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NUCLEAR REGULATORY COMMISSION

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MEETING

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

(ACRS)

SUBCOMMITTEE ON THERMAL-HYDRAULIC PHENOMENA

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WEDNESDAY,

DECEMBER 11, 2002

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ROCKVILLE, MARYLAND

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

COMMITTEE MEMBERS:

GRAHAM B. WALLIS, Chairman
SANJOY BANERJEE, Consultant
F. PETER FORD, Member
THOMAS S. KRESS, Member
FREDERICK MOODY, Consultant
VICTOR H. RANSOM, Member

ACRS STAFF PRESENT:

PAUL BOEHNERT, Staff Engineer

ALSO PRESENT:

DAVID E. BESSETTE, NRC
DON FLETCHER, ISL
DAN PRELEWICZ, NRC
JOSE REYES, Oregon State University
JACK ROSENTHAL, NRC

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(8:34 a.m.)

CHAIRMAN WALLIS: The meeting will now come to order. This is a meeting of the ACRS Subcommittee on Thermal-Hydraulic Phenomena.

I am Graham Wallis, Chairman of the Subcommittee. The other ACRS members in attendance are Peter Ford, Tom Kress, and Victor Ransom. ACRS consultants in attendance are Sanjoy Banerjee and Fred Moody.

For today's meeting, the Subcommittee will review the work performed by NRC's Office of Nuclear Regulatory Research pertaining to the use of the RELAP5 code for calculation of the thermal hydraulic parameters used in the Oak Ridge National Laboratories FAVOR code pursuant to the PTS rule reevaluation effort.

Tomorrow we will discuss the status of the Office of Nuclear Regulatory Research TRAC-M code, consolidation, and documentation project. The entire meeting will be open to the public.

Mr. Paul Boehnert is the cognizant ACRS staff engineer for this meeting, the last one that I believe he's going to be our cognizant staff engineer for. And, we'll sadly miss him. We're very happy with the work he's been doing over the years.

MR. BOEHNERT: Thank you, Mr. Chairman.

CHAIRMAN WALLIS: The rules for participation in today's meeting have been announced as part of the notice of this meeting previously published in the Federal Register on December 2, 2002.

A transcript of this meeting is being kept, and the transcript will be made available as stated in the Federal Register Notice. It is requested that speakers first identify themselves and speak with sufficient clarity and volume so that they can be readily heard.

We have received no written comments or requests for time to make oral statements from members of the public.

We will now proceed with the meeting. And I call upon Dave Bessette from the NRC's Office of Nuclear Regulatory Research to begin.

MR. BESSETTE: I'm David Bessette from the Office of Research, the Thermal Hydraulic Group. I thought I'd give like an overview of this, the thermal hydraulic aspects of this PTS program, and give you some general information.

We will have two main presentations: one by Professor Reyes who works out of Oregon State

University, and the other by ISL, Incorporated, where the body of the RELAP analysis has been done.

The purpose, like I say, is giving an introduction and background. We'll talk about APEX-CE experimental program results, the RELAP5 assessment carried out in support of the RELAP5 PTS analysis.

We want to show that the important phenomena in PTS events, important to hydraulic phenomena in PTS events, are identified and the RELAP assessment is adequate. Certain phenomena that's not able to be treated by RELAP had been treated separately for experiments and analysis.

And what we won't cover is specific results of the RELAP5 PTS analyses or results of thermal hydraulic uncertainty studies done by the University of Maryland. We do plan to talk about these at the next overall PTS meeting on February 5th.

CHAIRMAN WALLIS: So you're not going to cover that at all?

MR. BESSETTE: Either subject?

CHAIRMAN WALLIS: I just wondered if you could summarize something for us on uncertainty when you get to the --

MR. BESSETTE: I'll try.

CHAIRMAN WALLIS: Yes, please.

MEMBER FORD: So we will not hearing today anything at all on metal temperatures and time transients? We won't be hearing that on the data and predictions?

MR. BESSETTE: Not really. In fact, we don't really have what I think you mean. We don't have comparisons let's say of wall temperatures, you know, thermocouples in a wall compared to RELAP predictions of that.

MEMBER FORD: Who's responsible for that because it's a critical input to the whole PTS study? So does this fall between the cracks between metallurgical and the thermal hydraulic?

MR. BESSETTE: Well, you see, we don't have experiments typically that measure wall temperatures.

MEMBER FORD: So wall temperatures have not been measured in any of the --

MR. BESSETTE: The RELAP calculation includes models of the wall and it has a conduction solution. The RELAP does give you a wall temperature profile.

MEMBER FORD: A predicted profile?

MR. BESSETTE: A predicted, yes.

MEMBER FORD: Yes.

MR. BESSETTE: When we pass information to the Oak Ridge people, we don't give them our RELAP wall temperatures. We give them fluid temperature and heat transfer coefficients, and they solve the conduction equation themselves.

MEMBER FORD: That should be very simple to solve. If you get a heat transfer coefficient and a temperature, then it's trivial --

MR. BESSETTE: -- to solve the conduction equation.

MEMBER FORD: To calculate the metal temperature.

MR. BESSETTE: So since they have that built into their code, they don't use our metal temperatures.

MEMBER FORD: How do you know the heat transfer coefficient if you don't measure a wall temperature?

MR. BESSETTE: Well, in RELAP, of course, we do know the wall temperature.

MEMBER FORD: You do?

MR. BESSETTE: Well, in RELAP we do.

MEMBER FORD: Well, RELAP thinks it knows the wall temperature.

MR. BESSETTE: Thinks it knows the wall

temperature from the heat transfer coefficient.

MEMBER RANSOM: Well, it's an interval calculation. The real question is don't you measure any heater temperatures in APEX facility that you than can compare with both analyses?

MR. BOEHNERT: Yes.

MR. BESSETTE: Well, you're speaking of core heater temperatures, which are measured --

CHAIRMAN WALLIS: Maybe we should ask Jose what he's got on the wall.

MEMBER RANSOM: The whole idea is to compare the code with the APEX experiments, and from that derive something about uncertainty.

CHAIRMAN WALLIS: Let's ask Jose.

PROFESSOR REYES: This is Jose Reyes from Oregon State University.

We did measure some wall temperatures. Originally, we had some heat flux smears. And we do have heat flux smears on the outside surfaces of our wall. And I'll show today some of the inverse conduction calculations we did using STAR-CD, CFD code, and what we used for boundary conditions.

Now our wall, of course, is a thin wall. It's only a half-inch thick. So, it's not really representative of what you'd see in the actually plant.

MR. BOEHNERT: I just remember, I thought you had thermocouple rates along that wall, didn't you?

PROFESSOR REYES: We don't have anything embedded in the wall because of the requirements of the -- it's too thin. So in terms of pressure vessel code, we weren't allowed to do that.

MR. BOEHNERT: I see.

PROFESSOR REYES: We'd have exterior measures.

MR. BOEHNERT: Okay, okay.

MEMBER RANSOM: Well, do you analyze your results using RELAP5 so that you have some basis for establishing the uncertainty in the code calculations?

PROFESSOR REYES: I believe what you'll see are some RELAP5 analyses that have performed. And we also use STAR-CD. We were interested in the plume region, where we have these cold plumes coming in to the downcomer. We were particularly curious about the temperatures and the heat transfer coefficients in that region. And so, I'll present some results on that a little bit later on.

CHAIRMAN WALLIS: In one of these presentations, I forget which, we actually saw predicted profile temperatures in the wall. And once you get above a certain heat transfer coefficient, it doesn't seem to make much difference.

MR. BESSETTE: Yes, that's right.

CHAIRMAN WALLIS: So I think that it may be that, maybe you can show that it doesn't matter. That would reassure a lot of people.

MEMBER KRESS: Isn't that why it gets below a certain heat transfer coefficient?

MR. BESSETTE: So the problem, like Jose says, is that experimental facilities don't typically have wall temperatures. They try to measure some in APEX, but I don't think they --

PROFESSOR REYES: I can show you what I have.

MEMBER FORD: I guess the question arose, your comment that certain things will not be covered. What I'm understanding from the conversation so far, there will be some coverage of wall temperatures measured in predicted -- I mean, it may not be in your presentation.

PROFESSOR REYES: Right. There will be a small amount.

MEMBER FORD: Good.

DR. BANERJEE: Where is this PTS meeting

on February 5th? Is it going to be here or where?

MR. BESSETTE: Yes. It's a combined fracture mechanics, thermal hydraulics, and probabilistic risk assessment.

MEMBER KRESS: That's a new meeting we just set?

MR. BOEHNERT: Yes, just as of last week.

MEMBER FORD: The main reason was the question about the source terms. That's the main new thing that came up, so we wanted to hear about how the whole program was progressing.

DR. BANERJEE: Source terms for what?

MEMBER KRESS: You have to induct in the PTS thing, a prompt fatality. And, you have to have a source fission product for that. And there's some questions about what to use in that particular accident sequence.

CHAIRMAN WALLIS: That's going to be a big topic, a big meeting. We're going to go through everything from the beginning to the end of the PTS event.

MR. BESSETTE: Yes. Well, we hope to present the results from the three plants that are --

CHAIRMAN WALLIS: That's going to take all day.

MR. BESSETTE: I presume.

CHAIRMAN WALLIS: It'll probably be chaired by the Metallurgy Subcommittee.

MEMBER FORD: There's always a question whether I'm chairing it or whether Tom is chairing it.

MEMBER KRESS: We'll co-chair.

MEMBER FORD: Exactly.

MR. BOEHNERT: You could tri-chair

CHAIRMAN WALLIS: A troika. Let's move on.

MR. BESSETTE: A ruling triumvirate.

This is a brief synopsis of how this is organized. There are three main plots of PRA events: sequence analysis, thermal hydraulics, and probabilistic fracture mechanics.

Primarily, we find sequence that then gets analyzed. From here, we generate a pressure or temperature verses time, feed that to the Oak Ridge FAVOR code, and they use these boundary conditions and they generate a conditional probability of vessel failure. And, they also get the sequence frequency, the probability the sequence will occur, and get a yearly vessel through-wall crack frequency.

DR. BANERJEE: Dave, for those of us who have been out of the loop for a while, can you state the problem? What is the problem?

MR. BESSETTE: The problem is that the vessel gets embrittled primarily by neutron, fast neutron, but also some gamma. It gets embrittled because of the radiation damage to the lattice structure. And, there's a function of fluence.

If you then cooled the vessel fairly rapidly, from some thermal hydraulic transient, you'd go from a warm ductile condition down to a cold brittle condition. And the combination of thermal stress and pressure stress can be sufficient to generate a preexisting flaw. I mean to get a preexisting flaw to pop.

DR. BANERJEE: And what sort of transients, thermal transients are you talking about?

MR. BESSETTE: I'll get into that.

DR. BANERJEE: You're going to describe that?

MR. BESSETTE: Yes.

DR. BANERJEE: I don't see it in your slide. It looks like --

MR. BESSETTE: No, it's in some subsequent slide. But, not to keep you in suspense, it's primarily LOCAs. Although, we've investigated all transients we can think of.

CHAIRMAN WALLIS: It's pouring cold water down the wall after a LOCA is what you're -- a hot vessel and you're pouring this cold water?

MR. BESSETTE: Basically, it's the ECCS water that comes in, pours in to the downcomer.

MEMBER KRESS: It's generally a small break LOCA because you need to keep the pressure up also.

MR. BESSETTE: Well, that's what we thought for some 20 years or so.

MEMBER KRESS: Yes, that's what I --

MR. BESSETTE: But the current reanalysis has shifted the emphasis toward larger breaks.

MEMBER KRESS: I see.

CHAIRMAN WALLIS: So it's just the thermal stress that does the damage then?

MR. BESSETTE: It's primarily the thermal stress. It's the main contributor.

DR. BANERJEE: It's not cycling or --

MR. BESSETTE: It's not a fatigue thing.

DR. BANERJEE: Because there are, I have been told situations in the upper head region, where the temperature cycles. That's what the French think. And that's a completely different issue.

MR. BESSETTE: Yes, completely different.

MEMBER KRESS: That area never hits, generally not embrittled very much because it's out --

DR. BANERJEE: But instead you have the VHPs cracking.

MEMBER KRESS: I mean that's the stress.

CHAIRMAN WALLIS: It's an experiment you can do at home. You put a jam jar in the oven and then take it out and pour cold water into it.

MR. BESSETTE: I've even had it taking a glass out of the dishwasher and filled it up with water and had it crack in my hand.

DR. BANERJEE: But is there some assessment going on in the upper head regions, the cycling effects?

MR. BESSETTE: I wouldn't doubt it. There are thermal fatigue problems that occur in other positive systems, but it has nothing to do with what we're --

CHAIRMAN WALLIS: This is vessel embrittlement. It's tied in with vessel embrittlement from fluids.

DR. BANERJEE: So you've defined the problem to be one which is LOCA related?

MR. BESSETTE: Well, so, this particular problem has it's boundaries of being a thermal shock problem. We looked at all transients and found out that LOCAs dominate.

But the problem here is: Will the vessel fail or not? And failing is a fairly large crack developing.

CHAIRMAN WALLIS: You've already failed a pipe, so you don't care about failing another pipe really. But, if you fail a vessel --

MR. BESSETTE: Fail a vessel, you've got another problem on your hands.

MEMBER RANSOM: Actually, any transient that leads to overcooling at pressure causes this problem, doesn't it?

MR. BESSETTE: That's right.

MEMBER RANSOM: And Rancho Seco was a classic one. And I don't remember exactly what led to that overcooling transient.

MR. BESSETTE: Well, Rancho Seco basically got the whole PTS started back around 1979, '78. And there was that light bulb transient.

DR. BANERJEE: Why has this taken on a new lease for life? What have we learned recently that has put us into this situation that you're visiting? I thought it had been looked at. I remember Theophanos did some work and various people.

MR. BESSETTE: Yes, so we did a lot of work back in the '82, '85 timeframe, and experiments that Theo ran and all of that as part of that initial look at it. And then it go set aside. We wrote a PTS rule, 10 CFR 50.61.

And so basically it was let's say resolved. We did the analysis, we wrote the rule, and we had screening criteria that the licensees had to follow. You know, if your vessel embrittlement got to such and such a level, you had to come in with specific analysis on your plant.

And then we had, Yankee Rowe came along and it was at the screening limit. And so they started doing plant-specific analysis, and we started doing some analysis ourselves.

The upshot was this side of it would be too difficult to try to show the safety casings, so they shut the plant down. So after that, the Commission told us they have to take another look at the overall guidance, the reg guide and all that.

The other thing is that, you know, the fracture people have continued to work on the fracture modeling. It was felt that there was probably too much conservatism in their assumptions on the flaw size and flaw distribution for orientation. But, they continued to work on these things and they developed improved databases that allowed them to improve modeling.

So we thought that there was substantial conservatism in our previous analysis, '83 to '85 analysis. And substantial was we estimated about two orders of magnitude of conservatism in the risk numbers. So, we thought the time was right to go back and reexamine the whole issue on an integrated fashion from a hydraulics risk assessment and fracture mechanics. And that's the basis of the current effort.

CHAIRMAN WALLIS: Isn't there another reason for this, that these plants are being re-licensed, and they're going to run longer, and the vessels will get more brittle?

And so the question is: When are they going to come up against some PTS limit?

MR. BESSETTE: That's the other part. In the subsequent 15 years, it became clear that plants wanted to increase their life from 40 years to 60 years. And some plants would need a more, best estimate analysis of the PTS risks in order to justify operation for another 20 years. So, there was a strong economic incentive to take a look at the problem.

DR. BANERJEE: Now you said two orders of magnitude was some sort of a change in the risk. What was the main determinant there? Was it the fracture mechanics or the thermal hydraulics?

MR. BESSETTE: Well, I would say the major contribution --

DR. BANERJEE: Well, you said two orders. I'm not holding you to it --

MR. BESSETTE: It is.

DR. BANERJEE: Where did you get that two orders?

MR. BESSETTE: We believe that would come primarily from the fracture mechanics, but also by a more detailed examination of the thermal hydraulic sequences.

When we did the first study, because of the difficulty at that time in running a substantial number of calculations, we only looked at about 12 transients. And so, in the PRA terminology, we had these very course bins. So we had let's say one transient, and we calculated with RELAP. That was representative of the whole range of possible PRA sequences.

And in many cases this one transient was at the worst-case edge of that bin. So, you'd combine a worst-case thermal hydraulic transient with a rather broad probability so it gave you a conservative result.

DR. BANERJEE: Can you be concrete on that? Like, give me a real example.

MR. BESSETTE: If you analyze a steam-line break and you used that thermal hydraulic transient to represent any overcooling that you get from steam leak on a secondary-side, you get an answer that's totally conservative because a steam leak can encompass, or more often will encompass some sort of stuck open turbine bypass valve or safety valve, something like that.

There's a much higher frequency for occurrence than a steam-line break. So, you associate a high frequency of occurrence with a worst-case scenario.

DR. BANERJEE: So you're just sharpening your pencil on that?

MR. BESSETTE: That's right.

DR. BANERJEE: Is there any new thermal hydraulics involved or is it sort of just redoing some old stuff?

MR. BESSETTE: Per se, I would say there's nothing dramatically new in a thermal hydraulics setting.

CHAIRMAN WALLIS: I think what's dramatically new is the mixing in the downcomer. If you assume that the ECC can mix a plume, and you've got this really cold water coming down all the way, that tills the wall much more effectively. And then it comes in and it mixes and it reaches some warmer temperature before it flows down the wall. So, the mixing phenomena is pretty key to estimating the thermal shock.

MR. BESSETTE: I would agree. That would seem to be the primary thermal hydraulic issue that we need to take another look at in this current effort. So, you'll hear about that.

CHAIRMAN WALLIS: Send Sanjoy that figure, which has seven orders of magnitude in the fracture mechanics with data points all over the place. Send him that just to let him know that there's something far more scattered than thermal hydraulics.

(Laughter.)

DR. BANERJEE: Which is fracture mechanics.

MR. BESSETTE: Yes.

DR. BANERJEE: Now, before we move on,

just to get an overview because I'm -- Mr. Chairman, if you'll allow me because I haven't been up to speed on this.

CHAIRMAN WALLIS: I think it's helping everybody.

DR. BANERJEE: Right. So --

CHAIRMAN WALLIS: It's also helping to find out how much he knows.

(Laughter.)

MEMBER KRESS: Which is pretty impressive so far.

DR. BANERJEE: You're doing very well, Dave.

Now, why do you do this analysis with RELAP? I mean these are strictly 3-D effects you're talking about, right?

MR. BESSETTE: You mean CFD?

DR. BANERJEE: Yes.

MR. BESSETTE: Well, we have done CFD analysis as well to supplement the RELAP analysis. But the CFD can't give you the total system response, which you need. You need to know the whole mass and energy. You have to know what the whole primary system is in the mass and energy perspective.

DR. BANERJEE: Sure. But I mean that's

fine in setting the boundary in some way --

MR. BESSETTE: But we did supplement that with the CFD analysis to take a look at the problems of mixing in plumes, mixing and stratification in the cold-leg and the plume as it entered the downcomer and dissipates.

DR. BANERJEE: Someone will talk about those CFD results then?

MR. BESSETTE: Yes, Jose is going to show you those results.

CHAIRMAN WALLIS: What you should tell Sanjoy, I think is the question of stagnation. I don't think you've mentioned that. You don't need RELAP to tell what the flow rates are. If the flow rates are big, then everything gets mixed up and it's fine. But if the flow is pretty stagnant and then you put this cold water in, then all you're getting is cold water into the downcomer and there's no other flow involved. I think that's one other cause of the worst case, isn't it?

MR. BESSETTE: That's right, and I'll mention that too. There's always a difficulty in trying to have your whole presentation in your third slide.

MEMBER RANSOM: I thought it would be nice to see a diagram to overcome this mixing problem that generally looked at the cold-leg temperature. You know, so it was -- the coldest temperature actually that was coming in was at the cold-leg nozzle where there was thought that the risk of thermal shock was perhaps the most severe.

I had one other question that related to power uprates that we'd been listening to because they're increasing the fluence to the wall, these power uprates. And at that time, we were told I thought that the fluence issue was no longer an issue in terms of risk of fracture of the vessel wall, that this problem had been resolved. But, it seems like that's the other factor here, is how much damage has there been done due to neutron flux to the wall.

CHAIRMAN WALLIS: What they did was they sharpened their pencil on the fluence calculation and showed that with the new calculation. Though they increased the power, the fluence didn't go up.

MEMBER RANSOM: Oh, really.

MR. BESSETTE: And then again, what many people did after the early 1980s study was they changed their fuel loading schemes. They used to aim for as flat a profile as they could, and they went to a more center-peak profile. And now this allows them to go back to a flatter profile, which anyways is preferable.

CHAIRMAN WALLIS: We should let you go on I think.

DR. MOODY: With one side note, Dave, you rascal, if you had been able to write that paper you were going to send to the Pressure Vessel and Piping Committee a year ago, you could deflect all these questions right at the front.

MR. BESSETTE: This is your chance for revenge.

DR. MOODY: Yes.

(Laughter.)

DR. BANERJEE: And he exercises it often.

CHAIRMAN WALLIS: It's a very good discipline for you folks to write a technical paper. Perhaps you really get your ideas straight --

DR. BANERJEE: Which is peer-reviewed.

MR. BESSETTE: When is the next conference?

(Laughter.)

CHAIRMAN WALLIS: It's even tougher coming before the ACRS group.

DR. BANERJEE: There is NUREG-10 coming up.

MR. BESSETTE: All right. I'll put it in there.

DR. BANERJEE: You have to do it in the next few days.

MR. BESSETTE: That's no problem.

(Laughter.)

So, the interesting thing about the pressurized thermal shock is that most problems you work on, it's a fairly confined problem so it's limited to a very specific specialty or whatever.

As I indicated, this PTS problem involved three various divisions: the Division of Engineering Technology, and the developer of their code is Oak Ridge; the Division of Risk Analysis and Applications, and they rely on Sandia, Science Applications and University of Maryland in this project; and this is where I am, the Division of Systems Analysis and Regulatory Effectiveness.

We have four main subtasks that we worked on. This was the basic production runs of RELAP5 analysis, where we take the transients supplied by the risk people and we calculate them and feed the results to the Division of Engineering. We have the RELAP assessment, which you'll hear about today. We have the T-H, thermal hydraulic uncertainties, which we'll talk about in the future. And, we have the thermal hydraulic experiments and phenomena done at Oak Ridge -- I mean at Oregon State University. And you'll hear about that today from Professor Reyes.

CHAIRMAN WALLIS: Do you run some codes in-house too?

MR. BESSETTE: We did a little bit of work in-house. We did some, the Calvert Cliffs analysis, and we did run a few TRAC calculations.

CHAIRMAN WALLIS: You have the facilities to do that and you have plenty of computers and so on. So, it would always seem a good idea to run some confirmatory stuff in-house.

MR. BESSETTE: Yes. In fact, right now Norm Lauben is doing some calculations.

DR. BANERJEE: What does the ORNL work focus on?

MR. BESSETTE: Oak Ridge work is focused on the fracture. They have a probabilistic fracture analysis called FAVOR.

DR. BANERJEE: FAVOR?

MR. BESSETTE: FAVOR, F-A-V-O-R.

DR. BANERJEE: And so you take inputs from the thermal hydraulics calculations of temperatures and feed it into this code?

MR. BESSETTE: Yes.

DR. BANERJEE: And you'll get back some results?

MR. BESSETTE: Yes.

CHAIRMAN WALLIS: Oak Ridge busts some big vessels, don't they?

MR. BESSETTE: Yes. Oak Ridge had a program that they ran for some five or ten years, where they did thermal shock experiments in vessels about four feet tall and three feet in diameter. So, they ran about a dozen or so of these vessel tests.

MEMBER KRESS: They did a lot of the database on the radiation embrittlement also.

MR. BESSETTE: Yes, that's another main area they've worked on.

DR. MOODY: Do you remember how thick the walls were on those off-hand, just approximate?

MR. BESSETTE: They I think were about three inches thick.

MEMBER KRESS: They were three to four inches, depending on the diameter. But, they tried to simulate the thermal shock conditions. That's hard to do with a small vessel.

MR. BESSETTE: But anyway, they would take these three-inch or so vessels, and I think they would dip it in liquid nitrogen or --

MEMBER KRESS: Yes. To shock them from the outside in.

MR. BESSETTE: Yes.

DR. BANERJEE: Some of these tests, if I recall, were also done with other things than temperature, right? The concentration fields?

MR. BESSETTE: I'm not aware of any tests like that.

MEMBER FORD: There were quite a few tests, not just on pressure vessels, but on spinning disks. So there's a whole variety of structural geometries that were tested back in the `80s. There's a big database for probabilistic factors.

MEMBER KRESS: The big uncertainty is the flaw density and size that you start with in the first place.

MR. BESSETTE: Yes. So there was basically an absence of data, which led them to make conservative assumptions. And I think they did a considerable amount of work since then. They got the vessel off of one of these cancelled plants. They required a vessel and they --

MEMBER KRESS: It was a vessel that had never been used. And they went in and did a complete characterization of the flaw distribution, which is a pretty good database.

MR. BESSETTE: And one of the things about these flaws is that they're there from the time the vessel is manufactured. They're not flaws that develop in service.

CHAIRMAN WALLIS: Now with all these different things going on, somebody is in charge?

(No response.)

CHAIRMAN WALLIS: Who's in charge?

MR. BESSETTE: Who's in charge of this whole effort?

CHAIRMAN WALLIS: Yes.

MR. BESSETTE: Well, the nominal manager in charge is Mike Mayfield.

CHAIRMAN WALLIS: The nominal manager?

MR. BESSETTE: Yes. But in terms of the day-to-day activities, it's mostly myself, Mark Turk from the Engineering Group, and Roy Woods from the Risk Assessment Group.

CHAIRMAN WALLIS: So you're fully aware of all the work being done everywhere?

MR. BESSETTE: I wouldn't say fully, but I certainly follow it as much as I can.

MEMBER FORD: You said earlier -- and I'm completely throwing you off your stride. I apologize for that. But you did say something interesting, which is at odds with what we had heard before.

You said the small-break LOCA is the focus because maintaining the pressure and that was the reason why we went on to forget the secondary-side breaks and focus on, for instance, the safety relief valve failures. You then went on to say that you no longer believe pressurization stress was the prime driver. Thermal stress is far more important. Therefore, presumably, medium-break and large-break LOCAs are far more important.

Now, this is new from what I remember the previous presentation saying. Does that not therefore completely negate some of the main conclusions that were made back in the beginning of this year?

MR. BESSETTE: No. I think we said --

MEMBER FORD: For instance, the whole area of human performance issues, a lot was made of that.

MR. BESSETTE: Well, I think we have a more complete picture now. But I think when we did present it to you back in January of this year, I think we did say that the LOCAs were dominating the risk. And I think the concern was, well, how do you, how do we negate the secondary side transients on the basis of operator actions in terms of a probabilistic sense. I think that was the concern.

MEMBER FORD: I was thinking, are you not introducing new phenomena? For instance, if you depressurize to any great degree, that doesn't matter as far as the thermal stress. But it does matter, for instance, if you have boiling. That affects your heat transfer coefficient presumably.

Have these aspects come into the arguments?

MR. BESSETTE: Well, with --

MEMBER FORD: Is this going to be discussed later on?

MR. BESSETTE: Well, I probably should answer that question now because we won't get back into that.

MEMBER FORD: Okay.

MR. BESSETTE: During the 1983, '85 study, at that time thereafter, it was felt that the dominant transients were small-break LOCA. And, the break is small enough so the pressure stayed up to a 1,000 psi. Or even in an event small-break LOCA gets isolated, so you go back up to 2,500 psi. Those seem to be the dominant events.

But in some cases, contributions from

steam-line break. For those two events, steam-line break and small-break LOCA dominated the risk. And that was the picture we started with two years ago when we started the reanalysis.

What we found was we kept having to go to larger and larger break sizes because we saw the risk numbers continuing to climb until we went all the way up to large-break LOCA. And we started worrying, are we doing something wrong? But as of today, we're still dominating the risk as our large LOCAs: LOCAs four inches, twenty inches in size, very large, fast acting transients.

Now, the question of new phenomena. Well, from an analysis perspective, there's nothing new to us about large-break LOCAs. We've been analyzing them for a long time. But from a thermal hydraulic sense, there's nothing new. But from a perspective of PTS, it is new.

MEMBER FORD: You say it's nothing new from a thermal hydraulics, the fluid side of the equation, nothing new?

MR. BESSETTE: That's right.

MEMBER FORD: But does it not introduce something new from the material side of the equation, i.e., the heat transfer coefficients, and therefore the metal temperature? Does that not introduce something new from a phenomenological point of view?

MR. BESSETTE: Well, not from the perspective of the vessel I would say because, like I say, they generate a stress by the temperature distribution in the vessel and the pressure. That gives them the stress and that gives them, the temperature also gives them, that's the ductility distribution or toughness distribution.

So, that's how they do their analysis. They don't really care about what the fluid is doing other than, you know, give them a fluid temperature and a conductive heat transfer coefficient.

CHAIRMAN WALLIS: Isn't there something very different? In the small-break LOCA the vessel stays fill. In large-break LOCA, it empties. And then you're pouring water down the wall of the downcomer or whatever. It's not full anymore. So, all this mixing and CFD doesn't apply anymore to what's going on in the downcomer.

MR. BESSETTE: Well, it's that too. Well, actually the vessel doesn't empty. Well, it can empty in extreme cases.

CHAIRMAN WALLIS: Yes, in the large-break LOCA, it essentially empties.

MR. BESSETTE: Yes. And in the intermediate cases, the vessel may stay full of water.

CHAIRMAN WALLIS: Do you have an idea of what happens in that downcomer when it's essentially empty and you're pouring water into it?

MR. BESSETTE: Well, certainly we've analyzed up to 22-inch breaks. And in that case, the downcomer -- it's a large-break LOCA -- the downcomer empties and then refills.

CHAIRMAN WALLIS: Doesn't the liquid squirt across to the other wall and splatter around?

MR. BESSETTE: A lot of drastic things happen. There's a lot of condensation that occurs. One of the things that keeps -- in a large-break LOCA, you may not end up with as cold a temperature as you might expect because there's so much condensation that occurs around the injection locations in the cold-legs that the water can get near saturation before it gets substantially into the downcomer.

CHAIRMAN WALLIS: There's a question of scaling of that.

MR. BESSETTE: Yes, that's why we do UPTF and all that.

CHAIRMAN WALLIS: Well, it's interesting that large-break LOCA is turning out to be so important when there's discussion underway to sort of do away with it as an accident that needs to be considered.

MR. BESSETTE: So not only do you have a large-break LOCA, then your vessel fails on top of it.

MEMBER RANSOM: Dave, could you take -- where does the cold water come from in this accident, like in small break LOCAs? Is it ECC water that --

MR. BESSETTE: It's ECC water. So it's coming from the refueling water storage tank, which sits outside.

DR. BANERJEE: So in the small break LOCA, you have to have countercurrent flow, right? Hot water moving in one direction and --

MR. BESSETTE: You tend to get that, yes.

DR. BANERJEE: Moving at the bottom of the pipe?

