they are.

The problem with the iodine spiking even phenomenologically -- it seems backwards to me -- is you're getting pretty close to Part 100 someplace along the line, and to take a position that I don't see anything in the data that would lead you to a different multiplier when you run the risk of being criticized because you're getting close to the Part 100 limit; I think it really requires more justification than a one or two page memo.

CO-CHAIRMAN FORD: Okay. Any other comments?

Joe, have we helped?

(Laughter.)

CO-CHAIRMAN FORD: Okay. We are adjourned.

(Whereupon, at 5:25 p.m., the meeting was concluded.)