MR. BESSETTE: Yes.

DR. BANERJEE: But how do you calculate that as RELAP?

MR. BESSETTE: We don't. That's where we did some additional looking at that with CFD.

DR. BANERJEE: So you feel assured that your calculations for SB LOCA, which is sort of moving the high risk of large-break LOCA, is correct in its calculations?

MR. BESSETTE: I believe so. You know, the effects of -- the fact that we can't measure, you know, two fluid temperatures in a one-dimensional code, we miss that local effect.

But, you know, based on what I've seen in the past though, RELAP tends to predict the average behavior of these two fluids pretty well. So, if the fact that locally there are two fluid temperatures and a cold-leg, once you get to a more global perspective of the downcomer, it's washed out again.

DR. BANERJEE: So they mix sufficiently? By the time they come to the downcomer, it's one temperature or what?

MR. BESSETTE: Not exactly.

DR. BANERJEE: You can't see that because it must be sort of cold water spilling and hot water being sucked into the line.

MEMBER RANSOM: Are these being simulated in the Oregon State experiments?

MR. BESSETTE: We looked at that at Oregon State. And so I think I'd rather defer that to Jose, who's going to cover it.

DR. BANERJEE: So you're sense here though is that your SB LOCA calculations are sufficiently good that you can believe them and say LB LOCA is the problem?

MR. BESSETTE: The issue you mention is certainly one that I was concerned with at the start. You know, what effect does this have? We can't capture this phenomenon. But I feel more comfortable now that it doesn't really matter.

DR. BANERJEE: Will you tell us why?

MR. BESSETTE: I'll let Jose talk about that I think.

CHAIRMAN WALLIS: I noticed -- I went through all your slides here. They're all words. You don't have any figures or anything.

MR. BESSETTE: Yes. So it's better for this kind of thing to look at something more exciting than --

CHAIRMAN WALLIS: I think we ought to sometime, to see some figures.

MEMBER FORD: Were we not going to get the final report from Oregon State on the APEX?

MR. BESSETTE: Yes, it's in the mail.

MR. BOEHNERT: Like a check, huh?

MR. BESSETTE: It's in the mail some place. Federal Express has their hands on it right now. It's somewhere between Oregon and --

MR. BOEHNERT: So we'll have it by 10:30, is that it?

MR. BESSETTE: Possibly. They guarantee it.

CHAIRMAN WALLIS: Is there any electronic version that you have already?

PROFESSOR REYES: There actually is. We did express mail two copies. One 10 days ago, and then one again yesterday.

CHAIRMAN WALLIS: Why didn't you carry it?

PROFESSOR REYES: I thought it would've been here by now. I was quite surprised when I found out that --

MR. BESSETTE: It's over 400 pages or something like that.

DR. BANERJEE: You can send a PDF file or something.

PROFESSOR REYES: We can make a call today and see if can.

CHAIRMAN WALLIS: Okay. This is the CSAU process here?

MR. BESSETTE: This is basically like a modification of the CSAU process. So, this is basically -- one of the key aspects of the reevaluation was to try to account for uncertainties.

And we couldn't because it's such a different problem when a typical CSAU. We have to try to come up with let's say modifications to the CSAU process.

So, these first three boxes are the same as CSAU. They specify the plant, the frozen code, and input model, identify important plant characteristics. And then this is where we have to go through a screening because we're dealing with -- the PRA people started off with about, something in the order of 100,000 different event sequences.

And, of course, we can't run RELAP 100,000 times. So, we have to bin these event sequences. So we now are running RELAP on the order of 100 calculations for a given plant. So say 100,000 event sequences get binned into let's say 100 bins. And, of course, we can't do uncertainties on 100 different sequences.

CHAIRMAN WALLIS: It still seems remarkable that you need 100. I would think that 10 of them would probably dominate the risk.

MR. BESSETTE: Yes, but if we knew the answer ahead of time --

CHAIRMAN WALLIS: You have to find out.

MR. BESSETTE: We have to find out.

CHAIRMAN WALLIS: That's right.

MR. BESSETTE: But we had to run 100 to find the 10. In fact, that is the case, that 10 dominate risk or four even.

CHAIRMAN WALLIS: Four or five, yes.

DR. BANERJEE: But that screening is done on the basis of RELAP?

MR. BESSETTE: This binning?

DR. BANERJEE: The binning is done on the basis of your intelligence.

MR. BESSETTE: Yes. So, the binning, you come in with binning on the basis of -- initially, your initial review is on the basis of let's say judgment. And then as your run more and more RELAP sequences and look at the pressure and temperatures -- but for a screening, it was we're not going to worry about any transient that doesn't get below 400 F because below 400 F has no PTS significance. So, you throw out all those. And so we set the discard bins or whatnot on that basis.

DR. BANERJEE: It's hard for me to get this from words. But, 400 F I presume is the average temperature you're talking about?

MR. BESSETTE: Four hundred F let's say has a downcomer fluid temperature.

DR. BANERJEE: Average?

MR. BESSETTE: Average.

DR. BANERJEE: But it's not the average that matters here. It's the localized, right?

MR. BESSETTE: Yes. So what we're going to show is that the average -- the downcomer is very well mixed, so the average is very close to local.

CHAIRMAN WALLIS: If it's full.

DR. BANERJEE: And that's on the basis of what scale experiments you're going to show that?

MR. BESSETTE: The only thing that'll talk about that is the APEX facility. And they also looked at the, I think Creare data and some finished mixing experiments and whatnot.

DR. BANERJEE: So now you've got cold water coming out of this pipe, the cold-leg or something --

MR. BESSETTE: Yes.

DR. BANERJEE: -- and it's sort of falling into the downcomer. And you've got hot water getting sucked back in?

MR. BESSETTE: Yes.

DR. BANERJEE: And you're saying that the cold water falling is going to mix well with this hot water?

MR. BESSETTE: Yes, that's what we're

going to try to convince you.

DR. BANERJEE: And you're going to show us some data and analysis?

MR. BESSETTE: Yes.

DR. BANERJEE: It seems not that easy to me to show that.

MEMBER RANSOM: Dave, in the PRA analysis, how do you identify the sequences that are going to lead to this? Do you have some criterion based on when ECC water is injected?

I mean you talk about 100,000 sequences. Those are not RELAP5 calculations. Those are based on event three type analysis.

MR. BESSETTE: That's right.

MEMBER RANSOM: Then you only choose a few of those I guess that you try to analyze.

DR. BANERJEE: Representative ones.

MEMBER RANSOM: But what is the criterion there?

MR. BESSETTE: Well, the PRA people start to, like I say, the PRA people had some meetings early on where we discussed, you know, together how, what you have to do to get down to low temperature. If you fail one valve, is that going to do anything? If you fail two valves? How much cold feedwater do you have to add to the generator?

So, we went through those kinds of discussions early on. And then we kept revisiting that issue as we generated more and more analysis, and we got more and more RELAP calculations. You can start to screen out.

So, for Oconee, it took two years to do Oconee. The second plant, it took 15 months. So there was a learning curve to go through that screening process.

MEMBER RANSOM: Where is that at? Is that PTS screening in the six, box six?

MR. BESSETTE: Yes, it's in these boxes here. You know, at some point we started to feed results to Oak Ridge and get numbers back from the FAVOR code.

CHAIRMAN WALLIS: It's interesting. You didn't do the probabilistic analysis where all you had to do was run 59 runs.

MR. BESSETTE: No. We didn't do that 59 runs, no.

CHAIRMAN WALLIS: Vary everything statistically and do 59 runs.

MR. BESSETTE: That's right. We didn't follow that path.

But, basically, this is just to give you an indication. We used a modified CSAU method that had this iterative screening in it, but tried to decide what to focus on for the thermal-hydraulic uncertainty analysis. And that led us eventually to like a mid-sized LOCA to focus our uncertainties. That's from a combination of guessing and analysis. It's greater if the risk ended up being focused.

But the idea is you can't do a TH uncertainty analysis on 100 different things or 10,000 different things. You have to focus a small enough group. And to do that, you have to go through a screening process.

DR. BANERJEE: Why didn't you use the 59 methodology, which people seem to be using for other things?

MR. BESSETTE: Well --

DR. BANERJEE: Did you have anything against it?

MR. BESSETTE: I've always been a little dubious about it myself.

DR. BANERJEE: It seems sleight of hand.

MR. BESSETTE: It seems too much of a sleight of hand to me.

DR. BANERJEE: Yes, but Graham seems to

believe it. Why didn't you do it, I mean other than gut-feel? Is there any other reason?

MR. BESSETTE: I guess I should have the University of Maryland people here too to answer that question. But from my own perspective, it was more satisfying, rather than to do this 59 analysis, try to decide what the important, what the dominating parameters are, dominating phenomena and do sensitivity studies on those to generate your view of the thermal hydraulic uncertainties under the CSAU approach.

DR. BANERJEE: Is there sort of a number like these 59 go on PCT or percent hydrogen or something? Do you have a number for PTS like thermal shock of that many degrees or something like that?

MR. BESSETTE: Well, we have this key parameter approach because we're feeding pressure, temperature, and heat transfer coefficients. And of these three, what we find is temperature is most important, pressure is of intermediate importance, and heat transfer coefficient is of no importance.

CHAIRMAN WALLIS: Because it's so big?

MR. BESSETTE: Yes.

DR. BANERJEE: So do you have some number like thermal stress or something, which if it exceeds this amount then you're in trouble; and if it's not, then it's okay? I mean is there an equivalent to a PCT in this problem?

MR. BESSETTE: Kind of. So when you get into the fracture analysis, they speak in terms of a K-1 and K-1-C. K-1 is the stress the metals are experiencing. K-1-C is like a critical threshold for cracking, for crack propagation.

So when K-1 and K-1-C are --

MEMBER KRESS: Yes. Their key figure of merit though is a through-wall crack.

DR. BANERJEE: I see.

CHAIRMAN WALLIS: I guess the rule of thumb is the difference between the surface temperature and the average temperature because of the stress. Is that the same thing as K-1 --

MR. BESSETTE: Well, see, they interplay because K-1-C is changing with temperature and so on.

CHAIRMAN WALLIS: With temperature, the susceptibility of the material changes too?

MR. BESSETTE: Yes.

CHAIRMAN WALLIS: Okay.

MR. BESSETTE: And, you know, you can get these temperature distributions across the wall, which are constantly changing thermal stress.

CHAIRMAN WALLIS: K-1-C is not a non-dimensional either? It's got square roots of things and strange things --

DR. BANERJEE: But if had a number like K-1-C minus K-1 over K-1-C, that would be a figure of merit, right?

MR. BESSETTE: Yes. I guess so, yes.

DR. BANERJEE: How close are you to critical crack or something?

CHAIRMAN WALLIS: Maybe you should come to the February 5th meeting.

MR. BESSETTE: It wouldn't be a bad idea.

CHAIRMAN WALLIS: And get the whole historic --

MR. BESSETTE: So what plants that I'll be analyzing -- back in this original study, we had three plants, one from each of the PWR vendors. And these plants were Oconee, which is B&W; Calvert Cliff, which is combustion; H.P. Robinson, which is a three-loop Westinghouse plant.

So, in the current study, we were going to start with these. But instead we substituted another Westinghouse three-loop plant, which is Beaver Valley for Robinson, partly because of utility. The Beaver Valley people were more interested in participating in the event than the Robinson people were because Beaver Valley is more embrittled than Robinson. Robinson basically doesn't have a PTS issue, and Beaver Valley does in the sense of life extension.

And additionally, we added a second plant, which is Palisades, for the same reason.

CHAIRMAN WALLIS: Do you think you're half way through now?

MR. BESSETTE: I think so.

CHAIRMAN WALLIS: It's probably about right because we've asked all the questions. Maybe the questions will slow down.

MR. BESSETTE: Yes.

CHAIRMAN WALLIS: I think we're going to be interested in the key tenable questions rather than a lot of words.

MR. BESSETTE: Yes, well, I don't want to take up too much time.

But how we approached this from a thermal hydraulics perspective, you know, we started by classifying events into three broad categories: an increase in heat removal like steam-line breaks, increase in feedwater flow, and then on the primary side, loss of cooling accidents where either the break becomes isolated at some point in time or it doesn't.

So, to guide the overall effort, we tried to use the PIRT perspective. We had some preexisting PIRTS, which I'll show you later on in my presentation that were done for PTS, where we identified the thermal hydraulic phenomena had the most impact on the figures of merit. For PTS, like I said, pressure, temperature, and heat transfer.

It was just to guide the rationale for experiments conducted at APEX for RELAP5 assessment and for the uncertainty evaluation done at University of Maryland.

DR. BANERJEE: What do you mean by scaling studies?

MR. BESSETTE: Jose will get into that. He has already written a scaling report. To relate this facility, he modified the APEX facility to look like Palisades. But he did a scaling study comparing APEX with Palisades on the basis of the most important phenomena of the PTS.

MEMBER FORD: We will be hearing about that this morning?

MR. BESSETTE: Yes.

DR. BANERJEE: With some equations?

MR. BESSETTE: Undoubtedly. It won't be all words. The presentations get more exciting after mine.

CHAIRMAN WALLIS: When did you last solve an equation?

MR. BESSETTE: Me?

DR. BANERJEE: Five years ago.

MR. BESSETTE: Not today, anyway. It might've been yesterday.

CHAIRMAN WALLIS: But fairly recently?

MR. BESSETTE: Yes.

CHAIRMAN WALLIS: Okay.

MR. BESSETTE: I'm not a total paper-pusher. Although, if you look at my office, you will see a lot of paper there.

CHAIRMAN WALLIS: And you'll see equations on those papers?

MR. BESSETTE: Let's say I definitely don't solve them as often as Jose does.

These were the main thermal hydraulic issues we were worried about: a single and two-phase loop natural circulation, interruption of loop flow, and flow stagnation. We had some interest in knowing the number of cold-legs, which must be flowing into this intermediate zone between circulation and stagnation -- the number of cold-legs, which must be flowing to assure mixing the downcomer. And like we were talking earlier, the local fluid mixing, thermal stratifications of the cold-leg, plume mixing in the downcomer.

CHAIRMAN WALLIS: Now that number three, does it matter? I mean suppose you had a cold-leg break, then is that break different from let's say a hot-leg break in terms of the way the mixing occurs?

MR. BESSETTE: I'd say it's something we're interested in because when we started, we didn't know -- I mean we knew if we had full natural circulation, we didn't have to worry about stratification in the cold-leg and so on, or plumes. But, we wondered about these intermediate situations because all loops don't stop flowing at the same time. One loop will always stop first. If you have a four-loop plant, they stop in sequence.

CHAIRMAN WALLIS: Is this a loop seal question or what?

MR. BESSETTE: Well, it's mainly due to, because the secondary-side pressures are generally not equal in all four generators. That's how it starts. So the thermal behavior to four-loop is not identical. So, we had some interest in knowing about that intermediate stage between, you know, full circulation and no circulation.

So to look at these issues we wanted some experiments. So, we decided to run the program in APEX. We modified the APEX to resemble Palisades plants.

We wanted to generate integral system data focused on what we expected for the most important PTS transients and provide some data to address these specific thermal hydraulic issues. We came up with a test matrix and we bottled the test matrix as we generated analysis as to which transients to be risk dominant.

As I said, Professor Reyes performed a scaling study to relate his APEX experimental results to the plant, similar to what he did for AP600. So, it was modified. We added a lot of thermocouples in the downcomer and --

CHAIRMAN WALLIS: It's in the fluid?

MR. BESSETTE: Yes, in the fluid.

MEMBER RANSOM: You mentioned the mixing being fairly complete by the beltline. Is there a position along the vessel wall that's critical or more critical than others?

MR. BESSETTE: Basically, of course, the peak would be around the middle.

MEMBER RANSOM: Is that because of the

fluence, you mean, to the vessel wall?

MR. BESSETTE: Yes. But I'd say you're basically worried about anywhere adjacent from the bottom of the core to the top of the core. So that's about a 12-foot region.

MEMBER RANSOM: You said before that it was dominated by the thermal stress and not by pressure stress?

MR. BESSETTE: Yes.

MEMBER RANSOM: But I guess the fluence is an important factor in that, the weakening of the wall?

MR. BESSETTE: That's right. So, you are concerned about the fluence. And the fluence has like a three-dimensional distribution on the wall. You have some kind of a flattened cosine, axial distribution. You also have, the fluence tapers off through the wall, and you have kind of like a sinusoidal circumferential distribution. So, they generate a 3-D fluence --

MEMBER RANSOM: Well, for example, is this a non-issue in a new plant that doesn't have any weakening of the wall?

MR. BESSETTE: Well, see, the new plants, they use improved chemistry. The main issue is with the older plants.

MEMBER RANSOM: Sure.

MR. BESSETTE: A new plant today, I don't know if you'll ever have a PTS problem.

MEMBER RANSOM: I'm just curious about what role the weakening of the wall plays relative to the actual application of the thermal stress.

MR. BESSETTE: Well, certainly if PTS is not at issue with an unembrittled vessel.

DR. BANERJEE: Well, is there things that we don't know here? I mean it's not just fluence. You just said chemistry was involved. Is there stress corrosion?

MR. BESSETTE: No. This is --

DR. BANERJEE: What is the chemistry effect?

MR. BESSETTE: This is the material chemistry.

DR. BANERJEE: Oh, the material chemistry. Not the coolant chemistry?

MR. BESSETTE: That's right. So these trace elements, copper, phosphorus --

DR. BANERJEE: Sure. And do you have any welds around there?

MR. BESSETTE: Well, welds are definitely an issue because the weld chemistry is different than the base metal. So, there are welds, circumferential and vertical.

DR. BANERJEE: Around the beltline, right?

MR. BESSETTE: Yes.

DR. BANERJEE: Are these more at risk than the vessel wall, or what is most at risk?

MR. BESSETTE: For most plants, the focus is the weld material.

DR. BANERJEE: Which is what?

MR. BESSETTE: Well, you know, it's all carbon steel. So I guess there's some sort of a -- So, the welding rods, you'd have to ask one the fracture people for a detail. But, it's mostly carbon steel with some copper and whatnot.

DR. BANERJEE: So there are residual stressors and all sorts of --

MR. BESSETTE: There are residual stressors too. And then you've got the cladding inside of the vessel and so on.

MEMBER KRESS: I didn't think they counted residual stresses because of the annealing effect of the operation.

MR. BESSETTE: Well, see, it's better to ask one of the materials people how important those are.

CHAIRMAN WALLIS: Anyway, I think what we're interested in is this RELAP validation part.

MR. BESSETTE: Yes. So let me move on.

CHAIRMAN WALLIS: Are you going to show us any curves?

(No response.)

CHAIRMAN WALLIS: Maybe you have some backup slides with data on them.

MEMBER KRESS: We'll get data when Jose gets up.

MR. BESSETTE: I'll hate to tell you this is only the awful appetizer. If you're going to get to the gourmet meal, you have to --

(Laughter.)

MR. BESSETTE: Now being served bread and water before you get to the actual --

CHAIRMAN WALLIS: May we have wine with this meal too?

(Laughter.)

MR. BESSETTE: I knew these new guys were going to be here, so I wanted to bring them up to speed.

DR. BANERJEE: Thanks.

MR. BESSETTE: Like I said, dominant

scenarios are all primary system LOCAs. And in some of these, the break is closed -- the break being a stuck-open pressurizer valve -- at some time into the transient. And in some cases we get a small contribution still showing up from main steam-line break, small being a few percent of the total risk.

MEMBER FORD: Now that's at odds with your beginning statement. At very beginning, you said large-break LOCAs, medium-break LOCAs may be of more concern.

Am I correct on that?

MR. BESSETTE: Well --

MEMBER FORD: Those results, conclusions are exactly those that you had in January?

MR. BESSETTE: That's right. I think this is exactly what we said in January.

MEMBER FORD: That's correct. And you started off the conversation today saying that you believe that there was a significant risk contribution now from large-break LOCAs.

Is that at odds with that?

MR. BESSETTE: I don't have small LOCAs here. I mean LOCAs of substantial size.

MEMBER FORD: Okay.

DR. BANERJEE: Are we going to hear about these uncertainty studies from somebody?

MR. BESSETTE: We will tell you about that. But were not far enough along yet to give you a good story. We will be by February. I mean we can tell you something today, but I don't --

CHAIRMAN WALLIS: Well, that sort of statement bothers me. This work has been going on for some time. And it's somehow going to come together in February, but isn't together now?

MR. BESSETTE: We have --

CHAIRMAN WALLIS: What's going to happen between now and February to make it come together?

MR. BESSETTE: We have uncertainty results for the three plants now, but I didn't feel we'd be able to answer questions you'd have about them.

CHAIRMAN WALLIS: Okay. So the answers would be better than the last answers we got?

MR. BESSETTE: We will have, in another month or so, we will have a better understanding of why we're getting answers that we're getting.

DR. BANERJEE: Are they strange?

MR. BESSETTE: No, but there's things you have to check to make sure that they're correct. There's things that seem like they could be strange. Or, the things that seem strange when you look at them, you have to say is it right or not?

CHAIRMAN WALLIS: That's a good attitude to have. We have some presenters who don't care at all.

MR. BESSETTE: We spend a lot of time looking at stuff to see if it looks strange or not.

CHAIRMAN WALLIS: Well, I like this first line of page 12. You crossed over page 12.

MR. BESSETTE: Did I pass that?

CHAIRMAN WALLIS: Yes.

MR. BESSETTE: Oh, okay. Yes, I should talk about that. What's happened between 1983 and today in thermal hydraulics base, we've had these orders of magnitudes and improvements in computing. Remember, I said the first study was really constrained by how much we could actually calculate things. We've greatly improved input and output processing. RELAP5 is now much more robust and faster running.

CHAIRMAN WALLIS: Is it more accurate or anything like that?

MR. BESSETTE: It's hard to say.

(Laughter.)

CHAIRMAN WALLIS: Well, if it produces nonsense faster, it's not any better.

(Laughter.)

MR. BESSETTE: I think one thing that I can say is that the fact that it's more robust and faster running means it's more accurate because anytime you have these instabilities you get some unphysical behavior.

CHAIRMAN WALLIS: So you have removed some of the causes of uncertainty then?

MR. BESSETTE: Yes.

So, for the first time, we have I would say an adequate range of transient scenarios that we calculated. This is really, to me, the first time we've ever seen this. It's been a revolutionary change in transient analysis over whatever I've ever been involved with in the past. We were always really constrained by the number of calculations we could do.

DR. BANERJEE: With the AP600, it was a different reason. It was the low-pressure instability calculations. Have those gone away now?

MR. BESSETTE: Well, that's part of this bullet here. We did a lot of work --

DR. BANERJEE: What did you do to make them go away?

MR. BESSETTE: Well, I --

DR. BANERJEE: The reason they occurred

was there's a large change in the amount of vapor generated for a small change in heat input.

MR. BESSETTE: That's right.

DR. BANERJEE: And so this is a real life situation here.

MR. BESSETTE: Yes. So the small pressure fluctuations would cause --

DR. BANERJEE: Large void fractions.

MR. BESSETTE: Yes, large void fraction changes.

DR. BANERJEE: But that's real. It happens in real life.

MR. BESSETTE: Well, it's not clear that small pressure fluctuations on a nodal basis can happen as fast as the RELAP at the fill it's been calculated.

DR. BANERJEE: But you're going to tell us how you made it go away, right? Somebody is?

MR. BESSETTE: I can't tell you exactly what was done, but Joe Kelly can.

DR. BANERJEE: It wasn't just a smoothing function?

MR. BESSETTE: I don't think it was quite so simple as some sort of a smoothing.

DR. BANERJEE: Killing the partitioning

between vapor and liquid, the heat fluxes, just to make it stable.

CHAIRMAN WALLIS: So someday someone's going to have a slide, which says TRAC-5, TRAC-M is robust and fast running, and for the first time, we've done 1,000 runs or something?

MR. BESSETTE: That's right. You'll have to see that same bullet reappear.

CHAIRMAN WALLIS: We hope to see that before we're all retired from this committee.

MR. BESSETTE: I'd say what hasn't changed is the code still requires you to look at the results and see if they look strange or not, and it still takes a long time to put together an input deck.

CHAIRMAN WALLIS: Well, to see that they look strange is an interesting way of looking at it. When it looks strange, you mean that probably RELAP is calculating something wrong or it's predicting too rapid a rate of condensation or something, and then you go back and see why is it strange and how do you fix it in some way? Is that what happens?

MR. BESSETTE: It means you've got to look at a lot of plots and see if they seem consistent, and flows seem higher than they should be or lower and so on, and pressures are doing something unusual.

CHAIRMAN WALLIS: And then you go back and change the code?

MR. BESSETTE: Well --

CHAIRMAN WALLIS: Or is it a frozen code?

MR. BESSETTE: No. But in some sense, you try to see if this is a problem in the input model or in some modeling feature of the code that's not behaving properly.

MEMBER RANSOM: Well, is that how you found the six input problems that you corrected?

MR. BESSETTE: These were things that looked strange, yes.

MEMBER RANSOM: So often times it's simply input.

CHAIRMAN WALLIS: Someone made a mistake in the input.

MEMBER RANSOM: Right.

MR. BESSETTE: Probably nine out of ten times it's an input problem.

DR. BANERJEE: That's a new spelling for Barclay's name.

MR. BESSETTE: What was that again?

DR. BANERJEE: There's no "K". He doesn't bark.

MR. BESSETTE: Oh. No, that's one guy

that doesn't bark at you.

We did an H.P. Robinson and PIRT on PTS about 10 years ago, and these were the panel members. We started off by thinking in terms of four transients for H.P. Robinson: steam-line break, steam generator overfeed, cold-leg break, and a small hot-leg break.

CHAIRMAN WALLIS: So these guys didn't think of the large-break LOCA?

MR. BESSETTE: At that time, our perspective was that cold-leg dominated the risk.

CHAIRMAN WALLIS: That's the problem with asking people that are supposedly experts, who haven't done all the runs that you have data to do. You have to recycle and say, knowing what you know today you change the PIRT.

MR. BESSETTE: That's right. PIRT is not a -- I think we saw that in AP600. PIRT is not a one-time thing.

CHAIRMAN WALLIS: It's a useful starting point, and then you have to go back and reevaluate it.

MR. BESSETTE: That's right.

MEMBER FORD: That's a good point. Are you planning on reevaluating it on the basis of what you know now?

MR. BESSETTE: Yes, we have decided to do that.

So amongst these four transients at that time, small hot-leg break was the most limiting. And that was no news still. The other transients didn't even pose a PTS concern. Therefore, we did the small hot-leg break.

I'll go through this in detail. These are the phenomena that we came up with. And one of the things to note is that the so-called phenomena are about equally divided between things that are actually boundary conditions to the problem and something the code actually calculates as a phenomenon.

DR. BANERJEE: This was all sort of accumulator-based and HPI based injection because it was small break?

MR. BESSETTE: Yes, that's right. But this was a starting point. This is basically -- we didn't use these rankings. Basically, we considered all these phenomena regardless of their rankings.

MEMBER RANSOM: What was the significance of the bold?

MR. BESSETTE: Oh. I should've mentioned that. What I have in bold is things that RELAP cannot calculate.

MEMBER RANSOM: Okay. Good.

CHAIRMAN WALLIS: So if it's not calculated by RELAP and yet you have to put it into RELAP somehow, how do you do it?

MR. BESSETTE: Well, this is where I said -- so, we had to think of some way to address this. And this was one of the objectives of the APEX testing, was to take a look at the data and to do some CFD analysis.

CHAIRMAN WALLIS: So what you do is you run a RELAP without modeling these things, and then you take what you calculated from RELAP and use it as conditions that you then use later on to evaluate these details in some other way?

MR. BESSETTE: We had to decide, since these are things that are not modeling RELAP, what we were going to do. And so, the first step is how important are they. So if you look at them more closely, let's say outside -- you can't look at these in the context of RELAP. So, let's go back and look at them in terms of the experiments, the experimental data and 3-D modeling, and see if we can decide how important they are.

CHAIRMAN WALLIS: Well, it's funny that number 11, flow stagnation, is way down the list. Isn't that something that really needs to happen before you worry about a lot of these other things that are above it?

MR. BESSETTE: See, that's the thing with the PIRT panel. PIRTs are not perfect. Let's say the constraints you have and what you're looking at, in this case people are focused on a two-inch hot-leg break because that was believed to be the risk dominant sequence at the time it was done. At the time, everything we knew at the time, it was done, was a two-inch hot-leg break was the dominant sequence.

But, that was the focus of the PIRT. So at that kind of a break size you probably still have some natural circulation occurring. So then flow stagnation doesn't -- you're on the borderline of flow stagnation, so that's why it doesn't get ranked so highly. I mean I think that's why we're planning to go back and revise this PIRT in light of what we know today.

CHAIRMAN WALLIS: Well, it might be better to have Dave Bessette make up a PIRT because he knows what's going on, rather than invite seven experts who really don't know the details of what's going on or anything like as well as you do.

MR. BESSETTE: Well, in fact, that's the intention.

DR. BANERJEE: Yes. The problem with these sort of processes is that you said they'll come up to speed. You know, it takes them a long time.

MR. BESSETTE: That's right. When you start off, you don't know everything you'll know when you're finished.

CHAIRMAN WALLIS: That's the value of research.

MR. BESSETTE: Yes, that's right. Otherwise, there'd be no point in doing the research.

Final slide is we approach this problem with an integrated experimental scaling and code assessment similar to what we tried to do with AP600, or what we did in the end with AP600.

We see at the risk dominant PTS sequences for the three plants analyzed so far are LOCAs. And, they're LOCAs of substantial size, four inches and above.

And sort of in terms of the general feeling of whether we know what we're doing with RELAP on these is we have a considerable experience with these kinds of events, so we don't, we're not breaking new ground in terms of uncovering new phenomena and whatnot.

CHAIRMAN WALLIS: Now risk, risk dominant, risk involves frequency as well as consequence?

MR. BESSETTE: Yes.

CHAIRMAN WALLIS: And you're saying risk dominant sequences are LOCAs of substantial size. Now, that means that you're putting in some estimate of the frequency of LOCAs of various sizes?

MR. BESSETTE: That's right.

CHAIRMAN WALLIS: So how do you do that? There's been arguments recently that the large-break LOCA is so unlikely that you don't really need to worry so much about it.

MR. BESSETTE: Well, in fact, there's been an exercise recently to revisit the question of large-break LOCA probability. In fact, if I understand -- I wasn't involved in it, but I think the probability actually went up by a factor of two or so.

CHAIRMAN WALLIS: So what do you do? Do you have some sort of a curve of LOCA probability verses size or something that you use?

MR. BESSETTE: Roy, do you want to talk? Basically, we've divided LOCAs into three categories: small, intermediate, and large. And I think I'd like to have Roy --

CHAIRMAN WALLIS: Just three bins, that's all it is?

MR. BESSETTE: Yes.

MR. WOODS: I'm Roy Woods. I'm with the branch that's doing this stuff for this project, PRA Branch in Research.

Today the purpose here was to talk about thermal hydraulic calculations. So there really are three branches as Dave started out pointing out. There's the PRA branch that looks sequences, and the frequencies of the sequences. And that is indeed where the frequency comes from. Dave then just does the thermal hydraulic calculations.

And the focus of this meeting was to be whether or not the RELAP code or whatever he's using makes sense. And so he's not really prepared to talk about frequencies. The presentation we're going to give you on February 5th will start out and go logically through the whole process.

CHAIRMAN WALLIS: Well, I'm asking him because this is one of his conclusions, risk dominant sequences is so and so. Then he must include some of this --

MR. WOODS: The thing that's missing here, or I think it's missing, is this is a very iterative process. You go around and around the loop. You start out with sort of a guess as to what the dominant sequences are. You do some thermal hydraulic calculations. You might even do some scoping runs with the FAVOR code, the fracture mechanics code. And then, you see if your starting out assumption was correct, and you live through it again.

And yes, indeed, that process very thoroughly takes into account to all we know about the frequencies of the various size LOCAs. It's just not coming through in this talk, which is focused on the --

CHAIRMAN WALLIS: Okay. Let's focus on what this talk is about. I thought this talk was to convince us that RELAP was giving you useful information, that you had a good handle on the uncertainties, and so on. And I haven't really seen that.

I mean you haven't shown us how that runs. You haven't given us a measure of uncertainty and so on, and you haven't told us how that measure is related to the actual features of the code. I was hoping I'd see more of that.

Do you have some backup slides?

MR. BESSETTE: Well, the day's not over yet. We've got the two main presentations coming.

MR. WOODS: In the dry run, we spent hours and hours looking at over 100 graphs with exactly what you're asking about I believe. And you're going to see that this afternoon.

CHAIRMAN WALLIS: We're going to see that? So Jose is going to talk about RELAP runs this afternoon, or who is going to talk about that?

MR. BESSETTE: No, it's ISL.

CHAIRMAN WALLIS: Oh, it's ISL that's going to talk. Okay.

So, that's what I'm doing. I'm asking you the questions I should be asking ISL.

MR. BESSETTE: We'll spend the whole afternoon on it.

CHAIRMAN WALLIS: Okay. Okay, that's right. You've got two and a half hours, two hours, two and a half hours this afternoon. Okay, that's right.

But you are managing the program, aren't you?

MR. BESSETTE: Yes.

CHAIRMAN WALLIS: So do you have anything to say about the way RELAP is performing or any of the specific things that you're concerned about that you have somehow resolved or not resolved?

MR. BESSETTE: Well, I think there's

always a concern anytime you run the code as to how much you can believe the results. And that's where this, looking at the results a bit suspiciously comes in.

I think the code is always a mixed-performance bag. Sometimes some things it will do remarkably well. And some things you wonder how it can be so far off.

DR. BANERJEE: What things? Give us a few examples please.

MR. BESSETTE: I don't know if I can think of a good one off the top of my head.

Let's take cold-leg flows for example. It can be doing strange, they can see some strange oscillations in cold-leg flows. And you wonder why that's occurring and how to get rid of it.

CHAIRMAN WALLIS: Maybe it's real.

MR. BESSETTE: Well, it can be real. You have to decide is this plausible or not.

But I think what saves you a lot of times is the things you're really concerned with. The key things you're concerned with are typically things like core temperature or a primary system inventory, how much mass you have left in the primary system, you know, how close you are to core uncovery. In this case, what the downcomer temperature looks like.

When you look at it from that perspective, generally the code looks not bad. At least it's something you can live with.

CHAIRMAN WALLIS: Well, unless you're talking about marriage or something here, the definition of "not bad" and "something you can live with" needs to be more specific I think.

MR. BESSETTE: But I think once you look at all the results you'll see this afternoon, it'll give you a better feeling for that.

MEMBER FORD: Now you've got me really worried. We came into this meeting based on what we had heard in January. Things are going great, the results look good, promising, and we're just going to do the other three plants and we're all set for revising the 10 CFR PTS rule.

And, the main thing we were concerned about was the acceptance criteria, which was going to be the main topic for the meeting on the 5th. Now I'm hearing you say this huge -- there are some uncertainties.

Let me ask the question: Do those uncertainties impact greatly on the predicted temperature stress transients, strain-rate transients of the metal? Is this academic concern that you have, or is it a real concern when it comes down to predicting the material stress strain-rates temperature?

MR. BESSETTE: Well, see, that's exactly the question that I was concerned with answering myself before I showed you that these are the uncertainty results and we can believe them.

And the fact is the uncertainty numbers we're getting out of FAVOR, the latest results have only just come in the past month, within the past month. We haven't had time to look at everything and make sure we understand it. And until we can understand it ourselves, we can't explain it to somebody else. We have to go through that process, and we're not done with that yet.

But what we did is, this is the same set of, these are the uncertainties that we studied in our uncertainty evaluation. This is the same list I showed your phenomena, just categorized, you know, point of boundary condition; the same list of PIRT phenomena.

So, one question could be, well, have we left anything off of this list. The only thing I might add at this time would be condensation because we're dealing with large breaks, and the cold-leg and downcomer you'd think is an important phenomenon that doesn't appear here. So the question, what's been left off, is condensation.

DR. BANERJEE: The HPI and the accumulator may not be that important in large breaks?

MR. BESSETTE: It still shows up. The way it shows up is, you know, you're drawing off a tank that's outside. So in some cases you're drawing 40-degree water, and in some cases you're drawing 80,90-degree water. So that 50-degree difference gets translated almost directly into -- you know, it gets mixed in all that. But, you end up with substantially different temperatures whether summer or wintertime.

CHAIRMAN WALLIS: How does RELAP calculate condensation? You pour this very cold water into what could be a steam environment, and you can predict sort of mach 1 flows of steam towards the cold water to get at it and condense on it.

Is that what RELAP predicts, or how does it model condensation of very cold water?

MR. BESSETTE: Well, first it has to decide what flow regime it's in. You know, it does that by looking at void fractions, and vapor and liquid velocities.

CHAIRMAN WALLIS: It's very different. You know, condensation, the actual steam rushing in to condense can shadow the water, which means you get more. It's almost like an implosion. It's like a big collapse of the steam bubbles in the cold water of a torus in the BWR. You get very, very rapid condensation --

MR. BESSETTE: This is why --

DR. BANERJEE: And you get condensation shocks --

CHAIRMAN WALLIS: If you have mach 1 type flows.

MR. BESSETTE: The type of thing you're talking about is why people have been -- one of the problems in the code since day one has been modeling condensation.

DR. BANERJEE: But, you know, what Graham is saying is right. If you've ever taken a glass pipe and put cold water into it, it shatters the pipe. Boom. It's gone.

MR. BESSETTE: Yes, in extreme heat you end up with a waterhammer.

CHAIRMAN WALLIS: And also you can get incredibly rapid rates of condensation.

MR. BESSETTE: That's right. Inverse

steam explosion.

DR. BANERJEE: I did this experiment a number of times just for fun to show students what happens.

CHAIRMAN WALLIS: You have to use a pipe or something different.

MR. ROSENTHAL: I think we do want to hear from the other speakers, which will be answering your questions. But let me just make a summary statement.

And that is that, what I had hoped to accomplish by the end of the day was to convince you that for the purpose of PTS, that is pressures and temperatures and the downcomer, that RELAP was good enough. And we'll define what we mean by "good enough". And, that in no way are we making some arguments about let's say predicting PCT after a large-break LOCA.

For PTS, we're talking about events that go on for a couple of hours, where I think that the dominant phenomenology issue is just plain mass and energy balance as you go out a couple of hours. And we hope to show that RELAP does a sufficiently good enough job.

We wanted to demonstrate by all afternoon that we had done enough benchmarking of the code against PTS-like experiments to say that the code would have some veracity, without saying that the code's perfect. And, in fact, we're going to show you some bumps and warts in the code and how we overcame them. But, you know, let's keep our eye on the target.

And then the last thing that actually this morning, and part of this comes out of the PIRT, is that we recognize that RELAP was not going to do things like 3-D plume behavior. And it would've been irresponsible for us to somehow nodalize and mach up something that we know RELAP couldn't handle. So, we went to an experimental program to try to address those issues.

And, in fact, if the 3-D plume behavior, which is relatively benign, but if it had been a big effect, that might've been very much a showstopper because we wouldn't have had a way to proceed.

So I think the biggest weaknesses in the code, or in trying to understand this, we took on with an experimental program and then we've just done an enormous amount of code assessment to show you that the code would be good enough. But with the eye on the ball, we're not pretending that the purpose is pressures and temperatures or fracture mechanics.

DR. MOODY: Let me just make -- I think all your comments have been very helpful. I just want to see if I've got this sorted out right in my mind.

The whole problem of pressurized thermal shock involves thermal hydraulics, which gives you boundary conditions on a surface, metal surface. And, the thermal hydraulics are interactive with the heat transfer in the surface regardless of any fracture mechanics. That problem is decoupled then. The temperature distribution verses time in a surface is decoupled from the structural aspects. It uses a boundary condition in the structure is the next step in the process to determine the stresses and if there's likely to be a failure.

So far so good? Does this sound right to you?

MR. BESSETTE: That's right. I just want to make clear in terms of RELAP, RELAP takes into account the metal structure of heat in determining what the fluid temperature is. So that fluid structure, heat transfer --

DR. MOODY: Interactive, okay.

And then the other thing is, is there any academic type problem put together for just understanding in a very simple way how you determine whether you have a problem or not?

In other words, like in a graduate study problem, where you're going to calculate are you over the boundary on a PTS or not. Don't use the computer. This has all got to be straight analysis. Is there anything like that available to explain some of these limitations very simply where one could determine what is the worst possible condition that leads to maximum -- or being closest to failure in an academic sense?

MR. BESSETTE: Well, I think some simple examples can be shown like taking a given fixed temperature, some step change in temperature at the wall, and show you the FAVOR calculation as to how the stress just with conduction solution changes, the K-1 changes with time, and how K-1-C is changing with time. We have those simple illustrations available.

DR. MOODY: Those are available?

MR. BESSETTE: Yes. And so you see these curves crossing.

DR. MOODY: That's good.

MR. BESSETTE: I'll look in my office.

DR. MOODY: Okay, thanks.

CHAIRMAN WALLIS: Yes. I was -- somebody used the word "academic". You used it in I think a good sense here. I think somebody used it earlier in sort of a pejorative sense that you did what you had to do, which is good enough, and anything else was academic or something.

It seems to me that at least in engineering school what students should learn is how to do what's good enough. And that is the heart of the proper rigorous academic training, is you figure out what you need to do to get the job done. And, we should stop using the term in sort of the pejorative sense of going off and doing stuff which is on the fringes and irrelevant.

MR. BESSETTE: What we're trying to do is we're trying to do as good a job as is possible, and deciding if "as good as possible" is good enough.

CHAIRMAN WALLIS: Yes. Okay. That's the difficulty you sometimes have, and that's where I think you've got to have this discipline. You've got to actually lay out very clearly what is going to be your measure of "good enough". And then you've got to look at what you can do, and you've got to compare the two.

And too often, this sort of academic, to term, is used as an excuse. We do what we know how to do, we think we can do, and we don't make a rigorous comparison about whether it's good enough. You simply say, since that's all we can do, it must be good enough. And that really isn't the right way to do it.

MR. BESSETTE: Yes. We're not looking at it from that point of view.

CHAIRMAN WALLIS: That's good.

Now I think you've helped us gain some time, maybe because we asked good questions earlier. And, so, I think what I propose to do is take a break now instead of -- I mean we were going to take a break at 10:30.

And then, since Jose is here, then if Jose can start at 10:30 --

MR. BESSETTE: Yes.

CHAIRMAN WALLIS: Okay, we'll do that. We'll take a break now for 15 minutes until 10:30.

(Whereupon, the Subcommittee recessed for a break from 10:15 a.m. - 10:32 a.m.)

CHAIRMAN WALLIS: Let's come back into session and hear a presentation by Professor Reyes from Oregon State University.

And I was wrong earlier when I said we were ahead of schedule. I had two schedules here. And on one, we were ahead and we're behind. We're now just on the average track.

MEMBER FORD: With an uncertainty

associated with it.

MR. BOEHNERT: Right.

MEMBER FORD: Jose, are you going to put it right now, are you going to give us data?

PROFESSOR REYES: There we go.

MEMBER FORD: Fantastic.

CHAIRMAN WALLIS: That's right. Give us one of those really impressive academic presentations.

MR. BOEHNERT: That's not in the pejorative sense.

MEMBER KRESS: Are they the Ducks or the Beavers?

MR. BOEHNERT: Beavers.

PROFESSOR REYES: Okay. Well, thank you very much for inviting me to speak today. I'm excited about the results that we've obtained, and hope to present you with quite a bit of information. In fact, there's two fairly lengthy presentations that I'll be giving this morning. Hopefully, it'll be done this morning.

Here's the outline. Really sections 1 through 5 are essentially by way of introduction. So, I'll try to go through that relatively quickly. But feel free to stop me and ask questions.

There was a question earlier today about scaling. There was a scaling report, NUREG/CR-6731 I believe is the number, which was submitted in final form about a year ago. And I believe that is --

DR. BANERJEE: Sixty-seven what?

PROFESSOR REYES: Thirty-one. Sixty-seven, thirty-one.

That document describes the scaling approach that was taken with regard to the test facility. And I will be touching a little bit on the scaling, but not in great detail. So if you have questions on that, I certainly can review the report with you.

CHAIRMAN WALLIS: Now your outline on the screen is utterly different from the one we have.

PROFESSOR REYES: We're looking today at experiments first. There's two presentations. One is code comparison, and the first one is experiments.

CHAIRMAN WALLIS: Okay. And this handout covers both?

PROFESSOR REYES: There should be two handouts right there.

CHAIRMAN WALLIS: Two handouts?

PROFESSOR REYES: Right. There's two handouts.

CHAIRMAN WALLIS: That's the problem. I

have a 30-page handout and it looks quite different from the one you have.

PROFESSOR REYES: There's one labeled, similar title and in parenthesis "experiments". And so that's what we'll talk about first.

CHAIRMAN WALLIS: We don't have it. You're going to give two presentations?

PROFESSOR REYES: Yes.

CHAIRMAN WALLIS: Each with 30 slides?

PROFESSOR REYES: Oh, at least.

CHAIRMAN WALLIS: Okay. Show us how it's done.

PROFESSOR REYES: Okay.

CHAIRMAN WALLIS: Okay, we have it now. Let's go on.

PROFESSOR REYES: Okay. So the focus, the real focus of the experimental portion of the presentation deals with the key observations. And that's what I'd like to do is describe some of the things we've learned with regard to how thermal hydraulics affects the overall PTS issue.

Next slide, please. Program objectives, these are our main goals for the program. We were looking at specifically at the Palisades geometry and operating conditions. We want to remove some of the limitations of the previous PTS studies. I'll talk about that in a minute. We want to provide some information that would help revise the small-break LOCA and the main steam-line break PTS PIRTs, and also propose maybe some improved PTS thermal hydraulic assessment methodology.

Some of the limitations in previous studies, one of the things that we didn't have available were integral system overcooling transient tests. They weren't available to benchmark the TRAC and RELAP 5 calculations. So, we've done some of those with this new program.

We are onset of loop stagnation, asymmetric loop stagnation. We want to have some benchmarks for downcomer cooling rates, temperatures and systems pressures for a variety of overcooling transients.

Next slide. The previous studies, the results of the separate effects assessment really couldn't be adequately integrated with the system behavior. We had very detailed thermal mixing behavior with a single injection point, a single cold-leg, and a section of the downcomer. Now the idea is, well, how does that integrate into the overall loop behavior.

So, I've got some interesting results to present to you there on our new studies. So the effect of downcomer plume behavior in a co-flowing steam was not assessed for low HPSI flows in the previous study.

The effect of loop seal cooling on primary loop stagnation wasn't assessed previously. The effect of downcomer driven loop natural circulation was not assessed in terms of the plume behavior, and the tests didn't include core decay heat.

Next slide.

CHAIRMAN WALLIS: Did you look at the case where the downcomer is dry when you squirt in cold water?

PROFESSOR REYES: We looked at one test, our final test, the NRC-20 was a situation where we had steam-filled downcomer and we injected cold water into the cold-leg.

The other limitation was that computer speeds were not adequate 15 years ago looking at the CFD codes. In fact, back then we were using SOLA-PTS, if you recall, at Los Alamos as one of the CFD codes. And, it was taking for about 10 seconds of transient about 10 hours to run, and that was with only 4,000 nodes in the downcomer. So that was the state of technology back then, and that was running on their Creare machines.

Multi-dimensional aspects of cold-leg and downcomer mixing behavior were not modeled.

CHAIRMAN WALLIS: That's even just single-phase flow?

PROFESSOR REYES: That's just single-phase flow. Hard to believe, yes. It wasn't that long ago.

Effect of multiple plume interactions on wall heat transfers and downcomer temperatures were not assessed. So, there are a lot of refinements that could be made to the previous methodology that we want to try to incorporate with our new study.

Next slide, please. Now I'll talk about the overall plan. This is just a flow chart of our overall research plan for the experimentation. We start off with a review of the past PTS results. We looked at the small-break LOCA PIRT that Dave had mentioned and the main steam-line break PIRT. The main steam-line PIRT was done for Yankee Rowe I believe.

But, we looked at both these PIRTs and performed a scaling analysis. As I mentioned, that was submitted quite a while ago and actually was presented at an ACRS meeting at OSU a year ago or more than a year ago.

PARTICIPANT: July. July 2001.

PROFESSOR REYES: July 2001.

The scaling analysis included loop natural circulation, a cold-leg and downcomer mixing, and primary and secondary-side blowdown scaling. We used the scaling analysis to guide our facility modifications. So we added loop seals, cold-leg injection, additional instrumentation, particularly temperature measurements in the downcomer, and we developed our as-built documentation.

Next slide. So here are our facility modifications. We broke it up into two main braches of research. One was the integral system testing, and the other separate effects testing.

In our integral system tests, we looked at main steam-line breaks, hot-legs breaks, stuck-open pressurizer safety relief valves, and stuck-open atmospheric dump valves on the secondary-side. What we did was obtain data for integral system behavior. In particular, we were looking at conditions for loop stagnation, the effect of having multiple steam generator tubes, effects on draining, effect of multiple cold-leg loop seals, and thermal mixing in the cold-legs.

CHAIRMAN WALLIS: You don't look at cold-leg breaks because if you did have one, you'd have so much flow in the downcomer it wouldn't matter, they wouldn't get a PTS?

PROFESSOR REYES: Right, so we looked only at the hot-leg breaks.

And for integral system tests, we used RELAP5 to do some modeling. So we did perform five or six calculations, RELAP calculations using, to benchmark the code against our data. And, ISL has performed many calculations and has the real expertise in this area.

So, we modified our input deck. We had an APEX input deck. APEX-CE we're calling the new configuration.

Thermal hydraulic processes. Again, we were looking at RELAP5 against data. Then on this slide, we did some separate effects tests. And, so, we did single and multiple HPSI mixing with our main loop, and also we had a small transparent loop. And, we obtained some separate effects data.

We'll talk about the wall heat flux and some of the estimates we made there, plume temperature, and cold-leg thermal stratification also. Now for that we used two codes.

We used REMIX. REMIX was a code that was developed by Purdue and then was actually carried out at University of California, Santa Barbara, Theophanos and his group. And Norm Bach was working there at the time. So, this is very interesting. And I'll talk a little bit about why this was developed and how that worked a little.

And then we also used a code called STAR-CD for CFD calculations. And the idea was trying to assess how well we can predict the temperature in the cold-legs and the plume behavior in the downcomer. So, the idea was to feed all this information to the NRC. And then part of it might be of value to Oak Ridge in their studies, with the overall desire to improve the PTS thermal hydraulic assessment methodologies.

So we're trying to sharpen our pencils and come up with a better way of predicting the behavior in the downcomer.

MEMBER RANSOM: What is the STAR-CD code?

PROFESSOR REYES: It's very much like FLUENT or CFX.

MEMBER RANSOM: Who produces it?

PROFESSOR REYES: This is a company called Adapco, is the one who runs the code now. But if you trace the lineage of that code, I think it goes back to --

DR. BANERJEE: It goes back to Gosman at Imperial College.

PROFESSOR REYES: In England?

DR. BANERJEE: Yes.

CHAIRMAN WALLIS: Now these codes have difficulty with buoyancy driven flows, don't they? And the effect of buoyancy on turbulence?

PROFESSOR REYES: Right. This is one of the areas we were very curious about how well it predicted -- well, I'll give a description of this. But, yes, that's true, especially in interfaces.

CHAIRMAN WALLIS: Buoyancy tends to kill the turbulence in interfaces.

PROFESSOR REYES: Yes.

CHAIRMAN WALLIS: And to stratify, horizontally stratify interfaces.

PROFESSOR REYES: That's right, and I'll show you some results.

Next slide, please. Okay, I'll talk first about the test facilities we have. The APEX, we've been calling it APEX-CE configuration. What we did was we modified our facility. We added four cold-leg high-pressure safety injection lines, four cold-leg loop seals. We added a weir wall in each cold-leg to simulate the lip of the Palisades primary coolant pump housing. That turned out to be very important.

We found out that in the Palisades plant, they never really drained their cold-legs. There's a little dip on the pump at the outlet of the pump, the discharge portion of the pump, that always had a little level of water on it. And that had an effect on the results.

We added approximately 50 additional downcomer temperatures and 12 loop seal thermocouples and four HPSI mass flow meters, using Coriolis flow meters.

Next slide. Overall, we have about 450 thermocouples, 50 differential pressure cells, about 41 pressure transducers for local pressure measurements, 28 magnetic flow meters for the single-phase flow measurements, vortex flow meters, 17 for steam flow, load cells, three sets of load cells on our large tanks, and then again, these Coriolis flow meters on HPSI lines.

This just gives you a little bit of an overview of our fluid thermocouples in the downcomer. It's just an unwrapped downcomer. Here you have a hot-leg, and of course, here's where it would wrap to the other side. These are your four cold-legs, which shows you it's in the right orientation.

And then these are the different elevations where we were measuring our temperatures. These are existing thermocouples, and we added these thermocouples directly below the cold-legs and they branched out. The most heavily instrumented cold-leg was cold-leg number four. We actually added some additional thermocouples in the intermediate regions there.

So the way we mark these thermocouples are in terms cold-leg diameters. So, this first one is about 1.3 cold-leg diameters down from the center of the cold-legs. Two leg diameters, and then four, all the way down to eight over here where we focused primarily.

CHAIRMAN WALLIS: These are stuck in the middle of the flow somehow?

PROFESSOR REYES: They're actually close -- they're in the flow, but they're closer to the vessel side.

CHAIRMAN WALLIS: So they stick out on little needles or something? They stick out?

PROFESSOR REYES: Yes. That's correct. And actually in the flow, they're about a quarter inch away from the reactor vessel wall. So, we're trying to get some wall temperatures if possible.

MEMBER FORD: And where are the wall, the metal temperature thermocouples?

PROFESSOR REYES: The metal? Opposite, in particular in cold-leg four, opposite the 1.3 and --- I'll have to check, but I think it's the two cold-leg diameter thermocouples -- fluid thermocouples have a corresponding wall thermocouples and wall heat flux meters.

So, these are thin film meters with a known film conductivity and a very detailed thermal pile inside to give you an estimate of the heat flux on the outside of the wall.

MEMBER FORD: And you mentioned that you have load cells. What are they measuring specifically and where are they?

PROFESSOR REYES: Yes. We use load cells for our large tanks. And in this experiment, it was particularly, it was only used really for the RWST, the refueling water storage tank. It's the large tank that's feeding the --

MEMBER FORD: Oh, it's just a method of measuring --

PROFESSOR REYES: It's just a measurement of weight.

MEMBER FORD: It's not a load cell material?

PROFESSOR REYES: That's right, not in terms of materials. That's a good point.

MEMBER FORD: Okay.

PROFESSOR REYES: Yes, we didn't -- there were no stain gauges or anything on the surface to get a feel for --

MEMBER FORD: From a materials property perspective, it's really the stress and strain rate that you're really interested in. So those were not being measured?

PROFESSOR REYES: Correct. That's correct.

And our wall thickness, again, is not prototypic. We're a half-inch thick stainless steel wall. So our wall thickness is more along the lines of the cladding of the vessel, which could be up to a half-inch thick stainless steel.

MEMBER FORD: So, in terms of equilibration during a transient, is the wall pretty well a uniform temperature?

PROFESSOR REYES: Yes. And, in fact, in the final report --

MEMBER RANSOM: What are the hatched, before we move from this slide, regions?

PROFESSOR REYES: Pardon me?

MEMBER RANSOM: What are the hatched regions?

PROFESSOR REYES: These different elevations here?

MEMBER RANSOM: Well, no. You've got a hatched --

PROFESSOR REYES: Oh, in the center. This is the location of our large flange. So, we have a flange located at this point over here. This is about eight cold-leg diameters down.

For purposes of reference, for example, for the Palisades plant, the active core region is about 12.4 cold-leg diameters down, down to about six. And so the temperature profiles I'll be showing you go from two until about eight so you get a feel.

CHAIRMAN WALLIS: The previous questions yes, it's pretty well a uniform temperature for the wall because it's so thin?

PROFESSOR REYES: On a relative scale. But, I can show you the plots.

CHAIRMAN WALLIS: You're going to show us?

PROFESSOR REYES: Yes. And actually I can

--

CHAIRMAN WALLIS: Well, you can show us when you get to it.

PROFESSOR REYES: Right. Since the question was raised, let me take a moment.

MEMBER RANSOM: These are experiments to run at scaled pressures, is that right?

PROFESSOR REYES: That's correct.

MEMBER RANSOM: They're not prototypic pressures, right?

PROFESSOR REYES: That's correct.

DR. MOODY: Jose, what's a typical dimension up there?

PROFESSOR REYES: Okay. In terms of -- so a cold-leg diameter, for example, in our plant is only three and a half inches. Hot-leg diameter is five inches.

DR. BANERJEE: And what's the gap?

PROFESSOR REYES: The gap is two and a half inches. Actually, the gap in the length of the downcomer is about one-fourth. So, the L over D, the aspect ratio of the downcomer is actually one-to-one with Palisades.

DR. BANERJEE: So let me get it. The gap is, you said, two --

PROFESSOR REYES: Two and a half inches.

DR. BANERJEE: Two and a half inches?

PROFESSOR REYES: Right.

DR. BANERJEE: And the height above that flange?

PROFESSOR REYES: So this is about six cold-leg diameters down. So, about 20 inches or so.

DR. BANERJEE: From the center of the cold-leg?

PROFESSOR REYES: From the center of the cold-leg.

Okay, next slide.

DR. BANERJEE: And it's to scale roughly, right?

PROFESSOR REYES: Right. Right. And what I found was, when I looked at the original APEX design and started looking at the Palisades plant, I found that there were only a few modifications that needed to be done in order to get a reasonably good simulation of the Palisades plant.

In terms of what we changed, of course, we had to add the injection, safety injection lines. We had to add these loop seals. Now, we use our pumps. Normally, for the design we had before, they hung off of the steam generator. We had to put them below. So this is a little bit different. And that's why we had to add this little lip on the cold-leg to simulate the exit of the pump.

It's basically a two by four arrangement. You have two hot-legs, four cold-legs. We have inverted U-tube steam generators. This is our refueling water storage tank. This is our pressurizer. And, here's our safety line. And so this is really, the loop seal was an important addition. It actually turned out to be a very significant part of the stagnation phenomenon that we observed.

Next slide. Again, looking at just a geometric similarity, we found that in terms of cross-sectional flow area, in term of volumes, that the scaling factors were relatively constant throughout the entire loop. So we were very encouraged by that. In fact, we were surprised at how similar the original APEX design was to the Palisades design. So this is the Palisades, looking at the plant view, and here's the APEX facility.

Okay, next slide. Here's looking at a slide view. Again, here's the Palisades plant. Of course, we're one-fourth scale. This is enlarged just for -- we're not larger than real scale.

So, again, we tried to maintain similar geometries with regard to the loop seal in terms of scaling the volumes in these loop seals and the cross-sectional flow areas.

MEMBER RANSOM: With the total change in that cold-leg geometry, is the vertical height the same or scaled to the plant?

PROFESSOR REYES: Scaled to the plant. So, that's one-fourth height in terms of the loop.

MEMBER RANSOM: Right. The pump appears to be in a different position.

PROFESSOR REYES: That's exactly right.

Again, at the outlet of the pump, we added a very small weir wall to simulate the pump outlet.

CHAIRMAN WALLIS: I believe your loop seal looks bigger compared with the reactor vessel heads than in the real plant.

PROFESSOR REYES: Is our loop seal bigger than the --

CHAIRMAN WALLIS: In terms elevation change in the loop seal.

PROFESSOR REYES: No. It's actually scaled one-fourth. That might just be the image. I blew this up quite a bit so that you could see the details. But this is actually one-fourth elevation.

So, it would much smaller.

CHAIRMAN WALLIS: Much smaller.

MEMBER RANSOM: Where is weir that you talked about?

PROFESSOR REYES: At the exit of the pumps actually going into the -- on the cold-leg going in.

MEMBER RANSOM: Where's that in the plant?

PROFESSOR REYES: Oh. In the plant what you see is your reactor coolant pump is fairly large and it actually sits on a loop seal, and it extends all the way to the top. So this section of pipe here would actually be the full section of pump. They'd be a motor and then the pump casing up on top. So, you have a discharge coming out the top into the cold-leg.

MEMBER RANSOM: Well, is that what creates the weir in the plant?

PROFESSOR REYES: Right, the discharge of the pump. That's correct. Yes, the geometry of that pump and the little discharge lip.

And actually, it was the Palisades folks who informed me of that. When we were talking about the geometry of the plant, they mentioned that they never were really able to drain their cold-legs completely because there's that little lip on the pump that maintains a level at the bottom of the pump.

So we used the APEX-CE facility to do all of our integral system testing. We also built a small separate effects test just for visualization. So, it's a transparent cold-leg loop seal and HPSI line. And we did a little demonstration back in July of what we observed in terms of mixing behavior.

So, it's clear PVC piping. It's just a single cold-leg representing the APEX-CE, HPSI nozzle with a check valve, the weir wall again in the cold-leg, 50-gallon salt water mixing. So we're using salt water to simulate the density of the cold HPSI fluid. And then we had our pumps.

CHAIRMAN WALLIS: This is all single-phase mixing?

PROFESSOR REYES: All single-phase.

CHAIRMAN WALLIS: It's not condensation?

PROFESSOR REYES: No condensation at all.

DR. BANERJEE: But the diffusivity of salt is different from that of heat?

PROFESSOR REYES: That's correct.

DR. BANERJEE: So how are you able to use that to stimulate what's going on?

PROFESSOR REYES: The density differences were preserved. And you're right. The diffusivity is different. So I think what we actually see -- we did measure concentrations, so we had estimates of concentration in terms of these probes that we would drop into the flow to measure the densities of the freshwater verses the salt on the bottom of the pipe.

What was particularly useful was, because of this effect of the weir wall and that pump lip, we had a stratification criteria, which we were using to try to predict when we would transition from a well-mixed condition to stratified, that transition point. What we found was that we couldn't get good predictions using that criteria with our APEX-CE data. And we were wondering, well, why would that be.

And we've traced it back down to the fact that we've got this little lip, which actually in essence promotes stratification in a cold-leg. So, we wanted to see what that looked liked. So basically we used this data primarily just for visualization to see what it was doing. But, the temperature measurements, we used from the APEX.

DR. BANERJEE: So this was not at a temperature?

PROFESSOR REYES: No, no.

DR. BANERJEE: Basically this was just cold water test?

PROFESSOR REYES: Just a cold water test

for flow visualization. We wanted to see what was going on inside the pipe.

Okay, next slide. So this is just, all we modeled was this loop seal. There are a couple phenomena in the top view here. We modeled -- there's a pump that comes to the loop seal. We modeled the injection geometry of the Palisades plant. It's actually a horizontal injection and it comes in at a 45-degree angle.

There's a check valve over here, just like in the plant. So, it does limit, restrict the flow going back into the loop. And again, those were primarily for just seeing what's going on.

There were a simple phenomena we were particularly interested in. One was this spillover back into the loop seal, which became important. And, of course, the mixing at the injection location.

MEMBER FORD: There were some remarks made earlier on about the slight differences in geometry in the fabrication of these PVC pipes and those which we've obviously done with metallic materials.

PROFESSOR REYES: Right.

MEMBER FORD: Are those major concerns to you or not?

PROFESSOR REYES: I'll show an example of where small differences in piping will give you asymmetric loop stagnation. And so I'll show you some slides of that.

Not only that, but it's tied to this local behavior at the loop seal.

MEMBER FORD: Okay. But I was talking mainly about, for instance, the way this is fabricated.

PROFESSOR REYES: Oh, okay.

MEMBER FORD: You'd have different geometries at the T-junctions for instance.

PROFESSOR REYES: Right.

MEMBER FORD: You'd have a sharp edge rather than a rounded edge that you have in a weld.

PROFESSOR REYES: Right, right. You certainly do see differences in mixing behavior. And that's one of the conclusions I'm going to come to, is that these designs are geometry-specific.

And so, when you apply criteria like stratification criteria, you find that the geometry can affect how you apply certain criteria, whether or not it's mixing or not.

MEMBER FORD: Does that alter your conclusions?

PROFESSOR REYES: No.

MEMBER FORD: Okay.

PROFESSOR REYES: Next slide.

Okay. I'll talk a little bit about our test procedure. This was a very useful meeting. Roy Woods had organized this meeting with the Palisades folks. It was very, very valuable in that it gave us an opportunity to interact with the Palisades operators. And that to me -- I don't know if we've done that in previous programs, but that was very, very useful for us.

We were able to observe them perform small-break LOCA and main steam-line breaks on their simulator. And that gave us an idea of what are the typical responses to these events and how that might affect a PTS issue.

So, we got to speak directly to the operators. We watched them do the simulations. And from that we developed our procedures for our tests. So we used the input from the operation to develop our procedures. They were very, very cooperative. It was very nice.

Next slide. That was consumer's energy, consumer's power.

They provided us with their emergency operating procedures. We reviewed these procedures here, looking at standard post-trip actions, loss of coolant accident recovery, the main steam-line break or the excess steam demand events, their overall functional recovery procedures, and their supplements.

Next slide. One of the things to me that was very interesting was that they, in all of their functional requirements and response to different scenarios, they included this curve here. And their emergency operating procedures require that they remain within these bands. And the reason is they're trying to avoid pressurized thermal shock.

So I think one of the big, one of the very positive things I've seen as a result of the previous studies that have been done is that the plants have incorporated these types of plots within their emergency operating procedures. So this is part of the Palisades operating procedure.

And when they performed their simulations of the small-break LOCA and main steam-line break, they would start at one point and they actually tracked the time-dependent pressures and temperatures. And, they showed where they, how the operators have kind of deliberately manually tried to keep it within those bands.

So to me that was very encouraging because it wasn't an automatic system that just -- they didn't just let things go. They actually had curves that they knew in advance that they'd have to stay between. So, that was encouraging.

CHAIRMAN WALLIS: Also, in pressurized thermal shock, you're worried about the rate in which the temperature changes, not just the temperature itself.

PROFESSOR REYES: Correct. Yes, that's right.

CHAIRMAN WALLIS: That bottom curve is a boiling curve really, isn't it?

PROFESSOR REYES: This one is a saturation curve. This is their subcooling curve. They trip their pumps on 25 degrees subcool.

So, this gives you a feel that they've incorporated some procedures within the plant's operating procedures to address this issue.

Next slide. So when we ran our experiments, however, we were looking for a more bounding type of an assessment. So, in terms of what we did relative to what the Palisades folks would actually do, we had some very important exceptions in our procedures.

We didn't throttle our HPSI to keep within those bands. We just turned our HPSI on and stepped back.

CHAIRMAN WALLIS: It's conservative to do that? If you actually throttled it, you'd get less flow and therefore you'd get less thermal shock. Is that the assumption?

PROFESSOR REYES: That was the assumption.

CHAIRMAN WALLIS: Is that really backed up by some analysis?

PROFESSOR REYES: I think this is really the source of cold water. So, throttling back certainly would reduce how much cold water is available.

CHAIRMAN WALLIS: It would reduce flows and things, so it's not clear immediately that it's conservative.

PROFESSOR REYES: Well, for this design, I feel very comfortable because it's a side injection. And I'll show you. It just kind of trickles it. It's not a very high flow.

MR. BESSETTE: We also have analysis that shows that full HPI is worse.

CHAIRMAN WALLIS: So you have an analysis to back up this?

MR. BESSETTE: Yes, yes.

PROFESSOR REYES: In terms of isolation to a feedwater flow, we assumed it would take the operator about 10 minutes to isolate. Observations were that they responded very quickly.

During the simulation, they were able to identify very quickly which was the broken steam generator and which one's the isolate. But, we assumed 10 minutes. And there was no effort made to keep the plant within the pressure temperature bands that I showed you there on the scale basis. So, we just let the transient run its course.

Okay, next slide. Okay, here's our test matrix.

Next slide. We ran 20 experiments. This included a mixture of integral system tests and basically separate effects tests, where we were just focusing on the behavior of the downcomer looking at various HPSI flow rates. So this was our benchmark test to make sure we had our pressure valves modeled properly in our plant.

We did a natural circulation stepped inventory test. This is very similar to the Semiscale test that had been performed in the past. And so these tests, the way it works is you set up essentially a small-break LOCA, you open up a valve, you let it -- you lose certain fractions of inventory, you shut your valve, and you let it go into natural circulation. And then you take your measurements, and then you just step your way through. And that's just taking snapshots of the small-break LOCA.

And, we were able to duplicate the same behavior that the Semiscale produced. And so we were looking at a very slow transition to loop stagnation or to really it was a reflux condensation mode. Well, there was some flow behavior instead the loops, but we couldn't measure it because it was so low. So, we did do that test first.

We did a parametric study. These are eight different sets of conditions that we looked at how the natural circulation flow would affect our mixing in the downcomer for different HPSI flow rates. So we had essentially two different HPSI flow rates for one set of natural circulation flow conditions, and we had a specific core decay heat. I'll show you some results of core decay heat.

And we wanted to see if we would see cold-leg thermal stratification for natural circulation flow and what was happening in the downcomer as a result of that. And this is where we got a few surprises.

Tests number four, five and six, these are stagnate loop fluid mixing tests. Back in the old days, we had Creare do some tests for us. And those were basically stagnant loops. Basically, you're injecting cold water into a stagnant volume. And these are very nice because they're easy to model in terms of hand calculations. You had asked about hand calculations. These you can actually do by hand.

So, you can come up with nice well-mixed behavior. At least you could predict some of the temperatures very easily. So, I'll show you that.

So we looked at the effect of just having one HPSI operating, what was the rate of cool down, four HPSIs operating at one flow rate and then another flow rate.

Later on we repeated this series with some bypass flow to see what was the effect of having some warm water flowing through the upper head into the downcomer and to the cold-leg to see if that would, to see how that would influence the results.

We did several of the small-break LOCAs, a 1.4-inch simulation of a hot-leg break from full power.

CHAIRMAN WALLIS: When you say 1.4, that's 1.4-inch in the full scale or is it --

PROFESSOR REYES: Full scale. So, this would be 1.4 inch in the Palisades plant.

CHAIRMAN WALLIS: So it's a fairly small --

PROFESSOR REYES: Small-break, yes. So both, these are actually fairly small-breaks.

Another one is from hot zero power. Hot zero power conditions were assumed at 100 hours after SCRAM. So this is the decay heat equivalent about 100 hours after SCRAM. And, in fact, we found that the reactor coolant pumps provide a significant part of the power for this. So when you trip those pumps, then you really got power significant.

We got two stuck-open pressurizers. PORZ up here. There's safety relief valves from full power and from hot zero power.

Next slide. We ran a couple of main steam-line breaks. These were large, equivalent to about one square foot in the Palisades plant. And, this is with the failure to isolate feedwater. And then this is from hot zero power, and this is from full power. And I'm going to present the calculation run on this one a little bit later.

This was a stuck-open primary safety relief valve with subsequent reclosure. That's one that Dave I think had mentioned earlier.

We did several more of these stagnant loop cases at different conditions, two adjacent HPSI. In these we were looking for the behavior of the plume in terms of plume merging, which we did see. And what happens is you get two opposite HPSIs. So, we had a whole range of HPSI injection behavior.

And then we did some with the upper plenum downcomer bypass holes open. And, we repeated that with upper plenum downcomer bypass holes open with four HPSIs as one HPSI. And then we did a two-inch hot-leg break from full power with the upper plenum downcomer bypass holes open. So this introduced warm water from the upper head into the downcomer.

CHAIRMAN WALLIS: So you didn't do a really large-break LOCA?

PROFESSOR REYES: Right. The largest break we could perform in our facility is about I think four inches with our current separator off of a hot-leg. We can do somewhat larger breaks, but it requires a significant reconfiguration.

MEMBER FORD: Now 20, test 20, the separate effects test?

PROFESSOR REYES: Thank you. This was an initial test. In this test we started with a reduced level in downcomer. We were at saturated conditions and we were just injecting cold HPI water into the cold-leg. So, we're pouring cold water into the cold-leg and into the core barrel.

I saved it for last because I was really concerned about this test. My concern was waterhammer, condensation waterhammer. So, you were putting this cold water into a fairly long horizontal pipe and it's full of steam. So that was my concern.

We approached it fairly gingerly. What we found in that test was that as we injected, we couldn't measure the temperature difference between the injected stream and the saturated conditions. So, I mean, obviously there's enough condensation occurring on that stream. So by the time it was in the downcomer, all of our thermocouples were reading saturated. So, it was a significant one.

Now there's two things that affect that. One is that the HPSI flow rates for this design are very low compared to other designs. The CE plant has a very -- it's really, we would consider it for most plants a low-pressure safety injection. So, it comes on somewhere around 1200 psi is the starting pressure, and then it just increases from there.

So, it's fairly low. In fact, the

accumulators are also very low head. Some are around 200 psi as their injection pressure.

So we did get significant warming and we didn't see much of an effect. But that's not to say that a different plant might -- that's a difficult task because it doesn't -- the likelihood of a waterhammer event is there.

MEMBER FORD: The words "separate effects test" is puzzling me. Didn't you say that that test was done in plastic piping?

PROFESSOR REYES: No, no. Thank you. Some of the tests that we performed in our APEX-CE facility we actually called separate effects. In fact, we're using the entire loop. We were focusing on a very specific phenomenon.

So we didn't set up from initial conditions and then blowdown. We just started from a very specific set of initial conditions that would allow us to focus on one particular phenomenon.

Okay. Now I'll present some of the key results of these tests. Next slide.

So these are the key observations. And this is the area I'll try to focus on. In the area of integral system cooling transients, we were interested in whether or not the codes could predict or generate some data to benchmark these codes.

And we wanted to know in particular the primary side pressures and downcomer fluid temperatures, and in particular, between this region, 2.4 cold-leg diameters to about 6.8 cold-leg diameters, where the reactor core region is located.

What we found in general -- and I'm going to give you some very broad results since we're limited by time. In small-break LOCAs, transients resulted in the lower downcomer fluid temperatures, but they didn't repressurize generally. We had one case where we deliberately isolated, reclosed our pressurizer safety relief valve, and that one did repressurize. But about 10 minutes into the transient, we didn't really get the very low temperature. So I could see where that could be important if we had let it go much longer.

The one-square foot main steam-line breaks from hot zero power, test number 11, that resulted in the lowest downcomer fluid temperature while at repressurized conditions. So we were just trying to see which gives us the lowest temperatures in repressurized conditions.

Small-break LOCAs definitely gave us colder fluid temperatures. But the combination of high-pressure or full-temperature and cold temperatures was the main steam-line breaks, what we observed.

It was interesting to note that the original Calvert Cliffs TRAC studies in NUREG/CR 4109 did a similar set of -- did calculations for a similar set of transients and came up with the same results, that the one-square foot main steam-line break at hot zero power gave you the lowest fluid temperature with the highest pressure.

MEMBER FORD: Could you give us -- or are you going to come to it later on? When you say "lowest", how low?

PROFESSOR REYES: Yes. Next slide.

So these are our integral system tests. And this is the case that gave us the coldest temperature. So, here you can see that this gave us a minimum downcomer temperature of about 238 degrees F. And we went back to -- our full pressure was about 364 psia.

DR. BANERJEE: Why did you say that's the lowest compared to the --

PROFESSOR REYES: It's the combination.

DR. BANERJEE: Sorry. Go ahead. Explain.

PROFESSOR REYES: It gave us the lowest

temperature with repressurization.

DR. BANERJEE: Oh, okay.

PROFESSOR REYES: That was a combination.

But in terms of overall the lowest temperature, it was the LOCAs, the small-break LOCAs. So, for example, here you have -- even with the 1.4-inch hot-leg break from hot zero power, we were down to about 177 degrees F.

If these transients run out longer and your HPSI can keep up, you may repressurize those but it's very far out in the transient. So, there's a potential there.

So, LOCAs gave us lower temperatures but they didn't go back to full pressure, although they did repressurize some.

MEMBER FORD: Maybe you could give me a short tutorial as to whether my concern is a concern or not.

PROFESSOR REYES: Okay.

MEMBER FORD: When you're dropping the temperature from 600 or thereabouts down to 255, that's a big jump. Would you expect the metal surface temperature to change the same amount?

PROFESSOR REYES: Well, this is where I think the -- for our facility, it did. But again, we're very thin walls.

MEMBER FORD: You have thin walls?

PROFESSOR REYES: That's right.

MEMBER FORD: So you've got huge heat mass in the --

PROFESSOR REYES: That's right. So, six inches. Maybe eight inches at some locations.

So this, however, I think the computation methods that are available are certainly adequate to address that.

MEMBER FORD: Well, you say you "think". I sure as heck don't know. Give me a feeling.

PROFESSOR REYES: I'll show you some slides which show that the techniques that are available out there work very well in predicting temperature through the wall, external wall temperatures, and inside heat transfer coefficients.

MEMBER FORD: Okay.

PROFESSOR REYES: I'll present some of that.

MEMBER FORD: Okay.

MEMBER RANSOM: What were your original temperatures?

PROFESSOR REYES: Another very good question. Four hundred and twenty degrees F. So, we don't start at full temperature.

In term of energy, if you just did kind of a global energy balance, you know, we're going from 420 to an average of maybe 255 --

MEMBER FORD: So you're not simulating the full temperature nor are you simulating material geometries?

PROFESSOR REYES: Right.

MEMBER FORD: Do they give concern as to the accuracy, the realism of your final conclusions?

PROFESSOR REYES: There are several ways of responding to that.

In terms of energy scaling -- so this is scaled. This represents, in terms of that energy change overall if you did an integrated energy balance, it's about 270 of the energy of the actual plant. So, in terms of the transient, we can convert this back to what we would expect to see probably, expect to see in the Palisades plant.

But, moreover, I think what I'm going to show you is that the phenomena that occur during this transient is important to how a code like RELAP, for example, might calculate this behavior. So benchmarking those codes against this data I think is probably the key thing. It's to show, not necessarily that everything from this, not everything does scale -- in the scaling report, I point that out -- but to show that the codes can actually predict the right phenomena. And there's some phenomena it just can't because it is three-dimensional.

DR. BANERJEE: Are you going to show us sort of a schematics somewhere or what sort of the flow patterns and things were like? Are you coming to that?

PROFESSOR REYES: Yes. I will show -- I'll give you some images and some measurements.

DR. BANERJEE: Right. And how long does it stay at these temperatures?

PROFESSOR REYES: That's just the minimum downcomer.

DR. BANERJEE: Then it recovers?

PROFESSOR REYES: Well, depending on the transient, some of them will stay kind of at a saturation condition and then they'll stay at that temperature for --

DR. BANERJEE: Is that saturation conditions or what in some of them?

PROFESSOR REYES: For some of them, and some of them will be subcooled.

DR. BANERJEE: So the black one is

obviously subcooled, right?

PROFESSOR REYES: Correct.

DR. BANERJEE: But let's say the 177 Fahrenheit. Is that saturation?

PROFESSOR REYES: That's still subcooled also.

DR. BANERJEE: That's still subcooled. Right, of course. That's below the boiling point of water, right?

PROFESSOR REYES: I've got analysis that shows what the, basically the worst case ones.

DR. BANERJEE: Okay.

PROFESSOR REYES: Next slide.

Okay. So as we performed this integral system tests, we observed several different phenomena that appear on the PIRT table that we thought were important to investigate. And one of the big ones is this primary loop stagnation during HPSI operation.

The thought was, if you get to stagnation in the loop, now you're injecting this cold water into a stagnant system, that that would probably give us the worst-case conditions in terms of generating very strong plumes in the downcomer. And so we were curious as to how strong were these plumes and what were the mechanisms that caused loop stagnation for the different cases we examined.

So we had -- small-break LOCAs, main steam-line breaks were the two main categories we were looking at. What were the different stagnation mechanisms? Well, we narrowed it down to three: steam generator reverse heat transfer, and we saw that both in the small-break LOCAs and in the main steam-line breaks; steam generator tube draining, and we saw that in the small-break LOCAs above a certain size; and then cool liquid intrusion into the loop seal as a back flow. As a result of HPSI injection, it travels back along the bottom of the pipe and spills into the loop seals.

Okay, next slide. And I'll describe each one of these here and provide you with some data. We'll start off with some tables and then eventually we'll get to some --

CHAIRMAN WALLIS: So you did get the stagnation in all these runs?

PROFESSOR REYES: Every one except the --

CHAIRMAN WALLIS: That one.

PROFESSOR REYES: Right. So, we did see stagnation.

So our stepped inventory reduction, that was the goal of that test. So, we got all four legs to stagnate. That was just due to the steam generator tube drain.

The small-break LOCAs, we saw stagnation in two, three, and four cold-legs due to steam generator 1 and stem generator 2 reverse heat transfer. And then, negatively buoyant loop seals into the -- this cold water intrusion into loop seals.

CHAIRMAN WALLIS: So you're running a complete transient. So, you get stagnation as some period in the transient?

PROFESSOR REYES: That's right.

CHAIRMAN WALLIS: You also get temperatures and so on. So you can then look back and say, was the shock to the wall the worst during the stagnation time or was it at some time before or after? How did stagnation relate to heat transfer going on in the downcomer and so on? You're going to give us that perspective?

PROFESSOR REYES: Right, right. What I'll present is -- what we did was we looked at all the cases and looked at the downcomer temperatures, trying to determine when you have the steepest difference between plume temperature and ambient. And then also we looked at thermal stratification horizontally also in terms of the bottom of that active core region to the top of the active core region.

So, we did see stagnation. And we were able to identify stagnation in most of these tests with the idea that it was either due to one or a combination of these three mechanisms.

Okay, next slide. And I'll try to show you some of the -- I'll describe each mechanism a little bit.

Steam generator reverse heat transfer. During the main steam-line breaks, what happens is that the unaffected steam generator, the steam areas that's not broken remains liquid filled and isolated. So, it's a hot tank of water basically.

And the cold-legs attached to that unaffected steam generator will eventually become stagnate. And the reason is you get, as the other broken steam generator blows down, we're moving a tremendous amount of energy from the primary side. We dropped the primary side temperature below the temperature on the shell side of the steam generator. So then that becomes the heat source and you stop the flow in those loops.

For the stuck-open safety relief valve, in the 1.4-inch small-break LOCA tests, the steam generator also was a heat source. Stagnation occurred because of this reverse heat transfer process before the tubes could actually drain. So that was really the primary mechanism for the stuck-open SRV. And, in fact, for some of these tests, the tubes never drained.

Cold HPSI flow into the downcomer provided the positive driving head for natural circulation flow. So even when you had reversed heat transfer, it didn't happen when you see the temperature, when you first see the temperature of the primary drop below the temperature of the secondary. You'd think it would stop there, but it doesn't.

What's happening is you're putting cold HPSI water into the downcomer. So, you're not driving it to keep the flow going. And so you have to have enough of a Delta-T to actually overcome the positive buoyancy created by this cold HPSI water being dumped at an elevation above the core into the downcomer.

So the next slide shows a picture of that. Here, this was the Delta-T required to overcome the downcomer of buoyancy. So we're putting this cold water in, creating a -- so this is the test number 11, the main steam-line break at hot zero power. Here's the steam generator number 2 shell side temperature. And so you see it remains relatively flat. It's isolated. It's just a hot tank of water.

Here's the hot-leg temperature. You see that starts off above and then it comes down. But stagnation doesn't occur until about here, like 380 seconds or so. So, that was a key. Steam generator reverse heat transfer was one of the major mechanisms for loop stagnation.

Next slide. The other mechanism is steam generator tube draining. For the small-break LOCA tests greater than five centimeters, about two inches, stagnation was primarily determined or was caused by steam generator tube draining. And, we observed something interesting there also.

We saw that the long tubes -- in our system, we have 133 U-tubes, we have a set of long tubes. Just like a real bundle, you have long tubes and then you have shorter tubes as you get to the interior of the bundle. The long tubes drained much earlier than the short tubes. So, primary loop natural circulation continued until the shortest tube is drained is what we observed.

CHAIRMAN WALLIS: It's interesting if they were at zero length --

PROFESSOR REYES: Before you start.

CHAIRMAN WALLIS: This is sort of

backwards from what you'd expect.

MEMBER FORD: Is there a physical reason for that?

PROFESSOR REYES: In terms of which drains --

CHAIRMAN WALLIS: The driving force is bigger for the longer tubes?

PROFESSOR REYES: I guess I'm thinking about that you do have a longer tube --

DR. BANERJEE: I think if you break the natural circulation at the top --

PROFESSOR REYES: You break the natural circulation at the top, so you start seeing those tubes are bored first.

In terms of resistance I guess on the outer tubes, they physically are longer tubes. So, you have a greater resistance in those so you expect a lower flow rate.

CHAIRMAN WALLIS: So if they're drained to a certain height, they become short tubes? But apparently not because there's still that -- you haven't broken the seal in the top?

PROFESSOR REYES: In the top, that's right. That's right. And we measured levels in our longest tubes and our shortest tubes, so I can show you that.

The thing that was interesting to me was that RELAP5 typically uses one tube to model the whole steam generator. And so in terms of when stagnation occurs, that can cause some difficulty because -- it works well on the average. But if stagnation doesn't really occur until the shortest tube is drained and you do see a ramp down in the flow rates, then that does give us a -- it sometimes tends to predict maybe a little too early. It's usually never too late. It's always early. So I guess in that sense it's a conservative effect.

I know there was some look at some multiple tubes, like a 3-tube or more scenarios, which give somewhat better results I think.

DR. BANERJEE: Did you get any reflux condensation for any of these tests? Refluxing?

PROFESSOR REYES: Yes. In this test number 2 we did. The problem was that those flows are so low and it's countercurrent in the hot-leg that we couldn't really measure. It's like a zero flow to us.

CHAIRMAN WALLIS: Usually, the steam generators are a heat source?

DR. BANERJEE: No. It's a heat sink usually. Here, sometimes it's usually a heat source.

CHAIRMAN WALLIS: It's a heat source quite a lot of the time?

PROFESSOR REYES: That's right. That's right. So depending on how you treat your secondary-side, if you're not trying to stay within a certain band and you just isolate your steam generator, that's what'll happen. It eventually becomes a heat source.

Okay, next slide. This shows a picture. Okay, this is a steam generator tube draining. Over here, this is our long tubes. They start at a higher, slightly higher elevation than our short tubes. These are actually looking at a -- we measure the DP on both sides of the tubes. So, we have a long tube. We're measuring the rising-side and the downside of the tubes. And, they actually mesh pretty well.

So this shows they started draining about here, and eventually came down, and then the short tubes really didn't start to drain until about here. So you can see that they didn't empty until about here. So, it's about a 1,500 second difference.

CHAIRMAN WALLIS: RELAP is somewhere in between with an average tube?

PROFESSOR REYES: Right.

CHAIRMAN WALLIS: Is RELAP there or not?

PROFESSOR REYES: No, this doesn't show

any --

CHAIRMAN WALLIS: I know it doesn't, but do you remember where RELAP is?

PROFESSOR REYES: I don't know for all the tests. And, so, I didn't run a calculation with the --

MR. BESSETTE: So RELAP with single tube falls midway in between these two.

CHAIRMAN WALLIS: It does?

MR. BESSETTE: Yes. We looked, yes.

PROFESSOR REYES: Okay, good.

So certainly there might be some modeling improvements there in terms of a new methodology that could give us a more accurate prediction of when stagnation might occur.

Okay. Next slide, please. The third stagnation mechanism was really quite a surprise to us. It was this cold liquid intrusion into the loop seals. This shows the transparent inversion of the loop seal. And what we use, we used saltwater and a fluorasine dye so that we could trace the fluid behavior.

This is this little weir wall here. What we see is we maintain a certain level in our cold-leg as a result of this weir wall. You get a spillover.

For certain combinations of loop flow and injection flow, you get spillover back into the loop seal. And, eventually, you start filling this loop seal up with cold water.

In our APEX-CE facility, the pressurized facility, we have thermocouples in our loop seals. So, we can tell when we're seeing a plume coming down and what the temperature is in the loop seal.

What we found is when loop seal spillover begins, that we're producing basically a negatively buoyant section of pipe here. So, it's resisting the primary loop flow. What we saw was that when spillover occurred -- whatever loop seal the spillover occurs in first, we see that loop stagnate first.

CHAIRMAN WALLIS: But RELAP wouldn't predict this at all?

PROFESSOR REYES: RELAP couldn't predict this. No, because we've got the concurrent flow occurring in a single pipe. So, that's something that RELAP couldn't do.

But this was actually the cause of asymmetric loop stagnation. So depending on which loop seal spilled over first would determine which cold-leg would become stagnant first. So in terms of the plant, depending on the discharge geometry of your reactor coolant pumps, the height of that little lip will determine which cold-leg will become stagnant first.

What we saw was that this only occurred in conjunction with another stagnation mechanism. So, essentially, you had to have either a reduced flow because of the steam generator reverse heat transfer or because your steam generator tubes were draining. And so, you'd see the cold-legs flow going down. So this only occurred when flows were low enough so that you can actually backflow.

CHAIRMAN WALLIS: So this actually occurred in the heat transfer facility in APEX?

PROFESSOR REYES: Absolutely, absolutely. So we observed the same phenomena in APEX.

And all those tests, that table of tests, I identified a test where we saw this loop seal backflow. So, we have our temperature measurements. And you can see that in one loop seal the temperature stays relatively constant, and in the other loop seal you see this decay, just like a plume decay basically into a stagnant volume.

And, it would only appear when the natural circulation flow was low enough to permit loop seal spillover. So there had to be some other mechanism to drop that natural circulation flow low enough to allow you to spillback.

DR. BANERJEE: So the cold water is coming from the injection?

PROFESSOR REYES: Right.

DR. BANERJEE: So you're saying it's stagnant because the net flow is zero or what?

PROFESSOR REYES: No, there's actually flow this way.

DR. BANERJEE: There's flow both ways, right?

PROFESSOR REYES: That's right. So it's a countercurrent flow.

DR. BANERJEE: Right. But when you say it stagnates, it stagnates with regard to cold flow or what?

PROFESSOR REYES: Well, what I'm saying is that --

DR. BANERJEE: What do you mean by "stagnate"?

PROFESSOR REYES: Oh, in terms of the loop. Okay. So once this loop -- that's a good question.

Once this loop seal becomes cold, what we see is that the corresponding loop seal on the same steam generator, you'll see a flow increase on that side. So, it's diverted. I'm told eventually the primary mechanism, which is either steam generator reverse heat transfer or steam generator tube draining, causes the other loop to stop flowing all together.

So what we see here is that there's no -- at some point, this fills up with cold water and then there's no longer any positive flow through that loop to that cold-leg. But the adjacent cold-leg, attaches the same steam generator channel head, sees an increased flow until the main mechanism causes that loop to stagnate also.

Okay. So this was interesting to me because this is an example of a local phenomenon affecting integral system behavior. And that's one that, when we ran the separate effects test without having the integral tests, we wouldn't really see, recognize very quickly, the fact that this has a potential for stagnating a loop. I thought that was a very interesting result.

Okay. Next slide, please. Okay, another phenomenon, HPSI plume mixing behavior. We have a horizontal HPSI injection line in this design. What we saw for the flow rates that we were looking at, the fluid number in this line always was less than one. And so we always had backflow. And there's a significant amount of warming of this fluid due to the backflow.

CHAIRMAN WALLIS: I thought HPSI flow rates were much bigger than that, but apparently not.

PROFESSOR REYES: I think it may just be primarily the CE designs. It's a design with a fairly low HPSI, injecting in through essentially a large diameter pipe, which would be like an accumulator line. And so you've got a small flow rate. The fluid numbers, again, were always maximum flow --

CHAIRMAN WALLIS: Some plants have HPSI coming in from above the pipe?

PROFESSOR REYES: Yes, top injections.

CHAIRMAN WALLIS: In which case you might get even more of this.

PROFESSOR REYES: You get more mixing with the top injection I believe.

DR. BANERJEE: So the check valve is somewhere back there?

PROFESSOR REYES: Right, right. So it's coming in this way. Here's our cold-leg connection here, and we're seeing the backflow here.

CHAIRMAN WALLIS: So these things are not modeled in RELAP?

PROFESSOR REYES: So this would be something else that couldn't be modeled in RELAP.

MR. BESSETTE: In the plant, these flow velocities are one or two feet a second for Westinghouse and CE.

CHAIRMAN WALLIS: How big is the pipe?

MR. BESSETTE: It's about a six and half inch pipe in the plant. In B&W it's different. Flow velocity is about 20 feet a second.

PROFESSOR REYES: Yes, so it's very geometry specific.

In our transparent loop, what we did was we tried to determine how much of this backflow fluid would be entrained and mixed with the HPSI fluid. So, we were measuring density profiles in our cold-leg. And what we found was that we saw for a range of flow conditions here that covered the plant operation, we saw about one to three times of the HPSI was being entrained into this --

CHAIRMAN WALLIS: It's amazing.

PROFESSOR REYES: It was a significant amount of mixing.

CHAIRMAN WALLIS: So what's coming out is four times what goes in?

PROFESSOR REYES: So, in essence, that's right. You're mixing and entraining this fluid.

DR. BANERJEE: It's a big vortex.

PROFESSOR REYES: Yes. This goes way down to the end of the pipe. So, you're using all that surface area and you're just mixing all of that into it. So by the time your fluid gets to the bottom of the cold-leg, you've significantly warmed it up.

CHAIRMAN WALLIS: Of course, this was foreseen by the CE designers.

MEMBER RANSOM: There was a mention of a check valve. Is that a plant or your experiment?

PROFESSOR REYES: Plant.

MEMBER RANSOM: The plant actually has a check valve?

PROFESSOR REYES: Right, located downstream of this pipe.

MEMBER RANSOM: That's at the pump discharge?

PROFESSOR REYES: No, no. It's actually in this injection line.

MR. BESSETTE: Because in normal operation, plants in 2250 psi and max HPSI of 1600 psi, you need a check valve there.

MEMBER RANSOM: Did you mean a check valve in the HPSI?

MR. BESSETTE: Yes.

MEMBER RANSOM: But this is the cold-leg.

PROFESSOR REYES: No, this is the HPSI line.

MEMBER RANSOM: Oh, that's the HPSI?

PROFESSOR REYES: Yes. It's a little hard to see. The cold-leg is actually attached right here.

MEMBER RANSOM: Oh.

DR. BANERJEE: The cold-leg is bigger?

PROFESSOR REYES: Yes.

MEMBER RANSOM: Yes, all right.

DR. BANERJEE: So it really depends on the level in the cold-leg too? I mean if the cold water goes up above then it doesn't work. So it has to be below this level, right?

PROFESSOR REYES: That's right.

DR. BANERJEE: So it's spilling out into the cold-leg?

PROFESSOR REYES: That's a good point. Yes. And that's what we see in this design. It's pretty much like a waterfall coming in. It just spills to the bottom of the pipe, and then you have a head wave that goes out.

Okay, next slide. So that was an

important behavior that, again, you really can't predict with a 1-B code.

CHAIRMAN WALLIS: You'd better talk twice as fast in your second presentation.

PROFESSOR REYES: Oh, man. Okay.

Cold-leg fluid thermal stratification. We did observe thermal stratification in the cold-leg for all of our natural circulation flow rates. And we looked at core decay powers from one and half percent to about four percent decay.

We have a core active that generates a natural circulation flow rate. Those are scaled to Palisades to about one and a half to four percent. And our HPSI flow rate ranges from about 30 percent to 100 percent of HPSI flow.

We saw stratification in each of those. Now, the degree of stratification varied. As the natural circulation flow rate increased, the degree of stratification decreased. So, the more cold-leg flow, the less we saw in terms of stratification. But, there was always some present.

The presence of that lip at the reactor coolant pump, discharge, enhanced thermal stratification in essence as a screen. So, you got kind of the flow above. So it allowed some stratification to occur pretty much for all the cases.

And the screening criteria we were using, which works pretty well for an unobstructed horizontal pipe -- and we have some good data comparing the criteria against the Creare data. So, it worked very well for that.

And also, we have done some CFD calculations that show for an open horizontal pipe, that the screening criteria, as when do you go from well-mixed to stratified conditions, works pretty well. However, for this geometry, it didn't. It wouldn't predict a well-mixed condition because of the presence of this lip. We actually had stratification.

So, this significantly affects the PTS assessment methodology that was used in the past. And we'll talk about that in my second, very fast presentation.

DR. BANERJEE: If you didn't have the lip, does the screening criteria work?

PROFESSOR REYES: It should work pretty well.

DR. BANERJEE: It should or did you find it worked?

PROFESSOR REYES: We didn't try this geometry. We didn't really do a test where we moved the lip. But in previous tests that we performed or that were performed in the Creare tests and also even with some of the CFD calculations, we found that the screening criteria worked very well.

DR. BANERJEE: But not in your facility? Did you do any tests in your own facility where it worked?

PROFESSOR REYES: No. We always saw stratification.

DR. BANERJEE: No. I mean you never took the lip out --

PROFESSOR REYES: No, we didn't.

DR. BANERJEE: -- in any tests you've done ever in your whole life?

PROFESSOR REYES: Oh, oh. Now for another plant that we did perform tests, that's right, there was no lip there. But then the geometry was a bit different also.

DR. BANERJEE: But did the criterion work?

PROFESSOR REYES: That's a good question. We haven't applied it to that I don't think.

CHAIRMAN WALLIS: It's a two Froude number thing, is it?

PROFESSOR REYES: Yes, that's right. Froude number cold-leg squared plus --

DR. BANERJEE: Are there any other integral tests where the criterion has been tested? Integral tests, not separate effects.

PROFESSOR REYES: I don't believe in integral tests, no. I think -- we did some testing in the AP600 geometry. For that one, we used -- we did apply it to that and it worked well. And we also applied CFD calculations to that configuration, and the CFD was predicting that transition from stratified to well-mixed conditions.

DR. BANERJEE: Well, CFD has a lot of problems because turbulence is very strongly damped at that interface. So I don't think any CFD codes can cap that mixing properly.

PROFESSOR REYES: We did see problems with that --

CHAIRMAN WALLIS: I think it's more of a criterion, which is not too sensitive to mixing, isn't it? It's sort of an ideal flow criterion, countercurrent flow Froude number instability, and it's not too dependent on turbulence.

PROFESSOR REYES: That's true.

DR. BANERJEE: If it's not turbulent mixing, it's just sort of Kelvin-Helmholtz.

PROFESSOR REYES: Yes, it's like a lock

exchange problem.

Okay. So that does affect the PTS assessment methodology that was used in the past because there may be some geometries where it doesn't work.

Next slide, please. Okay, stratification. We have temperature rates inside of our cold-legs. So we're going from, this is the top of the cold-leg to the bottom of the cold-leg. So at the top of the cold-leg, we're seeing these temperatures up here. This would be the bottom of the cold-leg.

What this shows is that for different core decay powers, which corresponds to a different natural circulation flow rate --

CHAIRMAN WALLIS: There are eight different runs here on the same figure?

PROFESSOR REYES: Right. And then, we actually – and this is for cold-leg number four. There's another slide like this for cold-leg three, which I omitted, but similar trends.

So what we did was we varied the HPSI injection, cold-leg three and four. So, there are actually 16.

CHAIRMAN WALLIS: So you used stratification in every run essentially?

PROFESSOR REYES: That's right. So you can see even for the highest case, which was about four percent in decay power in the real plant, we had some stratification.

Now, the temperature -- but there is some.

DR. BANERJEE: The "LPM" means?

PROFESSOR REYES: Liters per minute. This is what we were measuring in volumetric fluid.

DR. BANERJEE: This is your injection rate?

PROFESSOR REYES: Correct.

And then the top number is our core power. That gave us the cold-leg flow rates.

MEMBER RANSOM: Is the time scale okay here, or do all of these occur at different times?

PROFESSOR REYES: Right. This test was done as a parametric study. So you can see that what we would do is we would set up an initial set of conditions, we'd let the test run, and then we would heat it up. I mean we would turn on our pumps, mix again and get to initial conditions, and then start with another set.

So, we ran through these tests in one day basically, trying to get a feel for what the stratification might look like. And then you get this kind of an exponential decay.

DR. BANERJEE: This was actually real-time sort of?

PROFESSOR REYES: That's correct.

DR. BANERJEE: Turned it on, organized it, and then started it again?

PROFESSOR REYES: That's right. And I'll show you some data how you collapse this data with very simple scaling. In fact, I've collapsed all 16, or all eight of these tests onto one line with a very simple scaling equation. So, it's a nice way to do it.

MEMBER FORD: Is there a physical limit as to -- it seems from this data that the higher the flow rate, the greater the temperature drop. It seems to make sense.

PROFESSOR REYES: Right.

MEMBER FORD: Is there a physical limit as to how far down it can go?

PROFESSOR REYES: This temperature --

MEMBER FORD: If you went up to five or six liters per minute, would it be down to 340 degrees?

PROFESSOR REYES: Well, what you'd see -- one of the things about having this core decay heat, that may become more important. But, this will level out. If you increased the flow rate, you would see it. But at this point, some of these are already at 100 percent flow. So, you wouldn't expect -- only if there was a changed in the plant I guess.

MEMBER FORD: Now that's 100 percent flow for the pump. How does that relate to the real plot?

PROFESSOR REYES: A hundred percent.

MEMBER FORD: Okay.

PROFESSOR REYES: So it's scaled.

MEMBER FORD: It's scaled.

PROFESSOR REYES: So if you take your numbers and multiply these numbers by 270, that would be the plant, the corresponding plant conditions.

CHAIRMAN WALLIS: Would it be a different scaling law, not be able to get the minimum to go lower?

PROFESSOR REYES: In terms of this?

CHAIRMAN WALLIS: If you were suspicious about your scaling law, so you say let's run five liters per minute.

PROFESSOR REYES: Right, right. I can show you --

CHAIRMAN WALLIS: You can't go lower --

PROFESSOR REYES: Yes, I'll show you the

slides. That's right. You can do that by hand. Good point.

Okay, next slide. Okay, so that was the stratification in the cold-legs.

Downcomer plume behavior. We looked at HPSI flow into stagnant cold-legs. We saw that they did produced plumes, but they were relatively weak. We could detect them eight cold-leg diameters down. But in terms of their strength, they were a lot less -- by strength, I mean the temperature along the centerline of the plume verses the ambient temperature. That Delta-T was not very large.

We ran a maximum test corresponding to about 150 percent of the Palisades HPSI flow into a single stagnant cold-leg, and that gave us a plume with about a four degree K temperature less than the surrounding ambient fluid.

The maximum HPSI flow into two adjacent stagnant cold-legs resulted in plume merger. The two plumes actually merged, and the coldest point was not below a cold-leg, but between cold-legs. I thought that was important to note.

CHAIRMAN WALLIS: These plumes are weak because of all the mixing in the HPSI line and the cold-leg?

PROFESSOR REYES: I think a big part of it is because of the mixing in the HPSI line and in the cold-leg.

Then if we used three or four HPSI injection nozzles, what we saw was that the whole downcomer became well mixed. And, it was a fairly flat profile. So temperature went down, but it was a flat profile in the downcomer, very uniform around.

So for two, you get that plume merging. And I think that probably gave us the largest --

DR. BANERJEE: This is with a horizontal line, right?

PROFESSOR REYES: A horizontal injection into the cold-leg, and then horizontal injection connected to a downcomer. So that was for stagnant conditions. We also did it for flow conditions.

CHAIRMAN WALLIS: Can we see the next figure?

PROFESSOR REYES: Next slide, please.

This show this one case, test number 14. We were looking at -- this is kind of, the ambient temperature around here is about 427 degrees K. And here is the minimum temperature, somewhere around 423.

This is the region directly below cold-leg four. Here's is cold-leg two. We were injecting only through cold-leg two and cold-leg four.

CHAIRMAN WALLIS: The different codes are for different numbers of diameters down below the cold legs, is it?

PROFESSOR REYES: That's correct.

CHAIRMAN WALLIS: It hasn't attenuated much by the time it gets to --

PROFESSOR REYES: It doesn't attenuate much.

CHAIRMAN WALLIS: So it hasn't mixed much. If it goes to 16 diameters, it's still recognizable presumably?

PROFESSOR REYES: I don't we saw it at 16.

DR. BANERJEE: Certainly at eight inches.

PROFESSOR REYES: So we're here around eight. So, this is eight. It is a bit warmer here.

DR. BANERJEE: So in fact the whole things turns very much on what temperature it's spilling out at because it essentially doesn't mix once it spills? It doesn't look like it mixes.

CHAIRMAN WALLIS: I think you're going to show us later on that it does mix, aren't you?

DR. BANERJEE: It doesn't mix very much.

CHAIRMAN WALLIS: Nor in this figure.

PROFESSOR REYES: This is the case where

you see plume merging. So now you've got two plumes joining and feeding one, which in the previous study we didn't look at that plume interaction.

DR. BANERJEE: You mean they get sucked towards each other?

PROFESSOR REYES: Yes.

DR. BANERJEE: That's interesting.

PROFESSOR REYES: Yes, yes.

Okay, next slide. Now I'll talk a little more about that.

CHAIRMAN WALLIS: Everything you've told us so far looks interesting and new compared with the way people were looking at this 10 years ago.

PROFESSOR REYES: Right.

For conditions of loop natural circulation, we were interested in this region, where if you have a plume in cold flow -- now the ambient fluid is moving close to the same velocity as the plume. The relative velocity between the plume and the ambient would be less. And so potentially, this would keep the plume intact longer. And so there's been some good work done on that.

But in practice what we saw as we increased our flow rate by increasing core decay power, you're putting more flow through your cold-legs and it just overwhelms the -- you can't observe the behavior because it overwhelms the mixing in the cold-leg.

So, in practice, the cold flow in the downcomer is caused by a cold-leg flow. And by increasing the cold-leg flow, we have more mixing in the cold-leg. As a result, we can't detect the difference.

DR. BANERJEE: But this is a very strong function of scale because the surface area of the cold flow to the hot flow will vary to the volume very enormously with the diameter of the pipe. Right? The volume goes up as the cube and the other goes as the square or whatever, something like that.

PROFESSOR REYES: So how you define your geometry, your plume at the outlet is --

DR. BANERJEE: What I mean is if you've got a four-inch pipe, the surface area for mixing, let's say the diameter, okay, and underneath is pi(D) or something, or pi(D) squared actually. So, as you go up, your mixing area to the volume changes the ratio because it's one over D roughly. So, in fact, the scaling is very poor for large pipes.

CHAIRMAN WALLIS: We've also scaled the flow rate by Froude number or something. So you better look into the interaction between the different scalings.

DR. BANERJEE: Yes. So as far as the mixing in the pipe is concerned, you may be getting completely wrong results.

PROFESSOR REYES: In terms of what sense?

DR. BANERJEE: In terms of mixing.

PROFESSOR REYES: The transition we feel we've got.

CHAIRMAN WALLIS: They won't be completely wrong. They might be not exactly scaled.

DR. BANERJEE: Well, they won't be wrong. That size is fine.

CHAIRMAN WALLIS: So you might want to run tests, which cover a bigger range than just a straightforward scaling range.

PROFESSOR REYES: Right. And maybe some other conditions.

MEMBER FORD: Jose, could you go back to the previous slide please.

If you had only one nozzle operating, say CL-4, presumably the plume would be symmetrical around that one nozzle?

PROFESSOR REYES: Yes, and it'll kind of meander about that location.

MEMBER FORD: Right. Now the minimum temperature presumably is going to get higher than the one that you show there, where the two plumes merge. Is that correct?

PROFESSOR REYES: Right. That is correct.

MEMBER FORD: Does the RELAP code predict that?

PROFESSOR REYES: What I've seen is that RELAP does a good job predicting the well-mixed temperature in the downcomer.

CHAIRMAN WALLIS: RELAP says nothing about plumes at all.

PROFESSOR REYES: You're right, it doesn't.

CHAIRMAN WALLIS: It's one-dimensional.

DR. BANERJEE: Is your length scaled down as well?

PROFESSOR REYES: Right.

DR. BANERJEE: So the length is one-quarter, and your diameter is what?

PROFESSOR REYES: About one-eighth in this design.

DR. BANERJEE: The diameter is one-eighth, length is one-quarter?

PROFESSOR REYES: I think that's about

right, yes.

CHAIRMAN WALLIS: You have to look at all this having relationships.

PROFESSOR REYES: It actually started up with a top down looking at the integral behavior, and then trying to match our HPSI injection diameter Froude numbers and then our cold-leg Froude numbers, getting those to match.

DR. BANERJEE: And your HPSI line is also one-quarter length from the check valve?

PROFESSOR REYES: Correct.

DR. BANERJEE: To the actual plant?

PROFESSOR REYES: Right. That's right.

DR. BANERJEE: The diameter is one-eighth?

PROFESSOR REYES: I'd have to check the diameter. I don't recall.

We scaled that diameter to match the HPI Froude number so that we would see if backflow was occurring.

Okay, next slide.

CHAIRMAN WALLIS: So it's a full-scale plant, but some of the diameters have a different scale because of Froude numbers?

PROFESSOR REYES: Right, because of Froude numbers.

Okay. This is a picture from the IVO test in Finland. And they did some very high injection flow rates with co-flow. And we were interested to determine, at least from the Palisades plant, if we would see thermal stratification horizontally.

So, as you fill up, you basically get this thermally stratified region, which increases. Now from the dye you really can't tell the strength of the plume.

CHAIRMAN WALLIS: They seem to have a column of dye, which doesn't mix at all.

PROFESSOR REYES: Yes.

So you don't see -- it's difficult to tell the strength from just the picture. And I don't think they've actually measured conductivities.

CHAIRMAN WALLIS: I thought the message we got the last time we talked to you was that everything was mixed out after a few diameters. And now there seems to be a different message.

PROFESSOR REYES: Well, I think the message, at least for the Palisades, is that what we see is the temperature difference between the plume and the ambient is not very great.

DR. BANERJEE: But that's only because of mixing in your cold-leg. And I think that's happening in the downcomer. The downcomer is not mixing at all.

PROFESSOR REYES: I think the cold-leg dominates, yes. I mean actually that --

DR. BANERJEE: I mean provided that is correct, then whatever --

CHAIRMAN WALLIS: Let's get some later data and see if that's the case.

PROFESSOR REYES: So we were curious about -- again, this is between 2.4 and 6.8, whether we see thermal stratification this way. So instead of looking at just the plume verses the ambient, we wanted to know if there was anything in temperature difference between the bottom and top of those regions.

Next slide. So the maximum flow temperature differences we observed from the 2-D elevation all the way down to the 8-D elevation -- for this one we used the 50-second average. So this temperature condition essentially was there for 50 seconds -- was about 13.6 degrees K. And that's for test number 9. And that was a stuck-open pressurizer safety relief valve case.

The primary reason for this temperature difference was because you had a saturated layer at this location. The next slide shows that temperature profile. So you mostly had saturated water up here, and then you can see it's fairly compressed down below here. So, this is eight diameters down, four diameters, three diameters, and then a big jump off to the 2-D.

DR. BANERJEE: So there was an interface there?

PROFESSOR REYES: Yes. So basically what this is showing is sort of a thermally stratified interface only going up the downcomer.

DR. BANERJEE: But is that, the top, is that just saturated water or is there steam in there as well?

PROFESSOR REYES: I believe this is saturated liquid.

DR. BANERJEE: Just saturated liquid. There's not steam. So it formed a thermal climb?

PROFESSOR REYES: That's right. And then you can see that the temperature grains are fairly flat around there. And I guess this is one of the -- a little bit of a dip there.

So in terms of stratification, this was the worst case, about 13.6 degrees K from the 8-D up to the 2-D.

DR. BANERJEE: Did this thermal climb sort of move around or did it stay?

PROFESSOR REYES: With time. Now, depending on the transient, with time you would see this change. It would either go up or --

DR. BANERJEE: How quickly did it move?

PROFESSOR REYES: This was very slow, so I did an average. This was a 50-second average. I did the same average over 1,000 seconds and it looked very similar.

DR. BANERJEE: Oh really?

PROFESSOR REYES: Yes, it didn't really change.

CHAIRMAN WALLIS: Is this fed by plumes that come down and then mix when they get down into that region?

PROFESSOR REYES: Right. It's just cold water mixing. But again, this temperature difference is not very great.

DR. BANERJEE: It's like the Finnish experiment you were showing us?

PROFESSOR REYES: Right. Except --

CHAIRMAN WALLIS: You don't share the plumes in this?

PROFESSOR REYES: We don't. That's right. It's hard to see.

DR. BANERJEE: Well, it really depends on the relative -- how cold the plume is. If it's 30 degrees below, then it'll be at 30 degrees. If it's 50 degrees, it'll be 50 degrees, right?

PROFESSOR REYES: Yes, it depends on the plume strength.

Okay, next slide. So, thermal stratification, I mentioned in our scaling analysis report, there were some attempts to try to collapse some of the data or come up with some techniques. And so, we issued this before we ran the test.

And a very simple equation is derived there in terms of the mixture temperature, the mean mixture temperature. This dimensional temperature can be related to a dimensionless time just by use of the negative feed.

CHAIRMAN WALLIS: It's like a well-mixed volume?

PROFESSOR REYES: It's like a well-mixed volume, yes. And I wanted to see how well that compared to our parametric tests. So where this dimensionless mixed --

CHAIRMAN WALLIS: So a one-node model?

PROFESSOR REYES: A one-node model basically.

CHAIRMAN WALLIS: That's a good place to start.

PROFESSOR REYES: Yes, it's kind of amazing.

These tests, they're a little bit different, is that this included the HPSI flows. So this T_I is kind of an ideal mixed temperature, which is average if we're using the volumetric flow of the HPSI. So Q-HPSI, T-HPSI plus Q-cold leg, T-cold leg kind of thing.

And then this time constant here is essentially just the mixing volume divided by the HPSI flow rates.

CHAIRMAN WALLIS: This is one of those academic studies?

PROFESSOR REYES: This is one of those academic studies, yes.

Next slide.

CHAIRMAN WALLIS: And it works?

PROFESSOR REYES: It worked.

So the temperature that we're using for a mixed mean is the inlet temperature for the core. So it's basically gone through the whole downcomer, and you're coming out of the downcomer through a turn, where it mixes some more. And it's the inlet temperature --

DR. BANERJEE: Go back to last slide. What is T_L?

PROFESSOR REYES: T would be the cold-leg fluid temperature.

DR. BANERJEE: And T_I?

PROFESSOR REYES: T_I is a volumetrically averaged temperature.

DR. BANERJEE: It's the inlet temperature?

PROFESSOR REYES: No. It's basically T-HPSI, Q-HPSI for Q being a volumetric flow rate plus T-cold leg, Q-cold leg.

DR. BANERJEE: So T_L into Q_L?

(No response.)

DR. BANERJEE: Is T_L the cold-leg?

PROFESSOR REYES: The cold-leg temperature.

DR. BANERJEE: So T_I is equal to Q_L and to T_L and to Q-HPSI and to T-HPSI?

PROFESSOR REYES: Divided by --

DR. BANERJEE: But does the T-HPSI include the backflow or is it a theoretical --

PROFESSOR REYES: No, it's separate. It didn't include the backflow.

DR. BANERJEE: It did not include?

PROFESSOR REYES: Right.

DR. BANERJEE: But now coming --

PROFESSOR REYES: But when you're doing this calculation, you're assuming everything is well mixed by the time you get to the core inlet. So, that's why that's --

DR. BANERJEE: So you're just mixing the two streams, that's all you're doing?

PROFESSOR REYES: Yes.

DR. BANERJEE: So it's like a CSDR. It's just like a big chain reaction.

PROFESSOR REYES: That's right.

And so when you do have well-mixed conditions, you can expect to predict reasonably well the mixed mean temperature.

And, in fact, when I talk about the REMIX model, it really was based on this idea that you could predict the well-mixed temperature very well. And then you have some additional correlations to -- deviations from the well-mixed.

CHAIRMAN WALLIS: This Tau-m comes from the volume in the flow rate?

PROFESSOR REYES: Correct.

DR. BANERJEE: It's a space --

PROFESSOR REYES: Yes.

MEMBER RANSOM: It's the volume and the mass flow rate through the volume, the Tau-m?

DR. BANERJEE: Yes, it's the transient time basically.

MEMBER RANSOM: Well, it's --

CHAIRMAN WALLIS: It's volumetric flow rate.

PROFESSOR REYES: Well, these tests were done with a constant HPSI flow.

CHAIRMAN WALLIS: You didn't tune anything? You didn't assume? You didn't tune anything?

PROFESSOR REYES: The tuning on this occurs -- in the scale report, I described this in terms of --

CHAIRMAN WALLIS: So you did tune it?

PROFESSOR REYES: In terms of the volume, there's some tuning of course.

CHAIRMAN WALLIS: So it's not just volume divided by flow rate?

PROFESSOR REYES: That's kind of the ideal case. In the scaling report, I tried to include some of the effects of heat transfer from the wall. And that just falls out of the energy equations. And so in the end it winds up being volume over HPSI plus a factor, which is a function of the biot number.

CHAIRMAN WALLIS: Oh, so there is a --

PROFESSOR REYES: So that biot number -- I don't know how much of the wall is interacting, so there is a fudge factor.

DR. BANERJEE: But nonetheless, what you're saying is that the combination of the cold-leg and the line leading up to the -- from the check valve to the injection point, if you take that volume as the well-mixed volume, at least the exit of it, then you're just homogenizing everything?

PROFESSOR REYES: Yes. And this is even more extreme because I'm saying we're mixing in the downcomer, and now we're measuring the temperature that's at the inlet of the core. And I'm calling that the mixed temperature.

DR. BANERJEE: The inlet of the core?

PROFESSOR REYES: The inlet of the core. So, we've gone through the whole thing. I've got a physical temperature measurement. And now if I want to predict the inlet -- the temperature to that core, I can predict that with this technique.

DR. BANERJEE: The TM.

PROFESSOR REYES: The TM, the well-mixed mean.

DR. BANERJEE: I see. But your picture shows also some stratification and stuff, the last picture you showed us. Right? The previous one.

Go back to the other one.

PROFESSOR REYES: This is in the cold-leg.

DR. BANERJEE: So why should the other one work? I mean this is separated, right?

(No response.)

DR. BANERJEE: Is this in the cold-leg?

PROFESSOR REYES: I'm sorry. This is downcomer. But this is at eight diameters. So, I haven't shown you -- so we're still fairly high up.

DR. BANERJEE: Right. But I mean, do you think it gets hotter underneath or what?

PROFESSOR REYES: I think it just mixes. You don't see this --

CHAIRMAN WALLIS: I think the actual volume that's mixed is changing, but not enough to change this exponential --

PROFESSOR REYES: Exactly.

CHAIRMAN WALLIS: The actual mixed volume is changing throughout this.

PROFESSOR REYES: Throughout the transient.

CHAIRMAN WALLIS: The transient. But not

enough to make a significant difference to your exponential.

PROFESSOR REYES: And the reason it worked also is because, again, these were those eight parametric tests and they were very short transients. So, the volume does change.

And so there are some things in terms of recommendations, CFD verses the simpler codes, I'd like to make when we get to that part of it.

DR. BANERJEE: But what relevance does your, that curve have to what the thermal shock problem is here?

PROFESSOR REYES: Oh, okay.

DR. BANERJEE: From here you can see there is a change. And depending on how cold the water coming out of your cold-leg is, it will stratify. There's a region where you're going to get a very high change in temperature in this.

PROFESSOR REYES: Right. So at least from the standpoint of coming up with a mixed mean temperature, what I'm trying to say is that you can scale some of the temperature behavior.

So I could use the same approach with Palisades and say, okay, here's an exponential decay, which you can do by hand, and determine kind of what you would expect the mixed behavior to be. And that's how some codes work. They deviate from that point.

But we'll talk about STAR-CD and some of the other things. We'll talk about a better approach.

MEMBER FORD: Jose?

PROFESSOR REYES: Yes.

MEMBER FORD: Presuming these data refer to 7,000 seconds after you start, the 6903?

PROFESSOR REYES: Right. That's correct.

MEMBER FORD: At a given location, eight diameters, what does the Delta-T verses time relationship look like?

PROFESSOR REYES: So you --

MEMBER FORD: One particular thermocouple.

PROFESSOR REYES: This is fairly flat. So, again, I did a 50-second and we started off with 1,000 a second. It changes some, but not very much.

MEMBER FORD: Okay. So what about --

PROFESSOR REYES: This is just averaging these thermocouples over a 50-second period.

MEMBER FORD: So if it levels out at two seconds or five seconds, there's presumably not much difference because of the heat capacity of the material. Is that right?

PROFESSOR REYES: So what we saw is -- I

picked the worst case.

MEMBER FORD: Okay. Those are the maximum over time.

PROFESSOR REYES: These are maximum for this test. That's right, yes.

DR. BANERJEE: What is really means though from what you're showing is that Delta-T over Delta-X are very high because this is a very sharp interface and they're just sitting there. It moves a little bit up and down. But you've got, the change in temperature with space is very sharp because of thermal climb. So that means it's cold on top or hot on top and cold at the bottom. So, there's a sharp change in temperature at that point.

CHAIRMAN WALLIS: So you've got sort of thermal stresses both radially and vertically set off by temperature grains both radically and vertically.

MEMBER RANSOM: I guess the other message is the change in temperature is relatively small compared with the overall temperature.

DR. BANERJEE: Isn't that the mixing model -- that his scaling of mixing is correct. I doubt if -- well, you could look at it in more detail, but when you've got a big pipe, that big --

MEMBER RANSOM: Well, this is not based on his mixing model. This is based on his test results.

DR. BANERJEE: No, no. It's based on the fact that he scaled the temperature of his -- I mean his diameter of his tube.

MEMBER RANSOM: Downcomer and the tube.

DR. BANERJEE: Yes.

MEMBER RANSOM: So you're saying the scaling of the experiment is not --

DR. BANERJEE: May or may not. I don't know.

MEMBER RANSOM: May or may not be reassuring.

DR. BANERJEE: That's something that has to be examined very carefully.

CHAIRMAN WALLIS: Jose, you've got a lot more in this presentation too?

PROFESSOR REYES: That's very true. There's actually a lot of information to present.

CHAIRMAN WALLIS: You actually should've asked for twice as much time as you have.

PROFESSOR REYES: Maybe three times.

CHAIRMAN WALLIS: Okay, three times.

PROFESSOR REYES: Okay. Well, we're close to the very end of this first half.

One of the things I wanted to do, as we

developed an understanding of all these different phenomena, how it might affect the ranking of the PIRTs. So the two, the main steam-line break and small-break LOCA PIRTs --

CHAIRMAN WALLIS: We can move on to the next page. We realize you might have to reassess some PIRTS.

PROFESSOR REYES: Okay. These items still remain high. Of course, the reason for that is the degree of cold-leg thermal stratification and the downcomer plume strength. So, that appeared over and over with regard to these. So those phenomena remain high.

The one thing that I've added is this number, HPSI flow rate and HPSI number. The number can affect the outcome. Because if they're two adjacent cold-legs, you can have plume merging and that might change your results.

DR. BANERJEE: It seems to me HPSI orientation is another factor, right?

PROFESSOR REYES: Right, the geometry. I don't know if I included that or not.

CHAIRMAN WALLIS: And the flow rate -- the Froude number is very important.

PROFESSOR REYES: The buoyant backflow is affected by the HPSI line geometry and flow rate.

CHAIRMAN WALLIS: This is a new PIRT really, isn't it?

(No response.)

CHAIRMAN WALLIS: You're making a new PIRT here, is that what it is?

PROFESSOR REYES: Right, basically what I saw in terms of our experiments. And what I found was that all these were already considered highly ranked.

CHAIRMAN WALLIS: Oh, they were?

PROFESSOR REYES: Except HPSI number. And in terms of the backflow, it's described in a more general way in terms of --

CHAIRMAN WALLIS: The backflow was anticipated in the first PIRT?

PROFESSOR REYES: No, not the back flow itself but the -- they actually list the HPSI line.

CHAIRMAN WALLIS: But they didn't list the phenomena?

PROFESSOR REYES: No, I don't believe the phenomena was listed in the first PIRT.

DR. BANERJEE: The geometry must have been important because depending on how --

PROFESSOR REYES: Yes, horizontal or -- so, I know the geometry was listed. So I'm saying that these are two that I've identified that would be of change. But the source water temperature, where cold-leg stratification occurs in that, that was already on there.

Next slide. The wall conduction heat transfer was on there. This wasn't there before: downcomer plume merging and mixing. So that's something that's new. But, again, we didn't see very large temperature differences in our tests. But it would be something that should be investigated I guess with the CFD codes is what I'm recommending.

And then this, the primary loop circulation, flow rate, and stagnation was on the original PIRT. So a lot of the --

CHAIRMAN WALLIS: I think we're going to want to look into this business of the plumes merging and what affect this has on temperature distribution. Because as I understand it the thermal shock analysis is based on good mixing in the downcomer.

PROFESSOR REYES: Right.

CHAIRMAN WALLIS: A bet that was taken early on, that it was going to come out that way, therefore, that was the way they were going to analyze it.

DR. BANERJEE: What you're replacing is

good mixing in the cold-leg.

PROFESSOR REYES: So it depends on how you define what Delta-T is considered good mixing.

CHAIRMAN WALLIS: I think they went through a stress analysis, which did not take account of peripheral circumferential variations in temperature. Isn't that true?

MR. BESSETTE: That's right. I was expecting to see more of a plume effect than it turned out. So, I was surprised.

CHAIRMAN WALLIS: We were too.

PROFESSOR REYES: Okay, next slide.

Main steam-line break. Again, the list that I presented actually was -- all of these items were on the original PIRT. Again, the only thing that's different would be the HPSI number and the backflow in terms of specific phenomena. But other things are the same.

Next slide. Wall conduction and then the plume merging would be the other one that I would add to that.

CHAIRMAN WALLIS: It's the same phenomena really as in the previous one?

PROFESSOR REYES: Really pretty much the same list of phenomena.

Okay, next slide. So some of the phenomena that I thought maybe were not as important, the convection heat transfer coefficient. What we saw was that it was conduction-limited. And so above a certain H, whether you change it by 10 or 100, it really didn't change the outcome.

CHAIRMAN WALLIS: As long as it's where there's high heat transfer coefficient?

PROFESSOR REYES: That's right.

The upper head downcomer flow. For this particular design, they didn't have like the B&W flapper valves. It was just the small bypass holes. And there was some warming of the downcomer fluid over time. It was pretty much over the length of the entire transient. It wasn't a very large effect for the size flow holes that would be typical of this plant.

Same thing with downcomer-to-core inlet bypass flow. We tested the bypass flow, but we didn't see a very large difference in our temperature conditions in the downcomer. So those were not ranked as high as previously.

Next slide. Timing of the reactor coolant pump trips was listed as one early on. For the small-break LOCA trips, the small break LOCAs, the reactor coolant pumps will trip on low subcooling temperature, which occurs fairly early in the transient before you've really had much HPSI flow. So, I wouldn't rank that as high as before.

For the main steam-line breaks inside containment, when you isolate your containment, you lose your component cooling water, which causes your pumps to trip. So, again, these were tripped early on in the transient before you have a lot of HPSI flow.

But these two timing of the trips, if it's an automatic function, it may not be that important for these types of scenarios.

A steam generator energy exchange, feedwater control, feedwater temperature, for the small-break LOCA tests with breaks greater than five centimeters, really what you see is a secondary-side temperature and pressure didn't affect the primary conditions until steam generator tubes -- or they did affect until the tubes are drained, which happens fairly early on.

So if your tubes drain then this energy exchange is not a big, important phenomenon. If your tubes don't drain for the smaller breaks then it becomes an important phenomenon.

Okay, next slide. That liquid steam

interface in the upper downcomer, for what we tested we found that you have this high up in the downcomer, you have an interface, a steam interface with liquid and it's saturated liquid. And so, that was decoupled.

For one test that we performed, test number 20, we had such good mixing that we didn't even detect a temperature difference in that test because there was some much condensation on that liquid. So, we didn't rank this one very high. But it was, again, for this particular test.

Okay, upper head heat transfer. It was important --

CHAIRMAN WALLIS: Now did the non-condensables in your experiment affect the condensation?

PROFESSOR REYES: We didn't try a range of --

CHAIRMAN WALLIS: Of the non-condensables in some of these LOCAs that come from the accumulator?

PROFESSOR REYES: This has a very low head accumulator, so we never got low enough in pressure --

DR. BANERJEE: Did you have nitrogen?

PROFESSOR REYES: No.

DR. BANERJEE: It didn't come into the

system?

PROFESSOR REYES: We never got it low enough in pressure to get to accumulator injection.

CHAIRMAN WALLIS: That can really change the condensation rate.

PROFESSOR REYES: And we were focusing pretty much on the repressurization behavior.

So in terms of the upper head heat transfer, the core energy and the break flow certainly overwhelmed this particular phenomenon. So I don't know if we ought to rank it high, but it does have an effect.

Okay, next slide. Conclusions of Part I.

CHAIRMAN WALLIS: That's the end?

PROFESSOR REYES: That's the end. So this just kind of summarizes a little bit of what was said.

CHAIRMAN WALLIS: Now, you have another presentation, which is about as long as this one?

PROFESSOR REYES: It's pretty long.

CHAIRMAN WALLIS: About as long as this one?

PROFESSOR REYES: That's right. And I certainly just hit the highlights.

CHAIRMAN WALLIS: Well, I think this stuff is important. And I'm not sure that we need to spend, what is it, three, over three hours on RELAP this afternoon. If you have equal time with RELAP, that may be a better balance of things. I don't know what the RELAP people think.

Do we really need to spend three hours on RELAP this afternoon?

PROFESSOR REYES: A big part of this is one of our RELAP5 calculations of a main steam-line break, which we could omit. We can skip that.

MR. BESSETTE: We can continue as long as you want today too.

CHAIRMAN WALLIS: That's what I'm worried about.

(Laughter.)

CHAIRMAN WALLIS: I think that if we take a break now and come back at 1:00 with Reyes Part II, and he can speak even faster than he did this morning --

PROFESSOR REYES: Pretty fast.

CHAIRMAN WALLIS: Then we will do that. We'll have a second presentation. Then we'll get on to the RELAP5 presentation, which originally was allotted 3.25 hours. That seems rather long compared with the amount of time that you've had for your presentation. Maybe everything will work out and we will leave here at a reasonable time today. Okay.

We'll take a break now and we'll come back at 1:00 o'clock and Jose will be on again, having had a break

(Whereupon, the Subcommittee recessed for lunch at 12:13 p.m.)

A-F-T-E-R-N-O-O-N S-E-S-S-I-O-N

(1:03 p.m.)

CHAIRMAN WALLIS: Let's come back into session. We will hear Reyes, Part II.

PROFESSOR REYES: Okay, Part II.

CHAIRMAN WALLIS: Even faster than Part One.

PROFESSOR REYES: Okay. In this portion of the presentation, I was going to provide you with a few comparisons of RELAP5.2 testing. That's where we have one test that we were going to present, but the majority of the work has been done by ISL in terms of calculation.

Some STAR-CD calculations, just very briefly what we've touched on. They won't include all the details, and then a comparison of REMIX, RELAP5 and STAR-CD for some very simple cases. Then just talk a little bit about our revised PTS methodology and what might be a better approach as opposed to what's been done in the past, and then just wrap it up.

So our objective was to assess only certain aspects of the codes that we thought were important to the PTS therm hydraulic assessment methodology. So this methodology is what provides the detailed information for the fracture mechanics assessment for a wide range of overcooling transients.

In the earlier studies back in the eighties, there were over 200 calculations that were done for the different plants, for Robinson and for Oconee, for Calvert Cliffs, that provided downcomer fluid temperature profiles, convective heat transfer coefficients on the inside of the RPV, and system pressures.

So this is what the original -- This is what the PTS thermal-hydraulics assessment methodology looked like back in the eighties. The way we were doing it is we had an integral system code, a systems code, RELAP5 or TRAC. We would use that code to provide the boundary conditions for some other model.

So we had cold leg flow, HPSI flow rates, cold leg and HPSI fluid temperatures, and primary system pressure would be obtained from a systems code. Then we had a stratification criterion that would take these boundary conditions to determine whether or not the cold leg was stratified thermally.

So that used the cold leg and HPSI flows to determine whether or not we had the cold leg stratification. If it was well mixed, then we would -- the RELAP5 with the TRAC calculations could be used to predict the downcomer fluid temperature and heat transfer coefficients.

If it was stratified, then at that time we used REMIX or another code called NEWMIX, depending on the HPSI geometry, to predict downcomer fluid temperature and heat transfer coefficients.

So what we've done is, for our test, we have taken a look at REMIX, and done some estimates and compared it to RELAP calculations and to STAR-CD CFD code, and then that would all -- this information would all go to the fracture mechanics folks.

So in terms of a cope for RELAP5, we wanted to see its ability to predict the downcomer fluid temperatures and the onset of loop stagnation. Those were two of our key goals.

For STAR-CD, the CFD code, we wanted to determine the ability to predict the downcomer fluid temperatures, the cold leg fluid temperature gradients, the HPSI backflow behavior, downcomer plume temperatures, and the motion and the interaction of the plumes.

Then REMIX is a regional mixing model. Again, we were looking to predict the downcomer fluid temperatures with REMIX.

DR. BANERJEE: Now STAR-CD and REMIX are

single phase codes.

PROFESSOR REYES: Correct.

DR. BANERJEE: So that presumes that you are in a situation there was no voiding in these legs.

PROFESSOR REYES: That is correct. That's correct.

So these are the tests that we analyzed using the codes. So we have one -- There's a RELAP5 calculation for our stepped inventory test. We used STAR-CD for that parametric test. We looked at some of the mixing behavior of a certain number of these parametric tests.

We used STAR-CD and REMIX for the stagnant loop test in numbers 4 and 5, and then we used STAR-CD, REMIX and RELAP for this test number 6. So I am going to show you that comparison. Actually, we did it for 5 also. So we have RELAP5 also for test number 5.

RELAP5 for the one-inch hot leg break from hot zero power, stuck-open core, and then the two main steamline breaks we also did some RELAP5 calculations.

We were using RELAP5 3.2 gamma version, which is the NRC version, and I'm just going to show you very briefly -- I'm not sure if there is anything beyond gamma.

DR. BANERJEE: Delta.

PROFESSOR REYES: In terms of the Greek. That was the version we used.

So I'm just going to show you the results for the one square foot main steamline break. Overall, for the main steamline break again, we have a large break on the secondary side. So we get a cooldown on the primary, but we don't really produce any voiding in the primary. So it is all single-phase.

So we have successfully performed the experiment in May of 2001. It was a hot zero case. So we simulated the K power about 100 hours after shutdown. It was inside containment break, is the assumption. So we lost our reactor coolant pumps early on.

The HPSIs were allowed to actuate just on -- when they reached the low primary pressure setpoint, and off speed was isolated after ten minutes.

This was the nodalization diagram. The model that was used was the model that was provided by ISL. So our group that was running the model based on an original -- it was the original AP600 model that we modified to simulate. So HPSI lines were added, and the loop seals, for example, were also added -- those lines.

DR. BANERJEE: So the downcomer was just 1-D?

PROFESSOR REYES: Right. Let's go back. There you go. Well, we show this region for the downcomer. So we had three sections, but it is 1-D.

MEMBER RANSOM: It's a very crude steam generator nodalization. Is that accurate?

PROFESSOR REYES: The one tube?

MEMBER RANSOM: Well, it is one -- or three volumes.

PROFESSOR REYES: Right, yes.

MEMBER RANSOM: That is the way it was done? The secondary side is just one volume?

PROFESSOR REYES: Yes. I'm not sure what the ISL had on there, but we can ask them. Different.

DR. BANERJEE: And the hot leg was one volume only? Hot leg was also one volume?

PROFESSOR REYES: Yes, one volume.

DR. BANERJEE: Where is the break?

PROFESSOR REYES: So in this one, this is an ADS -- excuse me, ADV, atmospheric dump valve opening off of the steam generator on the shell side.

These are just initial conditions. They

match very well in terms -- This is here English units and then the metric units, just conversions here. But in general, it matched very well with our model.

CHAIRMAN WALLIS: Except for the steam generator number 2 LOCA level, an extra 4 in there, 461?

PROFESSOR REYES: Yes. That wouldn't match very well, would it? This is a typo here. I want to mark that. It should be 61.46. Thank you. That was a spillover.

CHAIRMAN WALLIS: If it's a big error, you can detect it.

PROFESSOR REYES: That's right. If it's a big one, you can -- oh, that's a mistake. Thanks.

Then in terms of sequence of events, for the main steamline break it compared very well. This is just -- This shows the time in APEX and then the time predicted by RELAP. It does -- We performed the trip manually. So it was about four seconds after the opening of the ADV valve.

The RELAP tripped the pumps immediately. This was impressive. HPSI flow began at 91. It predicted 92 seconds. Steam generator 2 became a heat source. That's when the shell side temperature became greater than the primary side temperature. It was dead on.

Cold leg number 2 stagnated about 383 seconds. It predicted about 600 seconds, and really -- and I'll show you. It was an oscillatory type of a flow behavior. So it crossed that threshold and kind of oscillated around zero from this point on.

Same thing with cold leg. Both of them stagnated because of the steam generator becoming a heat source.

CHAIRMAN WALLIS: It did not oscillate in the experiment?

PROFESSOR REYES: Correct. Right. Did not oscillate.

CHAIRMAN WALLIS: So maybe it's a numerical oscillation of some sort?

PROFESSOR REYES: That could be. At these very low pressures, it just seemed to -- excuse me, at these low flow rates, it gave us oscillatory behavior.

We secured our feedwater at about 19 seconds late at 619 seconds. RELAP was ten minutes. HPSI flow automatically stopped on the pressure set point at about the same time, 1616 versus 1641. Then we concluded our tests at about 4,000 seconds.

MEMBER KRESS: Did you vary the noding any to see if you got different answers?

PROFESSOR REYES: For this, we have not. Have not. I think, in terms of the results, we got some very good comparisons.

So the blue line here is APEX-CE data and the RELAP5. This is basically our full pressure condition. So once you get past this point, the control system maintains a constant pressure in the test.

DR. BANERJEE: When you say APEX-CE, that's your model.

PROFESSOR REYES: Right.

MEMBER KRESS: His experiment.

PROFESSOR REYES: Experiment. So now I'm comparing RELAP5 calculation to the blue is the data, experimental data.

MEMBER KRESS: What causes that?

PROFESSOR REYES: That pressure drops a bit low. I think part of that may be due to the way in which the heat transfer surface on the steam generator tubes interacts. We are still trying to track that down.

There's another part of it that you will see later on, same kind of thing. I think it potentially could be the way we modeled the surface air in RELAP.

MEMBER RANSOM: Was the pressurizer modeled?

PROFESSOR REYES: Yes.

MEMBER RANSOM: Is it emptied or --

PROFESSOR REYES: No. Pressurizer --

MEMBER RANSOM: So this would be the pressurizer response then, I would guess.

PROFESSOR REYES: So that could be the pressurizer controller. So we have our levels covered, so the heaters are on.

MEMBER KRESS: That's the sort of thing it looks like.

PROFESSOR REYES: We were high, and maybe we didn't model enough.

CHAIRMAN WALLIS: That's essentially the loop pressure, though. It's not just pressurizer.

PROFESSOR REYES: That's correct.

DR. BANERJEE: But it's almost the same.

DR. KRESs: It is.

PROFESSOR REYES: Well, and our measurement was the pressurizer pressure. That's a good point.

Pressurizer collapsed liquid level -- so we had about the right levels here. Here's RELAP, and here is APEX. We were a little bit low, but again not by very much. I was surprised by the trends. They really matched very well.

This is at the 8-D location in downcomer for this test for the main steamline break. Here is the data, and here is RELAP. So it predicted a very small difference toward the end of the test.

MEMBER KRESS:Let's see. 8-D, is that where the beltline was?

PROFESSOR REYES: That's just below -- That is actually below the active co-region. So we are now past it. So it's closer to a better mixed region.

DR. BANERJEE: So this is not at saturation then?

PROFESSOR REYES: No. No, this is subcooled conditions.

This is below cold leg number 2. Again, here is the RELAP calculation, and here is the measured data. The HPSI flow rate -- Of course, the HPSI -- The way we modeled our HPSI was we had a pressure curve. So the flow rate is dependent on the system pressure. There is a feedback.

So we what we see is, as pressure drops, the flow increases, hits a maximum, and then as pressure starts climbing back up, the HPSI flow comes down. So RELAP predicts this curve here. It got the start-up and the shut-down pretty close, and the overall trend -- I mean, the shape is similar.

DR. BANERJEE: I guess that's due to the pressure being wrong. Right?

PROFESSOR REYES: So -- Yes, that's right. So RELAP dropped down to a lower pressure, which would give you a higher flow. That's right. So that's that little knee in the first curve.

MEMBER KRESS: Yes, that reflects it.

MEMBER FORD: What physically happens to around about 1700 seconds? What gives rise to both the drop observed and the change in scope predicted, typically?

PROFESSOR REYES: Okay. On this turn here where the HPSI is coming down, the system pressure is increasing, and part of is what we are doing is we are injecting -- we are continually injecting our HPSI water, which is filling up that system and can actually serve to pressurize the system. So HPSI could take you back to full system pressure.

Well, that is what is occurring here. We have put enough volume of water here to where we have repressurized it. In addition, we do have decay heat. So we are heating up the water that we are putting in.

So over here we have basically hit our full system pressure.

DR. BANERJEE: What is the HPSI pressure?

PROFESSOR REYES: For our facility, the shutoff heads about 385 psia. In the Palisades plan, it's about 1200 psia.

This is looking at the break flow rate comparisons. Here is our measured -- This is the steam flow rate data. We used a vortex flow meter. The cutoff flow rate for the vortex flow meter is about 50 liters per second here. So beyond this, you just basically have a straight drop.

What I did was we used the liquid level in the steam generator to kind of extend this out. So we were -- This basically would be our expected steam flow rate out after the low flow cutoff. So just using a max balance on the steam generator 1 shell side allows us to extend our data a little bit further.

What we see is a pretty good comparison up here. There is a bit of a discrepancy here. Now this sudden change -- and, hopefully, some of the ISL folks might be able to see it. I suspect maybe it was a transition from choke to non-choke conditions, but we get a sudden drop and then --

CHAIRMAN WALLIS: Why does it suddenly go to zero?

PROFESSOR REYES: That was my -- I don't know why it goes to zero and comes back up.

CHAIRMAN WALLIS: There's still a break on the pressure.

PROFESSOR REYES: So that's something that we are still trying to figure out what's going on with that.

CHAIRMAN WALLIS: Something is weird.

PROFESSOR REYES: But it was tracking pretty well, and then it just dropped straight. So we'll look into our models --

DR. BANERJEE: Do you mean zero or a little bit above zero?

PROFESSOR REYES: For this one? I think it was right -- It might have been right to zero. So I don't know if it is the models that we are using. There might be something that we did incorrectly in how we modeled it.

MEMBER RANSOM: This is a steamline break. Is that right?

PROFESSOR REYES: Yes. And so this is the steam flow coming out of the steam generator. So I'm not sure why it would suddenly drop, but it looked to me like it might have been a change in the choke flow to non-choke.

CHAIRMAN WALLIS: Well, that should still be continuous.

MEMBER KRESS: What was the pressure difference at that point?

PROFESSOR REYES: I don't -- Well, let's see, it's about 1,000 seconds.

DR. BANERJEE: It should be continuous, but it may not be in the code.

MEMBER KRESS: It may not be in the code, because they got to switch from some sort of a flowdown model and choke to some sort of a delta P model through a resistance. So it could very well be discontinuous.

PROFESSOR REYES: Well, we are the first to admit that we are -- in terms of our team, we are novices. We don't claim to be the really code developers or modelers. So when we identify something like this, we try to --

MEMBER KRESS: That may show a glitch in the code.

PROFESSOR REYES: Or it might just be our version, too. I don't know if you've seen anything like that in ISL.

MEMBER KRESS: There is no reason why it should behave that way.

PROFESSOR REYES: Yes, but it was tracking along pretty well up to that point.

CHAIRMAN WALLIS: No physical reason.

MEMBER KRESS: No physical reason. That's right.

PROFESSOR REYES: That's right.

Cold leg flow rates: This is the data, and this -- For cold leg number 1 we did not stagnate. So we reached kind of a steady state flow. RELAP also reaches a steady state condition. It does track the data pretty well up here, but it overestimates the cold leg flow for this region of the test.

I've got some tables with some numerical values to give you a feel for --

MEMBER RANSOM: Is that a natural circulation region?

PROFESSOR REYES: Right. That's right. So this is all natural circulation flow conditions. In fact, we initiated the test on natural circulation.

Here's cold leg number 3. So 1 and 3 were attached to the same steam generator, and that was the broken steam generator. We saw -- This was pretty good. This is a very good comparison with the data.

But it did a good job predicting 3.

Here's cold leg number 2. So two of the four, this was the impact steam generator loop, and the steam generator did act as a heat source. So we did get stagnation in these loops, and we got this initial stagnation occurring over here and then it basically flattens out.

This one didn't oscillate too much. This next was pretty well behaved. It might have missed the peak a little bit. So in terms of the on-site stagnation, it did a reasonable job there.

Cold leg number 4, again it's a little bit above zero there, but it worked -- it gave a reasonable --

DR. BANERJEE: So the flow reverses for a while.

PROFESSOR REYES: Right. In our experiment, we see a slight reversal in flow.

DR. BANERJEE: Both of them.

PROFESSOR REYES: That's right.

DR. BANERJEE: What does that do to it? Why does it reverse?

PROFESSOR REYES: Let's see. The other ones are flowing. So in fact, we have noticed that with this design you can have -- We've done some early-on shakedown tests where we had two pumps flowing, two pumps off, and you do see flow reversals in some of the loops, although this is at a very low rate. So we've done opposite pumps, side by side pumps, and you get some negative flow in some loops.

So overall, it actually predicted reasonably well. I'll give you some more details on that. Here is steam generator number 1 temperatures. What we see is that the RELAP predicts the shell side temperature -- it's a little bit high, but again not a whole lot, and the hot leg temperature it predicts a little bit low.

This all may be tied back to the fact that we had slightly -- RELAP predicted slightly lower pressure, which gave you slightly higher HPSI flows, which give you a little bit more cooling and might have dropped it down a little bit in terms of temperature. So that pressure curve from the very beginning with that little extra knee might explain some of this difference.

The important thing is that for this case what we see is that the shell side temperature always remained below the hot leg temperature. So this was always -- This wasn't the source of the -- It wasn't the heat source.

On the other hand, steam generator number 2 was a heat source. Early on in the transient, we see the hot leg temperature dropping below the cold leg temperature -- I mean, the steam generator shell side temperature. So at steam generator 2, the intact steam generator became a heat source.

It did a good job on -- or at least early on -- in predicting the hot leg temperatures. Then there is a bit of a deviation again. That could be partly due to that difference in pressure we saw early on.

Then up here, we are still looking at this. We don't know why -- This is -- The steam generator is buttoned up. It's isolated. So I'm not sure why we get a sudden drop over here in shell side conditions -- shell side temperature.

DR. BANERJEE: So to RELAP it's buttoned up, too. Right?

PROFESSOR REYES: That's right, yes. So this one we close up that steam generator. We did stop -- At ten minutes into the transient, we do stop feeding the steam generator. So this looks almost like the feedwater came on, but that's not what we did.

MEMBER RANSOM: Well, there was a leak?

PROFESSOR REYES: Or a leak in RELAP. But the experiment -- it just stayed flat, because it was a buttoned up system.

So that -- In terms of what is going on in the steam generator, those are the things that we are still looking at, to try to understand what caused that behavior.

MEMBER RANSOM: There is something inconsistent, though, because you have the steam generator break flow rate.

PROFESSOR REYES: Correct.

MEMBER RANSOM: And you don't show it. That's that strange glitch at 1,000 seconds, and I thought you said it was closed.

DR. BANERJEE: That's a different one.

PROFESSOR REYES: We had a broken steam generator which was --

MEMBER RANSOM: Well, it was the same test, though, I thought, CE-0011.

PROFESSOR REYES: There are two steam generators.

MEMBER RANSOM: Oh, you're talking -- Okay, one steam generator was --

PROFESSOR REYES: Is broken, and the other one is -- Yes. This is the pressure curve for the broken steam generator, and RELAP does follow that. So you would think the temperature would follow the saturation. It's just saturation temperature. So we are looking at that to see what it is that -- why it's different.

Then again, steam generator 2: Intact steam generator. Again, RELAP, for some reason, it just drifted down faster than APEX, and that corresponds to the saturation temperature difference.

Okay. So that's our experience with RELAP for this one case. Now you are going to hear a lot more about RELAP here in ISL's presentation, and I want to point out some other -- talk a little bit about the CFD calculations and some other phenomena.

Something that I noticed is the importance of these model uncertainties in terms of sensitivity to the transport rates. So there's a class of transients that exhibit a significant departure in behavior when you exceed a certain critical setpoint.

So, for example, there's some minimum core mass below which a fuel temperature excursion is going to occur. You drop below that mass, and it's like a switch. You get this excursion.

There is a maximum primary system liquid volume above which the HPSI pumps will rapidly pressurize the system. So these types of transients are somewhat susceptible to the uncertainty in your models, if your transport rates are on a similar -- inputs and outputs are on a similar -- So if you had a code prediction of the outcome of these types of transients, you really have to consider them indeterminant without additional study.

If the sum of the uncertainties in the transport models are on the same order, it has a net difference among the transport rates. I'll give a little explanation of what I mean by that.

Here's a test we ran, 0008. These are the -- This is our break flow. This is a two-inch hot leg break. So this is primary side break flow, and then this is our total HPSI flow.

So here we see the break flow comes down, and it starts to oscillate kind of around the same value as the total HPSI flow. It goes above it and below it and above it and below it. In fact, they are very much on the same order, and eventually the break flow is less than HPSI, and the HPSI can actually recharge that.

Well, the more I looked at that, the more I realized that this would be a very challenging problem to predict for the codes, for the computer codes to have to try to predict this kind of -- you know, which one is higher first. It is also dependent on pressure. The break flow rate is choke flow. So it depends on your choke flow models.

So it seemed to me that, if you had the integrated mass balance in the code that looked something like this, you have initial mass. You've got your inlet mass flow rate with some uncertainty attached to it, minus your outlet mass flow rate with some uncertainty attached to it.

If you assume that these uncertainties typically are small relative to your flow rates, which is normally the case -- it's not necessarily a problem, and for systems with really large HPSIs where you are putting lots of water, well, this may dominate the whole behavior in terms of timing of when you might reach one of your critical setpoints and change the behavior.

We can rewrite this like this. Now the problem occurs is when your inlet flows, your outlet flows, are kind of on the same order. Now your uncertainties can become very important. So the uncertainties become -- will impact the mass predictions, for example, in this case, if your inlet flows minus outflows is on the same order as maybe plus or minutes the sum of your uncertainties here for this particular case.

So an accurate estimate of when or if the system becomes liquid filled and repressurizes is strongly influenced by the magnitudes of the time dependent model uncertainties for this particular case, because your inlets and outlets are on the same order.

So I just -- I thought this was important to point out, especially for designers who are trying to fine tune their designs with the code, and they are limiting maybe HPSI flow to get -- to be the most economic design, you might go to a smaller pump, but you have to be careful in your models. Even if it predicts things are fine, you need to do a very careful mass balance and look and see how well it is predicting for these very low flow rate differences in your transport models.

I just wanted to point that out. Overall, in terms of conclusions, we used the gamma version of the RELAP5. We found that the maximum deviation in primary system pressure was about 10 percent was the maximum, about .25 megaPascals, and that was for a very short portion of the transient, that one section we saw.

Otherwise, the difference was on the order of about one percent. So it was pretty close. The maximum deviation in the well mixed downcomer fluid temperature -- and I'm referring here to the 8D -- was about four percent, and that was at the very end of the transient.

The predictions of the HPSI flow rate, the pressurizer collapsed liquid level, feedwater flow -- those were all in excellent agreement with the data.

The maximum break flow rate we saw was about 289 liters per second, and that was within three percent of the measured value, was 281, and it was really within the uncertainty of our vortex flow meters.

The RELAP5 predicted the break flow would experience a sharp drop at about 980 seconds, and we are not sure what caused that. Possibly, it was the transition from one type of model, choke flow model to a non-choke flow model.

RELAP5 predicted stagnation in the cold legs 2 and 4 as a result of steam generator number 2 becoming a heat source. The time at which the steam generator 2 became a heat source was accurately predicted by RELAP.

Trends in the cold leg flow rates were very similar. The numerical values were in reasonable agreement with the data, with the exception of the data for cold leg number 1 where RELAP overpredicted a bit.

Just as a warning, caution has to be exercised when you are analyzing transients that involve small differences in the transport terms, because the model uncertainties can become important. So the outcome of those transients, you have to be very careful as to whether or not you exceed some critical setpoint or not.

Okay. Any questions on RELAP? You will have opportunities, I guess, to talk about the details of the models with ISL, but I'll jump straight into STAR-CD, again just to give you a little bit of an overview.

We used STAR-CD to -- It's a CFD code that we used to model two stagnant cases. The loops were stagnant, and we just have HPSI injection, test number 5 and number 6.

The code was able to predict, in terms of producing the phenomena, HPSI line backflow. It showed cold leg thermal stratification, cold leg countercurrent flow. It also showed downcomer plume merging with the code. So I was impressed that it could do -- it could capture the phenomena.

We also used it to do a transient main steamline break case, which we hadn't tried before, but we wanted to see how well STAR-CD would do with a transient case. I've got some calculations for that.

Our base model for STAR-CD -- We had 768,784 cells and two million vertices for the fluid domain. The solution of the problem was --

CHAIRMAN WALLIS: Does it matter which problem you were solving?

PROFESSOR REYES: Oh, this is for the stagnant case.

CHAIRMAN WALLIS: That must be for one of them.

PROFESSOR REYES: That's right. This is for the stagnant. So for test number 5 and 6, we used this model. Thank you. You can tell the students -- It was the students who ran these things, and we reviewed it.

You know, in the old days we would talk about your hot rod, you know. So this was run on a parallel on four SUN Fire 240R servers with the SUN Spark III 750 MHz, 64-bit processors and one gigabit of RAM. The students talk about these --

DR. BANERJEE; One gigabyte.

PROFESSOR REYES: I've seen gigabit used in terms of -- which is unusual to me. I always see gigabytes, but recently I saw an advertisement in gigabits, and I don't know what that --

So the fact that we can run these things in parallel certainly speeds things up, but you will see that it took a long time still. So for test number 5, we had a constant time step of .1 seconds. We ran about 2200 seconds of transient. It took 33 days, a long time.

MEMBER RANSOM: Did you do a convergence study to show that that's the right number of cells to use?

PROFESSOR REYES: To actually use? Yeah. No, we would still be doing it.

DR. BANERJEE: Just get another machine.

PROFESSOR REYES: Three and four machines, four parallel machines.

Since we've invested in these machines, of course, there are much faster machines now, and --

DR. BANERJEE: This is very slow.

PROFESSOR REYES: Yes, compared to what is available now. You just wait a year, and everything has changed, and all your money that you invested is in a slow machine. So I understand now NRC is running on PC-based parallel networks and getting some very good speeds with that, a lot less expensive, too.

MEMBER KRESS: So if you used one second, you would have done it in three days?

PROFESSOR REYES: Point-one seconds -- yeah, it takes about 2200 seconds over 33 days.

MEMBER KRESS: Yes, but if you did that one second, 2200 would come in three days.

PROFESSOR REYES: Yes. This is pretty big, yes. These are pretty big models. Like I Mentioned, when we were doing CFD calculations back in the Eighties, the most we ever noded was about 4,000 nodes.

DR. BANERJEE: I remember that Ringhouse was running STAR-CD with 2 million nodes about five years ago.

PROFESSOR REYES: Wow. This is the model that we used for the stagnant conditions. We modeled two cold legs with loop seals and HPSI injection. We modeled the downcomer fluid volume and the downcomer steel, and we modeled the fluid in the core region.

MEMBER RANSOM: Do you know what sort of turbulence model is included in this?

PROFESSOR REYES: Yes. There were six to

two in STAR-CD, and I think it was just the straight K-epsilon type model, the very basic one. In fact, they had looked at running this at laminar and also turbulent, and turbulent ran a lot slower, but they didn't see a lot of difference in the results. So there's a lot of questions we have with regard to the turbulence modeling in this system.

DR. BANERJEE: Well, you probably get a lot of numerical diffusion.

PROFESSOR REYES: With the laminar maybe. It was interesting to see, yes. The one thing that was different is that when they modeled it, they modeled the bend this way instead of that way. So I wanted to point that out.

MEMBER RANSOM: Actually, there is very little difference. One is just the laminar viscosity, and the other one is equivalent viscosity.

PROFESSOR REYES: Maybe that's it. So here we've got this thermal-coupled rake in our cold leg, and again this is for this test number 5. We are just injecting cold HPSI water into the cold leg. There is no natural circulation flow in the loop. It's just a stagnant system.

Here is our -- these four thermal-coupled locations here. The blue -- In this case, the blue here is the calculation, and then the red is the data. So this is the APEX data.

We see, we start off kind of high. I mean, our data is higher than the prediction. Eventually, the prediction and the data do agree. It seems like -- So you can imagine we are injecting -- we are performing the stratified layer inside this cold leg. So these are the temperatures that we are measuring.

It did pretty well at the bottom of the pipe. So it got the lower location in the pipe pretty well, and it did fairly nicely on the second location. So the stratified layer, that elevation -- the change in that location, warm water on top and the cold water on the bottom is where it might have some trouble early on. But it's predicting that this whole region is pretty warm. But eventually, it does match these two pretty well.

CHAIRMAN WALLIS: At the same time it is doing the HPI line, is it mixing the HPI line?

PROFESSOR REYES: Right. That's correct. So it's also -- We've modeled that geometry, and it is also showing backflow in that line.

MEMBER RANSOM: What did you do for boundary conditions where the nodalization ends out of the pipe?

PROFESSOR REYES: Oh, in terms of the flow coming out?

MEMBER RANSOM: Flow or --

PROFESSOR REYES: Yes, we specified -- We do measure those flows. So those are put in as --

MEMBER RANSOM: Boundary conditions.

DR. BANERJEE: But uniform.

PROFESSOR REYES: Correct. Right. That's right.

MEMBER RANSOM: Based on data, I guess. Right?

PROFESSOR REYES: There's no profile. What they have done here is they have kind of taken the STAR-CD data and done some graphical imaging, just to show that it does predict the plume merging behavior. So this is what we see.

We have injection in two of the legs. Eventually -- For the video that they produced, these plumes kind of meander about. Eventually, they merge, and you form one plume.

CHAIRMAN WALLIS: They seem to go a long way, though.

PROFESSOR REYES: Yes, and again in terms of the temperature difference, there's not a big temperature difference between this and the ambient. It is just highlighted that way so you can see the behavior.

We also -- So in terms of what we are seeing with the STAR-CD calculations, it's very promising. It looks like you can -- and I'll show you some more in just a minute. It looks like you can -- The phenomena -- it is predicting the phenomena that exists. How well it predicts the phenomena, I'll show you some more slides here in a minute.

We did one transient case, because we wanted to get some measurements -- We wanted to estimate the temperature profile in the wall and what we might see in terms of heat transfer coefficients inside the wall.

So we used STAR-CD for this main steamline break case, and we used these as our boundary conditions. We had a measurement of the wall heat flux on the outside of the reactor pressure vessel. We had our cold leg flow measurements coming into the cold legs, and we had our cold leg fluid temperatures. So those were the boundary conditions.

Then we gave STAR-CD -- We had it calculate the local -- and in fact, you have to back out the heat transfer coefficients. You have to make some -- You have to define which fluid temperature you are using for the -- to come up with your H.

It could predict the local heat transfer coefficient or the heat flux. It would predict the inside surface temperature and the temperature profile inside the RPV wall, and RPV wall outside temperature. Of course, actually, we did the whole wall profile.

MEMBER RANSOM: The local conductor heat transfer coefficient was based on the vault temperature of it defined by the calculation?

DR. BANERJEE: Well, it does the calculation. So you don't have to put anything.

MEMBER RANSOM: Well, I assume you're not talking about local temperature.

DR. BANERJEE: He took it off the wall, didn't you?

PROFESSOR REYES: That's right.

MEMBER RANSOM: Well, you've got to have a delta T to find the heat transfer coefficient.

PROFESSOR REYES: So in terms of relating what STAR-CD calculates relative to what we conventionally use in terms of heat transfer, you have to pick a fluid temperature. So we did it for both. Now what I'm going to show you is just the heat flux, because I think that gives you a feel for what is going on. So I'll show you that.

MEMBER RANSOM: Oh, you are just going to show the heat flux, not the heat transfer coefficient?

PROFESSOR REYES: Right. And I can show you the delta T across the wall.

Now to run this problem, because it was a transient case, we had transient boundary conditions. They went with a much smaller model, had 41,000 solid cells and 185,000 fluid cells, for a total count of about 200,000 cells.

It did incorporate the stainless steel vessel and the fluid within the downcomer. We used a .25 second time step, and we ran about 4,000 seconds of transient, and that took about 20 days. Again, a smaller model. Actually, we used less computer for that also.

This is what the model looks like. It's a little hard to see here, but basically we have the metal contribution here. We modeled the -- We did include the flow from the two other cold legs that we measured as a boundary condition. It's a little hard to see. But this part here just shows the metal structure of the downcomer.

Okay. So again, we input the cold leg temperatures. We input -- and we had a heat flux at the outside wall, boundary conditions. So we input that.

DR. BANERJEE: You put the measured temperatures.

PROFESSOR REYES: The measured -- not temperature, just the measured -- We have a heat flux meter. So we just used that heat flux measurement at the outside of the reactor vessel wall, and then we asked it to calculate for us the temperature at the outside wall and temperature inside the wall and, actually, a whole profile, and the fluid temperature at that location, at that elevation.

So this shows the -- So the red is the STAR-CD calculation, and the blue is the actual measured data. Here it is predicting the fluid temperature at the location adjacent to where we wanted to get a temperature profile across the wall out to the outside of the reactor pressure vessel.

So it matched that pretty well.

MEMBER RANSOM: Now your thermocouple extends into the fluid. Right?

PROFESSOR REYES: Right, for the fluid temperature. That's right.

MEMBER RANSOM: So are you taking a calculated value at the same distance into mesh?

PROFESSOR REYES: Right. So that was -- compared very well, and I hadn't seen any STAR-CD transient calculations before. So I was pleased that this was predicting so well. But again, we are giving it the heat flux at the outside boundary. So that helps.

We had it predict the outer wall temperature. So now we got a measured temperature on the outside wall. We had STAR-CD predict that. We do some deviation here down at this point. Again, STAR-CD here is the blue. The data is the measured, but in general, we are looking at about a 5 degree K difference down below there.

MEMBER KRESS: Now what goes into that calculation, because you are still giving it the heat flux.

PROFESSOR REYES: We are giving it the heat flux on the outside wall. Outside wall.

MEMBER RANSOM: This is the outer wall.

PROFESSOR REYES: Right. This is just the temperature.

MEMBER KRESS: So you -- I mean, this is just an outside calculation using thermal radiation?

PROFESSOR REYES: Oh, no. No.

MEMBER KRESS: You actually start from the inside?

PROFESSOR REYES: From the inside all the way through, and then we modeled -- We actually modeled the insulation on the outside also. So we've got the insulation modeled. We've got the reactor -- the steel modeled, and then we are just giving it the boundary condition up here saying this is our cold leg temperature and cold leg flow rates, and then this is the heat flux at this location.

MEMBER KRESS: Okay. That's all you gave it.

PROFESSOR REYES: That's all we gave it, and then with time dependent values, and we let it calculate, and this is what it gave us in terms --

DR. BANERJEE: A heat flux is just a heat loss, right?

PROFESSOR REYES: In essence, that's all it is, really. It's a heat loss. But it's a measured one. So it's able to calculate our outer wall temperature pretty well.

MEMBER FORD: In this particular test, you've got a half-inch stainless steel pressure vessel.

PROFESSOR REYES: Correct.

MEMBER FORD: And you are blowing cold

water onto that heated surface, 475, blowing some cold water onto it, and you are calculating the outer wall temperature.

PROFESSOR REYES: The thing about this test is that we do see that the temperatures in the downcomer are fairly uniform in terms of the cooldown, and you've got this big -- On the steam side of the plant, you've got a big blowdown, and we are moving energy from that primary system.

So we are cooling down that primary temperature. And so what you are really seeing on the inside wall is a change in temperature, which is fairly uniform around the whole downcomer. So I think that made this calculation a lot easier to do.

MEMBER FORD: And physically, what is causing the temperature to go up again?

PROFESSOR REYES: And so in this system, we are gradually -- Decay heat is causing the temperature to go back up, and we are repressurizing the system, which is reducing our HPSI flow rate.

MEMBER RANSOM: Correct me if I'm wrong, but the wall temperature is being driven by the fluid temperature.

PROFESSOR REYES: That's right. So what this -- That's really one of the key points, is that the H -- the fact that this predicts so well tells me that it's not too sensitive to H, and then later on we did do some sensitivity to see if the increased H doesn't change the wall temperature much, and it doesn't really.

Okay. There was a question in the final report.

DR. MOODY: Excuse me. So the heat transfer in the wall is in every direction. Right? Across the wall and in the plane of the wall, 3-D?

PROFESSOR REYES: Right. That's right. So they have axial conduction. Now in the final report, and I'm going to show -- because there was interest in the beta, I am going to present this very quickly here, if I can.

This is for the same -- a little hard to see. Let me focus that. There we go. This just shows temperature difference across the wall. So you are going from -- Here you have the positive being from the wall to the fluid. So it goes positive into negative and then back up.

This is looking at three different locations, the 1.3 down to the 8. So this is what STAR-CD is calculating in terms of the delta P across. Then we were able to get the -- It's a small temperature difference. Again, we had a very small thin wall. That's right.

MEMBER RANSOM: I also assume it is -- You said it is well insulated or insulated.

PROFESSOR REYES: Right.

MEMBER RANSOM: So the heat loss is presumably fairly small.

PROFESSOR REYES: It's small.

MEMBER KRESS: What drives those little bumps in there? Is that because you had little bumps in your heat flux?

PROFESSOR REYES: That's right.

MEMBER KRESS: Otherwise, it would be smooth.

PROFESSOR REYES: Right. If we didn't provide it as a boundary, then --

DR. MOODY: If that is a half-inch wall, what kind of time constant is that from inside to out again?

PROFESSOR REYES: It's not very long.

DR. MOODY: We're talking seconds?

PROFESSOR REYES: Seconds, I think. I kind of remember 19 or 20 seconds. It wasn't very long, maybe less.

Since we weren't measuring the inside --

the actual inside wall temperature, we were measuring fluid temperature and we didn't have any thermocouples inside the wall, this is kind of an attempt to do sort of the inverse conduction problem where we know something on the outside, but we want to know what's going on inside.

So this at least gave us a feel for what was going on. These are different distances inside of our wall up to 1.2 centimeters, about half an inch. So initially, we are at high temperature inside the wall, and this is on the outside of the wall. So we've got a very small, like -- This is very small, about half a degree K difference.

Then you can see -- As the transient proceeds you can see the change in the slope here. This temperature drops very quickly. This is about 100 seconds. At 200 seconds we see a little steeper. At 300 seconds, again a bit steeper. But keeping in mind that the inside temperature is changing very quickly. So here we have 451. That was 471. So we got about a four degree delta T.

So this method then allows us at least to get a feel for what the temperature profile is doing inside the wall. It's going from a positive, basically, to a negative and then back to positive again.

So in terms of usefulness, it allowed us to very quickly determine some additional information about our test, which we didn't have before, in terms of measurements. And the fact that we did have measurements in terms of heat flux and wall temperatures and fluid temperatures, and that STAR-CD was able to calculate it for these conditions reasonably well gave us some confidence that this is what is occurring inside the wall.

MEMBER RANSOM: Now one more thing it might be interesting to get out of this data is you do have the heat flux, and you have the delta T between the wall, and you could calculate the bulk temperature from this code.

PROFESSOR REYES: Right.

MEMBER RANSOM: And then put it in conventional heat transfer coefficient terms and see how well that compares with the convective heat transfer coefficients that are being assumed in any of these thermal shock type calculations.

PROFESSOR REYES: That's right. So this technique allows us then to expand not just this test, but there might be other tests that we could use the same model and see if we can balance some of that.

MEMBER KRESS: That data makes it look like you've got pretty good insulation on the inside.

PROFESSOR REYES: We do.

MEMBER KRESS: Because it flattens out.

PROFESSOR REYES: We use a cowsill. It's about -- I think it's about two inches or three inches of the cowsill. It works pretty well.

Okay. So I promised to show that data. Again, copies of these plots are available in the final report. You've got a copy there.

Okay. Then I did want to do some comparisons of the downcomer temperatures using the three different methodologies, REMIX again really being one of the work horses of the earlier methodology that allowed us to go from a system code analysis to more of a local analysis, because at the time the CFD code in terms of calculation time was too expensive.

In fact, I think we had something like over 200 calculations that had to be performed for two-hour transients, and with the CFD code it was very expensive.

So this is just kind of an overview. STAR-CD uses five different types of models for turbulence modeling. It's a 3-D code. You can pretty much -- any geometry that you would like. It doesn't, however, do any boiling or condensation. It does include heat structures.

You can input variable boundary conditions, time dependent boundary conditions, but it is very expensive to run in terms of time and computers.

REMIX was developed, because it was a very simple code, a regional mixing model that would allow us to get an estimate, and typically a conservative estimate, of the downcomer fluid temperatures for a range of conditions. Essentially, it's 1-D. You can input a HPSI flow rate, and the cost of running it was negligible. It would run very, very fast.

It was designed for one particular type of basic configuration, but you could input other models to try to simulate different types of injection angles and things like that.

RELAP5, of course, is a systems code, and what we were using was a 1-D version. There are lots of predefined components. It does do the boiling and condensation. So that was the advantage of that, and you can model the entire plant with relatively little computational expense.

MEMBER RANSOM: What is the lock exchange model for closure on the REMIX?

PROFESSOR REYES: Oh, yes. This was the stability at the interface kind of model. So, basically, we talked about when you would get the onset of thermal stratification in your cold leg. Incorporated into REMIX is essentially a lock exchange model which ties the conditions at the downcomer side of the cold leg to the interface height.

So using that model plus a conservation of mass and energy, you are able to establish the height of that interface and the relative flow.

Okay. So here is comparison data with REMIX, STAR-CD, and RELAP. The dashed line here is RELAP. This solid -- this looks solid -- is REMIX, and then the red is the STAR-CD, and then this black line is the APEX data.

So this is looking at just below the inlet of the cold leg. The 1.3 diameter is down into the cold leg. So we have a fluid thermocouple there. We measure temperature then. In STAR-CD we bring it out about 2200 seconds, matched very well with that data.

DR. BANERJEE: Is that the 2200 second run you were talking about?

PROFESSOR REYES: Right. Correct, way back when.

DR. BANERJEE: Way back when.

PROFESSOR REYES: Thanks. Yes.

DR. BANERJEE: That same boundary conditions for REMIX and STAR-CD or different?

PROFESSOR REYES: Yes. Well, the way the -- The boundary conditions are the same, yes. So we had a constant HPSI injection flow rate. We specified the volumes. And now how you model in each one is different, of course, but we are using the same RELAP5 model that we used for our transient cases.

In STAR-CD we are using the 700,000 node model, and then REMIX is set up for just -- you specify the HPSI flow rates, the volumes of different components, the metal structure. So the inputs are different, but the same geometry.

So RELAP5 initially underpredicts a little bit, and then it kind of overpredicts, and that is what you might expect, if it's really a well mixed model. So it's trying to predict the well mixed temperature, and here we are at 1.3D right at the injection site. So it is going to predict low -- I mean high here.

Over here REMIX did predict a bit -- underpredicts somewhat in terms of the temperature measurements.

Again, looking at the 2-D location, here is RELAP5 predicting a little bit warmer. Here is the STAR-CD. Here is the data here, and then here is -- They all, of course, have the same trends. REMIX is a little bit low, RELAP a little bit high.

Here it's at 4 diameters down. Again, the comparisons are similar. Down to 8 diameters, we see again here STAR-CD is predicting pretty well, and the values are bounded by the RELAP and the REMIX results.

Here are just some numerical values. This is in terms of the change in temperature. So we start off with the fluid at the HPSI location somewhere around 60 degrees Fahrenheit. We wanted to determine the warm-up to give a kind of a good assessment of how much did the STAR-CD warm up the fluid versus the actual measured tests in terms of percent difference.

So STAR-CD at 200 seconds we saw from seven percent to eight percent -- well, excuse me, down to four percent up to about 14 percent difference as the maximum difference at that time. It was closer later on. So we are seeing somewhere on the order of seven to eight percent on the average difference in terms of the warm-up temperature, the delta P from HPSI conditions to the temperature at that location.

Same thing here with REMIX. We see again, not too bad, eight percent, very close. This is a little bit higher, up to 24 percent here and up to about 30 percent. This tended to predict a little bit low.

Then RELAP, again if you actually look at the numerical values and the changes in temperature, they were not -- we are not looking at very big differences in terms of what we are seeing. Now on the scale that I showed you so that you could see the differences, it kind of exaggerated a bit.

What we are seeing is that, if you can predict relative well mixed conditions, the deviation is not too far for this particular design is what it's really saying.

MEMBER RANSOM: And all of the predictions are positive, meaning, I guess, they predicted higher temperatures than were measured in APEX?

PROFESSOR REYES: Well, I think -- yeah, these were just percent -- These are just an absolute value.

MEMBER RANSOM: It's an absolute value?

PROFESSOR REYES: So REMIX, for example, just from the graph you can see, was negative. It was always predicting lower. That was consistent.

MEMBER RANSOM: Okay. These are

absolutes.

PROFESSOR REYES: Yes. I'll have to change that.

MEMBER FORD: Now you are showing there for RELAP a ten percent difference. It's a nonconservative change. It's 128 versus 116, which would predict a lower strain in the metal.

PROFESSOR REYES: Right.

MEMBER FORD: Do you have any feeling as to how much that difference in strain would be? You're saying ten percent is low. My question is --

PROFESSOR REYES: Yes. I don't have a clue.

MEMBER FORD: Use ten percent, I guess?

MR. ROSENTHAL: They are due into February. Hold that question.

PROFESSOR REYES: Right. The idea here is we are leading up to a couple of things. One is, if we come up with an assessment methodology, that might give us better -- a more accurate picture of what is going on. That was really one of the goals of -- at least our goal -- in looking at these calculations.

So one improved methodology might be, well, we still use our systems codes, RELAP5 and TRAC, because at this point we really haven't developed a CFD code that will model the entire plant. It's just too expensive, and again CFD codes don't model the boiling or condensation.

So we keep that component up on top. However, what we did find is that the CFD codes can predict all the essential phenomena which you couldn't predict very well with a simple code like REMIX. For example, REMIX doesn't predict the downcomer-plume interactions, the merging of plumes and that type of behavior.

Loop seal spillover, HPSI backflow, the cold leg temperature gradients, the RPV heat transfer -- these things for single-phase conditions is ideally suited for CFDs. So in terms of an improved methodology, the CFD codes could certainly replace existing REMIX component that we had there, plus a stratification criteria. So we actually have two components, stratification criteria and then a REMIX component.

So this one would replace those two sections and then, of course, we would feed that into the fracture mechanics. So it's not much of a difference in terms of what we are doing with regard to the information flow. It's just how we get that information. I think we are getting a much better picture in terms of phenomena and measurements compared to data. So far we've gotten some very good comparisons.

So this would certainly represent an improvement over what we have been using in the past with the simpler codes.

CHAIRMAN WALLIS: Well, I was wondering. The curves seem to show the STAR-CD does the best, the detailed temperature curves.

PROFESSOR REYES: Right.

CHAIRMAN WALLIS: But when you get to a table of percent differences, it's not clear that STAR-CD is superior to RELAP in terms of percent. Maybe the message depends on how you present it or something. RELAP in that particular example seems to do pretty well, but maybe that's just for that particular run.

PROFESSOR REYES: Right. And this is out to 900 seconds. When this was prepared, we hadn't finished the 2200 seconds. It should be carried all the way out. It gives us a little of a snapshot at a particular set of time.

CHAIRMAN WALLIS: Well, I guess we have to look at how accurate we need to be in order to get the sort of answers we are interested in.

PROFESSOR REYES: Right. If we are looking at tens of degrees or, you know, 20 degrees K, we are well within the range of what this seems to predict. If we are looking at very small differences, again it's much more challenging.

Okay. So overall, the RELAP5 predictions for the main steamline break were in good agreement with the well-mixed downcomer fluid temperatures. It did a reasonable job of predicting the stagnation mechanisms in terms of reverse heat transfer for the main steamline break.

REMIX tended to a be a little -- tended to conservatively underestimate the downcomer fluid temperatures. For some of the trends there has to be some extra work to make sure that the uncertainty in the models doesn't overwhelm the result.

STAR-CD captured all the phenomena, the HPSI line backflow, the cold leg thermal stratification, downcomer plumes merging, and the predictions were we are pretty good agreement with the measured data.

I think the CFD codes offer a significant improvement. So if you really want to know what is going on in a plant, you can certainly model up your

HPSI line or your cold leg and get some good information about what is going on.

DR. BANERJEE: As long as it's single phase.

PROFESSOR REYES: AS long as it's single phase, yes. Two-phase, no guarantees there. I know some --

DR. BANERJEE: There are no guarantees at all.

PROFESSOR REYES: That's right. And I don't know if there are any CFD codes that claim two-phase capability.

MR. ROSENTHAL: They are working on n-phase at Penn State. Come back in a half a dozen years.

PROFESSOR REYES: Half a dozen years, okay.

DR. BANERJEE: I think the problem is not with writing the code. It's what models you put in for three dimensions.

DR. MOODY: Is the situation likely to get better or worse in two-phase?

PROFESSOR REYES: In terms of prediction?

DR. MOODY: Yes. Well, in terms of how hard your are working the metal. In other words, the destructive temperature gradients that are being produced -- would they be better or worse?

PROFESSOR REYES: Well, in terms of what we saw in downcomer thermal stratification, having a saturated liquid up on top and some subcooled on the bottom certainly gives us the biggest gradients, is what we saw. If you translate that to a Palisades plant, saturation temperature is going to be higher than what we see here. So it could be a large gradient, but then they've got a larger length. So maybe the DT-DX is --

DR. MOODY: You are still talking single phase still, though?

PROFESSOR REYES: Correct.

DR. MOODY: Let's see.

PROFESSOR REYES: It could be single-phase steam.

DR. MOODY: Okay. There are states or conditions where you would have bubbly flow or something that would be a -- make it behave any differently?

PROFESSOR REYES: In terms of the downcomer temperatures?

DR. MOODY: Yes.

PROFESSOR REYES: There are some. I know

there is an interest in low flow. In terms of these very thick vessels, if you input into downcomer fluid, the potential may be for saturation. I mean, if you put a lot of energy into this thing and you are close to saturation temperature, possibly you can get saturated conditions in the downcomer, which would certainly change the phenomena quite a bit.

Since our vessel walls are fairly thin, we don't -- we can't drive that type of a condition.

CHAIRMAN WALLIS: I guess you say significant, because they can model things which the other methods cannot model which are actually happening.

PROFESSOR REYES: That's right.

CHAIRMAN WALLIS: But whether it is significant to the actual evaluation of PTS, I'm not quite sure whether you would want to run CFD codes all the time in evaluating PTS or not. You might just want to run them for a check.

PROFESSOR REYES: That's right. Certainly, I think there's methods that can conservatively estimate the cold temperatures. If you use those temperatures, I think you are going to be lower than what you predict. So if you wanted to fine tune that, that's basically what that says, and find out what physical phenomena is going on.

Okay. I think, with that -- I talked quite fast, but it still took an hour.

MR. BESSETTE: One thing you could do is, you know, once you identify your four dominant sequences, if you can choose to, you can go back and further refine your --

CHAIRMAN WALLIS: And ask more detailed questions.

PROFESSOR REYES: That's right. Okay.

MEMBER RANSOM: Well, it would seem like you could get high heat transfer if you get downcomer -- but I imagine that only occurs under depressurized conditions or fairly low pressure. But that certainly is going to produce bigger gradients in the wall, if you ever get into that condition.

CHAIRMAN WALLIS: That would be on the, say, large break LOCA condition where you depressurize everything, and then you pour liquid.

MEMBER RANSOM: Spray water on the wall. Pretty high stress.

DR. BANERJEE: One thing you could do is increase your radial nodes by a factor of eight and your axial nodes by a factor of four, and run -- You've already got it nodalized. So it's trivial to do that, and just run a case and see what happens.

CHAIRMAN WALLIS: This is with RELAP.

DR. BANERJEE: No, no, no, with STAR-CD, because you've got it all nodalized. So it would be a little bit coarser, but who cares, and you can see whether it scales or not. That, actually, would be a very interesting case, and it would take you minimal effort to do it.

DR. MOODY: If it took him 30 days to calculate.

DR. BANERJEE: Oh, that's just because his computers are slow.

DR. MOODY: I know. I know. Maybe I missed something. I probably did half a lap behind. How did you get heat transfer between the fluid and the wall? You specify a heat transfer coefficient?

PROFESSOR REYES: No. Actually, the CFD codes will actually -- What they do is they have the law of the wall, which allows them to essentially predict what the temperature gradients would be through the wall.

If you want to convert that information then into an H, which we are accustomed to, a standard heat -- to compare to a heat transfer correlation, you can back that out. So you can take the temperature of the fluid node adjacent to the wall, if you want to do it that way, and have a delta T and predict an H, or you come up with a bulk fluid temperature and the wall temperature, then back out an H. So just for purposes of comparison.

MEMBER RANSOM: You are saying STAR-CD uses the law of the wall formulation to obtain the heat transfer coefficient.

DR. BANERJEE: It's more complicated than that. They use damping functions. It amounts to that.

CHAIRMAN WALLIS: Okay. Anything else to present? Thank you very much. That was very, very interesting.

PROFESSOR REYES: You're very welcome.

CHAIRMAN WALLIS: I think we might move on and get started on the next presentation and then have a break maybe half an hour or something where we've got into it.

DR. BANERJEE: Let me have one last question. Are you boundary conditions sort of scaling, too, in terms of pressures? Is there any scaling associated with that?

PROFESSOR REYES: The flow rates? The cold leg flow rates, the HPSI flow rates, they are all scaled.

CHAIRMAN WALLIS: Now we have another marathon presentation, 62 transparencies.

MR. PRELEWICZ: And I'm not going to be able to speak as fast as Jose.

CHAIRMAN WALLIS: I don't think there is any way that NRC employees could get through at this speed. Seems to me something academics can manage. Jose is used to getting through whatever he has to get through in the time of a lecture.

Okay, come back to serious matters. When it makes sense to break, we'd like to break, but I don't think we need to break quite yet.

MR. PRELEWICZ: We usually start with the credits at the end of the movie, but there were quite a number of people involved in this effort. So I would like to acknowledge them at this point.

Dave Bessette and Gene Rhee from the NRC made a lot of contributions. I've listed the ISL people. We also had a couple of subcontractors, Applied Analysis Corporation and ITS Corporation, which did some of the RELAP assessments.

MR. BOEHNERT: Would you identify yourself, sir?

MR. PRELEWICZ: Oh, I'm Dan Prelewicz.

Our objective is to establish the applicability of RELAP5 for PTS analysis. That is the primary objective. Also when we started, we wanted to make maximum use of available experimental data and RELAP5 input data, and also demonstrate limitations of RELAP5 and how those would be handled.

Major points to be made: First of all, the PTS significance involved relatively rapid energy removal from the primary system, and again we have talked about some of these things, the loss of high energy coolant through the break or the valve, excessive heat removal by the secondary or injection of low temperature coolant.

Basically, RELAP5 is used to perform energy balance and the pressurization analysis. Then important parameters: Primarily, the downcomer temperature; downcomer pressure; and of course, the heat transfer coefficient, of less significance, because as we stated a couple of times, basically the problem is conduction limited in the vessel wall.

We would like to show that some phenomena, the ones that RELAP5 can model, are modeled in a reasonable manner, for example, loop flow stagnation, some phenomena which cannot be measured by the one-dimensional code, for example, cold leg thermal stratification, have a minimal effect on the result.

Again, continuing on the major points: Many events have single phase flow in the primary loops throughout the event. So complex, two-phase flow phenomena do not play a role. We also will show that there was some behavior that was predicted to be unphysical -- for example, cold leg recirculating flows within two by four plants, in one cold leg and out the other on the same side; and also some unrealistic physical recirculating flows in the downcomer, and talk about what steps were taken or how we addressed those in the PTS analysis.

CHAIRMAN WALLIS: You had to selectively disable the momentum flux model. That's interesting.

MR. PRELEWICZ: Yes, we selectively disabled the momentum flux model.

CHAIRMAN WALLIS: So if you didn't get the momentum flux right, you could get into trouble.

MR. PRELEWICZ: That's correct. That's why you have to look very carefully at the results to make sure that they are physically realistic.

DR. BANERJEE: What does selectively mean here? Wherever there were problems, you disabled it?

MR. PRELEWICZ: Well, we found, for example, the place that gave us trouble was the bottom of the downcomer where the downcomer connects to the lower plenum.

CHAIRMAN WALLIS: We discussed that the other day, and we felt it was a little bit hokey down there, too.

MR. PRELEWICZ: When you divide it up into six, the six connecting to one gives the formulation of momentum flux, which is based on a nodal average velocity, which is very difficult to define for these codes, it gives it a problem. So we turned it off at that location, and we will see, we got good comparisons to the test data.

MEMBER RANSOM: When you say you turned it off, you mean at the juncture of the nodes connecting to the plenum?

MR. PRELEWICZ: That's correct.

MEMBER RANSOM: So both the in and the out would be disabled?

MR. PRELEWICZ: If you're talking about in being at the cold leg, no, that was not --

MEMBER RANSOM: Well, no, I didn't mean it that way. I meant that, if you look at the junction, you presumably have a gradient or a divergence of the momentum or velocity, and so that's just disabled.

MR. PRELEWICZ; Yes.

CHAIRMAN WALLIS: Do you have a coefficient that multiplies some V-squared terms or something, and you just make that coefficient zero. Is that what happens?

MR. PRELEWICZ: Again, I'm not familiar with the innards of the code, but there's a switch that lets you turn off momentum flux. So I assume it just takes -- It does not use that term when it is solving the momentum equation. That's what I believe it does.

DR. MOODY: Does this relate to your momentum questions last month?

CHAIRMAN WALLIS: Well, I'm sure, very much so, that L-shaped strange control volume we were talking about.

MR. PRELEWICZ: Other points to be made: The modeling practices that were followed were consistent with past experience. For example, we drew considerably on the extensive amount of work that was done for AP600, and later Don Fletcher will present some of the relevant AP600 -- APEX AP600 results.

Also, consistency was maintained between the plant analysis and the assessments against experimental data in terms of modeling options and modeling philosophy, and as we will see, comparisons of RELAP5 predictions against experimental data from integral tests are in reasonable agreement for PTS significant parameters.

Our conclusion that we will try to get you to is that RELAP5 is applicable for a PTS analysis. What we are not going to address is uncertainty. That is the subject that will be covered later. However, I understand that this will be an input to it.

ISL has been running both the PTS analysis cases and the assessment, and we'll turn these decks over to the University of Maryland and, as they are with the PTS cases, they do sensitivity studies by changing parameters and using that as input to the uncertainty analysis.

So what we will be talking about today is the setting up of those decks, the running of the transients, and the comparing to data, but not the uncertainty analysis.

CHAIRMAN WALLIS: So your nodalization is about like what Jose showed, is it?

MR. PRELEWICZ: I don't -- Again, I don't think that was quite an honest diagram, but I'm not sure. I don't know that, when you came to a component like a pipe, you showed the nodes in each pipe? Looked like you just showed the component.

CHAIRMAN WALLIS: Oh, there were nodes in the hot leg.

DR. BANERJEE: But they were just numbered. I remember that number 356 or something was for the whole hot leg, and then his lower plenum was very -- was just like --

CHAIRMAN WALLIS: One big box.

DR. BANERJEE: Well, yes, it was one horizontal box or maybe more, and then with pipes going in and one pipe coming out in the middle. Did he sort of disconnect, Jose, momentum flux as well or did you leave it on?

PROFESSOR REYES: No, we didn't.

DR. BANERJEE: Oh, okay. So you didn't have to disconnect anything?

PROFESSOR REYES: That's correct. We didn't -- We ran with the original model that we had. We didn't disconnect anything.

DR. BANERJEE: So why did you have to disconnect it then?

MR. PRELEWICZ: Well, we found that -- Again, it's transient dependent, and it's mostly when you get two-phase flows in the downcomer. Isn't that right? If you get two-phase flow -- in single phase, it seems to do reasonably well. When you get the two-phase flows in the downcomer, it give it a real problem.

I think the ones you were doing probably at that point in the downcomer were pretty much single phase.

PROFESSOR REYES: Right.

MR. PRELEWICZ: So that's probably the difference.

MEMBER RANSOM: Well, the other thing you mentioned is the more connections you have to a single volume, the more questionable the modeling becomes.

DR. BANERJEE: So does this involve a lot of judgment on the part of the user, and during the transient you turn these things on and off?

MR. PRELEWICZ: No. We don't turn them on and off during the transient. What we do do is we make a run, and we look at the results to make sure they are physically realistic. If they are not, then we make adjustments to make sure that they are believable and physically realistic.

DR. BANERJEE: How do you know they are physically realistic?

MR. PRELEWICZ: Well, if you have the downcomer flows which are on almost the order of magnitude of the full flow circulating down out of some of the six azimuthal segments and up the others, circulating around in these patterns without any driving force, we don't have a perpetual motion machine. Something has to drive it.

In this case, it's a numerical problem that is driving it. So it is unrealistic. So we know that that cannot happen.

CHAIRMAN WALLIS: I think, as opposed to feedback, you shall make an error in the momentum flux, and it gives you more momentum which then gives you momentum flux.

MR. PRELEWICZ: Our code developers tell us that that is what the problem is. It's an instability which feeds on itself. Once it gets started, it feeds on itself and builds up a recirculating flow, which eventually gets limited by friction.

CHAIRMAN WALLIS: Momentum flux terms behaving like a pump.

MR. PRELEWICZ: That's exactly right. It's behaving like a pump. And again, it happens at the low flow, generally in two-phase when the momentum flux term becomes more significant compared to the other driving forces.

DR. BANERJEE: Is there sort of a rulebook which tells people where to turn it off and where not?

MR. PRELEWICZ: Well, that is going into the user guidelines of what we have learned on this. This is not the first time this has reared its head as a problem. It was a problem for AP600. There it had to be turned off in the whole downcomer for all those cross-flow junctions, and eventually the code developers fixed the problem, and it didn't have to be turned off after they fixed the problem. However, we notice in this case that at the bottom where you connect the six to one, it's still caused a problem.

DR. BANERJEE: So when you say it can be used for PTS, you mean it can be used for PTS if you turn things off selectively and ordered in a certain way and so on?

MR. PRELEWICZ: If you have an experienced user who looks at the answer and sees what he is getting and makes sure it's realistic.

DR. BANERJEE: But now suppose the answer looks realistic. How do you know it's right?

MR. PRELEWICZ: Well, we're going to see some comparisons to the integral test data which shows that these parameters, like the downcomer fluid temperature, the pressure in the wall -- well, we don't do much with heat transfer coefficient, but the other two are reasonable well predicted.

CHAIRMAN WALLIS: It would be more reassuring if you could make different assumptions about this momentum term, and you still converge to the same answer. It would be more reassuring, and you wouldn't have to use all this judgment about whether or not to switch it on and off.

MR. PRELEWICZ: Well, that's true, although there certainly were some cases where we turned it on and off everywhere, and it made very little difference for single phase cases. As we were examining this problem, that is one of the things we did. It sort of was accidental. We were having some code failures, and we thought it was momentum flux causing this problem. So we turned off momentum flux, and it didn't change the results at all for these single phase problems.

DR. BANERJEE: Well, for single phase it wouldn't probably, because there is no acceleration term almost.

MR. PRELEWICZ: Well, there is when you have an area change, but if you go around the loop, it doesn't change the loop pressure jump. It just shifts the distribution a bit.

DR. BANERJEE: Well, what happens through an area change. Does your pressure rise if the area increases or not?

MR. PRELEWICZ: If the area increases --

DR. BANERJEE: Yes. Suppose I'm going from --

MR. PRELEWICZ: -- the pressure will go you. You will recover your dynamic head.

DR. BANERJEE: Right. Does it do that without these terms?

MR. PRELEWICZ: Yes. In fact, that's why you don't turn it off where the cold leg connects to the vessel, because you do recover some pressure when you go from the small cold leg into the larger downcomer.

MEMBER RANSOM: Let me make a couple of comments there. I think, in answer to your question, yes, it does, if you assume a smooth area variation. I'm talking strictly one-dimensional now. It does have a capability of modeling an abrupt area change, an abrupt area change where you do not recover the pressure. It's a Bourda-Carnot type model, and it --

DR. BANERJEE: But you need a momentum flux term for that. Right?

MEMBER RANSOM: Yes, and the other comment I was going to make is -- correct me if you want --

that these problems have arisen pretty much in the attempts to extend the 1D modeling to multi-dimensional phenomena like the downcomer, then multiple connections.

Because of the way the momentum flux is approximated, some of these recirculation problems develop, and the correct way to do that, of course, is go to a correct 3-D or multi-dimensional --

DR. BANERJEE: Well, the only issue I have is not with -- is with the previous slide where his objective, he states, is to show that RELAP5 can be applicable for PTS analysis. Since most of the interesting areas there are multi-dimensional, I don't see how you can say that with all honesty. I mean, just because it agrees with some data taken somewhere, is that the reason or is there some reason actually to believe that this code can capture multi-dimensional effects or are you going to argue that multi-dimensional effects are not important? Which of the three?

MR. PRELEWICZ: Well, it's probably the latter, because we put in --

DR. BANERJEE: Well, Jose Reyes just showed us whether they were important. He spent most of his presentation talking about multi-dimensional effects.

MEMBER RANSOM: Who was that?

DR. BANERJEE: Jose.

MEMBER RANSOM: Hose? But yet he compared it to a 1-D model.

CHAIRMAN WALLIS: That's surprising. RELAP seems to do quite well anyway.

MEMBER RANSOM: Which seems to be some evidence that really --

DR. BANERJEE: All this suckback and this into the HPI line or whatever was unimportant?

MR. PRELEWICZ: Well, that local phenomenon takes place quite a ways from where --

DR. BANERJEE: Yes, but it's because of that local phenomena that the effect is small. If, in fact, there was no mixing in the cold leg or in the HPI line, you would get a hell of a lot of temperature difference between the plume and the surrounding fluid.

MEMBER KRESS: I'm not so sure that's true now, because as Dave mentioned earlier, if your temperature difference is bigger going in, you get a bigger driving force for mixing.

DR. BANERJEE: For what Dave said, that's right, but the case hasn't been proven.

MEMBER KRESS: Oh, yes. That hasn't really been proven.

CHAIRMAN WALLIS: Doesn't that mix them anyway? Doesn't RELAP mix them when the HPI comes in, and it mixes?

MR. PRELEWICZ: RELAP, being a one-dimensional code, has a mixing -- type of mixing.

CHAIRMAN WALLIS: So you're lucky that there are physical phenomena there.

MR. PRELEWICZ: I guess you could say we are getting the right answer for the wrong reason or we are representing the mixing in a very simplistic way. We are doing it in a mixing cup fashion, even though the mechanisms are, as Jose showed, quite complex.

MEMBER KRESS: Well, I would hate to think that's the case, because as Sanjoy said, all of the plants may not have the same injection geometry; and if the real phenomena is occurring back there in the injection line and not really due to the mixing in the downcomer, then you may have problems showing your -- proving your case for other reactor systems.

We just don't like compensating errors is the thing.

MR. BESSETTE: Seems to me, I think what

Jose showed is that with injection geometry, we understand the local mixing, where it is occurring and why, and I think we showed that there's so much mixing in the injection line in the cold leg that the downcomer temperatures are fairly uniform, which is what RELAP says as well for different reasons, is RELAP has no other choice. But then there's a question of the other geometries.

We know that Westinghouse and CE have a fairly similar situation in terms of the injection velocities, the mixing that you might expect in the injection line. We know B&W is different. B&W comes in at a high velocity, but then you have this mixing region that occurs at the injection location, this high mixing region at the injection location, which we could show that you will end up with the same situation by the time you get to the downcomer.

CHAIRMAN WALLIS: What will you do with Beaver Valley or Oconee -- or maybe not Oconee anymore. Are you going to run STAR-CD in order to show that you get enough mixing or are you going to run new experiments or what?

He said on the Palisades numerical and experimental results. So --

MR. BESSETTE: Yes. He said Palisades.

CHAIRMAN WALLIS: How about these other geometries? How are you going to do -- assess them? You can't just talk about them. You have to make a calculation of some sort.

DR. MOODY: While they are thinking about it, Dan, I think you've done everybody's tune by putting those two statements on one slide here, that you selectively take out momentum terms and that RELAP is applicable.

MR. PRELEWICZ: Just one comment on what they are talking about. The lower injection flow probably would be expected to mix less than the high injection flow.

CHAIRMAN WALLIS: I don't want a qualitative argument. Are they going to analyze it numerically or are they going to do experiments?

MR. PRELEWICZ: That's a question I can't answer. They got the budget to do that.

DR. BANERJEE: Well, one suggestion that I made to Jose was to run the case for the full scale, which you can easily do with CFC. If you preserve the same type of phenomenon on that scale, then at least we believe that your experiment is properly scaled in some way, at least if you don't know it for sure, but you have some supporting evidence.

So that would probably be the least difficult thing to do immediately to show the effect of scale. Now the effect of geometry probably is a little bit more difficult, because even if you go the CFD route, you would have to renodalize and look at two or three representative plants, and that may or may not be easy to do. I don't know.

MEMBER KRESS: But that's a lot easier to do than experiments.

DR. BANERJEE: But then it would at least indicate --

MEMBER KRESS: It would sure go a long way for me to answer the question.

DR. BANERJEE: Right. Now this sort of last conclusion there in the light of what we have seen, I think, is too -- if you have your previous slide, please. I think this is just too sweeping a statement to make when you take out momentum flux and have no multi-dimensional effects, where experiments are showing multi-dimensional effects.

You may say that it gives the wrong -- the right answer in some cases for the wrong reasons, but this is not very satisfying.

CHAIRMAN WALLIS: I think we need to hear all the rest of the presentation, then come back to this conclusion and say, you know, is it really applicable. Maybe we should move along here.

DR. BANERJEE: Take it off that slide.

CHAIRMAN WALLIS: Otherwise, we are going to have to break, and I'll just stop this conversation.

MR. PRELEWICZ: Here we go. The three phenomena we looked at were natural circulation flow and flow stagnation, integral system response, and of course, pressurization itself, which is a primary figure of merit.

Other phenomena influenced the main phenomena -- for example, critical flow -- but they are secondary effects. For example, critical flow, we run whole break spectrum. So we cover all of the break areas.

There are a number of phenomena that RELAP5 cannot predict -- for example, reflux condensation, mixing and stratification in the cold leg, downcomer plumes and dissipation. Assessments were performed where these phenomena were known to occur to establish the impact on the RELAP5 PT calculation results.

So some of the cases we look at --

CHAIRMAN WALLIS: So you are going to show us the things that RELAP can't do don't matter. Is that what you are going to show us?

MR. PRELEWICZ: Again, the PTS -- the significant events, we kind of covered that already; primary side valves open and recloses later with operator failure to control the HPSI flow; primary side breach in which the HPSI flow cannot compensate for the break flow; the small primary side breach, the HPSI can compensate; plus some other failures, and then multiple system failure and large secondary side depressurization.

We've got some examples of the first four, and I think Sergei -- or Jose has already covered the large secondary side depressurization.

Again, maximum use was made of existing experimental data. We used existing RELAP developmental assessment cases. Again, the NRC identified cases to be run, 19 or so different assessment cases, from Marviken for critical flow, MIT pressurizer, Semiscale for natural circulation, Upper Plenum Test Facility for downcomer condensation, then relevant -- these were all analyzed on the kind of separate effects phenomena basis -- and then relevant integral test data from MIST, which is a B&W type Semiscale at a B&W design; a LOFT, ROSA-IV, and also some relevant AP600 facility data from APEX and ROSA.

CHAIRMAN WALLIS: A lot of these are not anything like the APEX integral test facility. They are just checking out certain details of RELAP5. Marviken didn't look at PTS at all. It just looked at critical flow.

MR. PRELEWICZ: That's right. The first bullet is kind of things we looked at for separate effects for different phenomena. The others are integral tests, and including -- We also analyzed APEX-CE-13, which is one of the tests that Jose mentioned earlier.

We started out with the Marviken experiments for critical flow. We analyzed two cases, run 22 and 24. Henry-Fauske Critical Flow model which is a default model was used, and it was also used for all the PTS cases.

This is a description which you may be familiar with Marviken already, but it's basically -- one of the reasons we selected it is it is full scale, unlike many of the other tests which are at some smaller scale.

CHAIRMAN WALLIS: Now two-phase critical flow is an example of a scale dependent situation. If you go to a big scale, then you have a longer time for the fluid to go through. It comes to equilibrium more readily. It's a small scale. Things happen over a very short distance and so on.

So I'm not quite sure how this is taken care of by Henry-Fauske. I don't think they have an equilibration model.

MR. PRELEWICZ: One of the parameters is a nonequilibrium parameter, and I believe that does try to account for it.

CHAIRMAN WALLIS: Pressure count for scale?

DR. BANERJEE: It's an L-by-D ratio.

CHAIRMAN WALLIS: It's not a scale then. If it's L over D, it doesn't scale. Anyway --

MR. PRELEWICZ: Well, we will see what the comparison shows. And again, as we have said, a large number of whole break spectrum was run, which makes the precise value calculated by the critical flow model of less significance to the overall conclusion.

This is just a schematic of the facility, just a large vessel, blowdown from the bottom through a discharge pipe and a test nozzle with different size orifices. This is a schematic of a RELAP5 model. This is just a string of one-dimensional nodes. Then there was an initial temperature profile, subcooled liquid with a vapor on top, superheated vapor on top.

CHAIRMAN WALLIS: Everything worked out pretty well.

MR. PRELEWICZ: Well, we're a little bit off. There's an initial drop, and then a recovery, initial flashing, a little bit low pressure recovery after the initial drop. But otherwise, for test 22 this is the pressure response.

The next slide shows the mass flow rate, measured at the break, and again comparison is quite good.

CHAIRMAN WALLIS: The thing that ends in gamma is the prediction.

MR. PRELEWICZ: Pardon?

CHAIRMAN WALLIS: The thing that ends in gamma is the prediction.

MR. PRELEWICZ: That's the prediction, right. And the dashed line is data.

This is test 24. It's not quite as good, but again you can see it followed the pressure, and it gets away from the subcooled, timing isn't much different between RELAP and the test data.

This is one that kind of goes in the other extreme. Marviken was full scale. We were asked to analyze the MIT pressurization data. This is a very small scale. So it has some problems associated with small scale testing.

Basically, it was an insurge under quiescent conditions into a pressurizer. Water was injected into the bottom, and basically pushed the steam up and caused the pressure to rise.

CHAIRMAN WALLIS: There's very little mixing. You have sort of a piston compression.

MR. PRELEWICZ: That's right, basically a piston, and RELAP -- We will see several times, RELAP does tend to overpredict condensation. It turns out in this facility environmental heat loss is a fairly significant factor.

Let's see. RELAP kind of underpredicts the repressurization. This is -- The up part of the curve is when you are putting the water into the pressurizer. Then, of course, as you stop putting it in, the pressure decays fairly rapidly through the environmental heat losses.

In fact, without the environmental heat losses, RELAP5 just about overpredicts by the amount it underpredicts here. So something that is rather hard to measure, the environmental heat losses play a relatively significant role in this, because it's such a small facility.

Again, this is probably the worst pressure prediction we got, and we will see that in the tests we actually do quite a bit better.

CHAIRMAN WALLIS: This is almost a hand calculation. It's just a piston compressing some steam.

MR. PRELEWICZ: Well, except you got to account for the heat losses.

CHAIRMAN WALLIS: That's right.

MR. PRELEWICZ: The next one we looked at was Semiscale Mod-2A. Again, you are probably familiar with this. It's a scaled model of a four-loop PWR, 1/1705 scaling. These are, again, Semiscale. Most of the tests run were integral tests. What we looked at in this case was separate effects tests on natural circulation flow.

In this case, the facility was run in a single loop configuration. The intact loop pump was replaced with a spool piece that contained an orifice simulating a locked rotor pump, and the vessel was modified from a normal configuration in that they wanted to eliminate the stagnated region in the upper head. So they basically replaced it with a cap. So there wasn't an isolated hot -- a region in the upper head to be at a different temperature.

CHAIRMAN WALLIS: Water packing or something like that?

MR. PRELEWICZ: Well, I think what they didn't want is -- They wanted all the fluid to be able to circulate through the loop, and they didn't want to be picking up as it flowed either cold or not fluid out of that upper head.

Anyway, this is a schematic of the configuration that was used for single loop. Again, this is the nodalization diagram, and you can see it's fairly detailed like the one that Jose showed, and we have eight nodes -- well, actually, nine nodes up and nine nodes down in the steam generator.

CHAIRMAN WALLIS: Lower plenum still has just an in and an out. I guess it has two volumes down there.

MR. PRELEWICZ: There are two volumes in the lower plenum, yes. And again, the downcomer in this case is no multi-dimensional modeling. It's all one-dimensional downcomer.

In semi-scale test S-NC-2, which is the first one we looked at, they examined single phase, two-phase, and reflux steady state modes as a function of the primary system mass, and what was measured was the loop flow as a function of the primary system mass, and there was reflux boiling occurring at the low values of the total primary system mass. RELAP was not capable of predicting that. Instead, it goes through an oscillatory flow and predicts an oscillatory flow in the hot leg.

CHAIRMAN WALLIS: So you are assessing RELAP. What does this have to do with the PTS phenomena? Are there particular phenomena --

MR. PRELEWICZ: Well, natural circulation, the magnitude of natural circulation flow.

CHAIRMAN WALLIS: It's important to predict that right. So you've got to check it against something which looks something like the PTS situation.

MR. PRELEWICZ: Right.

CHAIRMAN WALLIS: Okay.

DR. BANERJEE: And the draining, I guess.

MEMBER RANSOM: Dan, those nodalizations, did you just take those over or are they standard nodalizations?

MR. PRELEWICZ: That was the standard nodalization for semi-scale. That's correct. We did not redevelop a semi-scale deck for this application.

DR. BANERJEE: So for the refluxing test, if I recall there was a core level depression in semi-scale due to the holdup in the steam generator. Did you see that in RELAP, too?

MR. PRELEWICZ: We didn't look that carefully at what was in the core depression. We looked at the magnitude of --

DR. BANERJEE: A lot of liquid got held up in the steam generator.

MR. BESSETTE: Yes. You are referring to a different test than this one.

DR. BANERJEE: Well, was it a different one?

MR. BESSETTE: That was like about a four or five-inch cold leg break regular integral test where you go through a liquid level depression in the core before the loop seal clears.

DR. BANERJEE: Right. That was a different test?

MR. BESSETTE: It's a different test.

DR. BANERJEE: That would be a good test to take a look at, because -- I mean, reflux condensation presumably is important for small breaks.

MR. BESSETTE: Well, yes. So the liquid -- The liquid holdup is part of that phenomena, but -- So it's -- That kind of phenomenon occurs in like a four to six-inch cold leg break.

MR. PRELEWICZ: If I'm not correct, Don, isn't some of this in the ROSA? I think we are going to see some of this.

DR. BANERJEE: You probably would see the same in ROSA.

MR. PRELEWICZ: Yes. We ran the same tests in ROSA after we saw that --

MR. BESSETTE: It shows that RELAP holds up more than what is in --

MR. PRELEWICZ: Yes. so when we saw this happened in semi-scale, we then turned to ROSA and had them run the same test.

MR. BANERJEE: We'll see it then?

MR. PRELEWICZ: But we will see that in Don's presentation.

Anyway, this is the result. They started with a full system, and then ran until they got a steady state, measured the flow, then decreased the inventory in steps, waited until another steady state was achieved, and basically you can see here that RELAP produces in some -- again, the circles are the RELAP5 gamma version -- reproduces the trend fairly well. Again, these lower points here are the refluxing mode.

Test NC-3 was a similar test but instead of varying the primary system mass, they varied the secondary system inventory and determined the natural circulation flow rate as a function, actually, of the steam generator heat transfer area.

Again, this is less important than the other one, since in many of the transients -- this is the -- Again, we start out with a large heat transfer area and then decrease the secondary system inventory. You can see, at the lower values of the steam generator heat transfer area RELAP does not do a real good job of predicting the natural circulation flow. But nevertheless, it produces the trend reasonably well.

CHAIRMAN WALLIS: Now I think this might be a good place to take a break. I just want to check with you. You are going to hand over to Don. Is that what you are going to do?

MR. PRELEWICZ: When we get -- Don is going to do the ROSA.

CHAIRMAN WALLIS: He's not going to add more transparencies to our stack, is he?

MR. PRELEWICZ: No. All the transparencies are in the stack that you have.

CHAIRMAN WALLIS: So we have hope of

finishing at a reasonable time.

MR. PRELEWICZ: Yes. Actually, I think this is the last separate effects test. Maybe I could just do this one, and then we can break between the separate effects and the integral effects. Is that okay?

CHAIRMAN WALLIS: Sure, that's fine.

MR. PRELEWICZ: Okay. Upper Plenum Test Facility, UPTF -- again, one advantage is full scale for loop 1300 megawatt PWR with four full scale hot legs and cold legs.

Basically, in this test -- Again, none of these tests were really intended for PTS. The reason this was put into the matrix of tests for PTS is that we know that RELAP has some problems with predicting condensation on steam. In fact, it tends to overpredict the condensation. So this was put in to examine the behavior of condensation in the downcomer.

This is a schematic of the test facility. It actually was set up for test 6, and basically what they did was inject steam into the top of the core and into the steam generators, and then injected cold water into the cold legs. So there was steam coming up the downcomer and back from the steam generators at the same time there was injection flow into the cold legs.

The test we ran was Run 131 where the steam injected was superheated 400 degrees F, and ECCS was injected from the accumulators in the three intact loops, and it was again slightly subcooled, 246 F. At the pressure that it was run, the saturation is 263 F. So it was only --

CHAIRMAN WALLIS: It's awfully warm for an accumulator.

MR. PRELEWICZ: Slightly, yes.

CHAIRMAN WALLIS: Accumulators are normally 100 degrees.

MR. PRELEWICZ: Right. So it was only slightly subcooled. Again, in this case RELAP is fairly close to the data, but it is in the direction you would expect. It does, as expected, somewhat overpredict the condensation or somewhat lower pressure, but the downcomer penetration is fairly reasonable.

CHAIRMAN WALLIS: The RELAP prediction -- it's not a CCFL type thing.

MR. PRELEWICZ: This is a RELAP prediction of the penetration of flow into the injected ECCS as it filled the lower plenum. And again, we are a little bit low on the pressure, but that's not unexpected, because RELAP, as we would expect, condenses a little bit more -- or condenses the steam a little bit more rapidly, not unexpected.

Again, this is the refilling of the lower plenum, and the suspicion was that there's something wrong with the data here, because they give a time when it starts to fill up, which is right about here. So I think this jump-up is just a problem with the data.

So if you shifted everything up, RELAP would do even better at predicting the flow into the downcomer.

So with that, we are transitioning from separate effects to integral tests, and maybe this is a better time to take a break.

CHAIRMAN WALLIS: So we will take a break now then. Take a break until five minutes past three.

(Whereupon, the foregoing matter went off the record at 2:50 p.m. and went back on the record at 3:08 p.m.)

CHAIRMAN WALLIS: Let's come back into session.

MR. PRELEWICZ: We did a number of assessments against integral test facility data. the first plant that was done was Oconee, a B&W plant, and

MIST is the facility that models an integral test for B&W type plants. I won't go through all the details.

Basically, it's power-volume scaled. In this case, the power and the volume are scaled slightly differently, a power scaling of 817 and the volume scaling of 820 on the primary system. Next slide.

This is a schematic of this test facility, and the one point of interest is that they have an external downcomer. So it's not an annulus, although at the top of the annulus they have a rod so that the flow coming in from the four cold legs doesn't directly interact. It hits the rod first and then goes down. But later in the bottom part of the downcomer, it's just an open pipe.

Again, they also have the vent valves which, in a normal plant, are kind of check valves. In this plant, they have them controlled. They are basically motor valves that they control based on some measured pressures. Those were active in this simulation. Next slide.

This is looking down -- another view of the facility looking down from the top, and here you can see again that external downcomer, which is again one of the unprototypicalities with this test for PTS where we are interested in downcomer behavior, and this is a side view showing the candy canes and steam generators. Next slide.

This is actually half of the nodalization diagram. It shows one of the two sides with a single downcomer and the two cold legs with two pumps. They refer to them as the A-loop and the B-loop, and you again you can see that fairly detailed nodalization.

The HPI injects into the cold legs, and both the core flood tank or the accumulator and the low pressure injection inject into the top. Next slide.

We looked at three cases for the assessment, selected because they were kind of typical of transients that we are analyzing for pressurized thermal shock. The first one is a feed and bleed case which is similar to a pressurizer core stuck open PTS event, and then two cold leg break LOCAs, a 10 square centimeter break and a 100 square centimeter break. They are equivalent to a 1.4 inch break in the plant and a 4.4 inch break. So it's kind of a smaller cold leg break and then more toward intermediate size. Next slide.

CHAIRMAN WALLIS: I thought Jose wasn't looking at cold leg breaks at all.

MR. PRELEWICZ: I think in the risk significance, the cold leg breaks do play some role. Right?

CHAIRMAN WALLIS: For PTS?

MR. PRELEWICZ: For PTS, right.

MR. BESSETTE: Yes. They are of less significance than the hot leg breaks. One of the difficulties is, if you go back to our experimental database, we ran mostly cold leg breaks and not hot leg breaks.

MR. PRELEWICZ: We do have some hot leg breaks for ROSA. So we are not without hot leg breaks.

In any event, the first test we looked at was the feed and bleed test where we are feeding in through the HPI and out through the PORV, and again initial conditions of the facility was operating with full pump flow and ten percent scale power. Transient was initiated by stopping the aux feedwater pumps, isolating the steam generators until the PORV -- that is, removing the heat sink, and then they pressurized and the PORV popped open, and when the PORV popped open, at a little later time the HPI was turned on.

Again, key parameters we're looking at are the pressure and the downcomer temperature, which we will see were predicted well. Next slide.

This is a sequence of events for this case. Time zero, as we said, the aux feed pumps were stopped. The steam generators were isolated. At nine seconds there was a scram signal which initiated the core power decay, and then again we are a little bit off on -- quite a bit off, actually, on the time when the pressurizer sprays were actuated on high pressure.

Then the PORV popped open by itself, and then it actually reclosed momentarily. Then it opened again, and after it opened the second time, it was locked open. The pumps were tripped. So we got into a natural circulation mode.

There was liquid flow out of the PORV. There was also in the test stagnation in each of the two loops, the A-loop and the B-loop, actually quite a bit into the transient. This was run for eight hours. So this is a long transient, and it was a couple of hours in before the stagnation occurred.

CHAIRMAN WALLIS: Now would the time when you might be interested in PTS would be in that period?

MR. PRELEWICZ: Obviously, the loop flow stagnation is the time. You will see, the temperature almost continuously decreases during this event. So it's hard to tell exactly when the most significant -- when it would be most significant without running a fracture mechanics calculation. Next slide.

Again, one of the things we found with most of these cases is, if you get the boundary conditions right, you're going to be pretty close on the temperature, and that really is in line with the PIRT that Dave showed for Robinson. Important items were the temperature and the flow rate of the HPI, the accumulator flow and so forth.

This is the PORV flow which, you can see, is quite well predicted by RELAP5. Next slide.

CHAIRMAN WALLIS: This is a choked flow through the PORV?

MR. PRELEWICZ: This is choked flow through the PORV, right.

CHAIRMAN WALLIS: The water fills the pressurizer. So this is a --

MR. PRELEWICZ: Eventually, it did, yes. I had -- On the sequence of events, there was a time when the pressurizer filled solid.

CHAIRMAN WALLIS: So some of this is two-phase flow through the PORV?

MR. PRELEWICZ: Actually, it's very short. The two-phase flow is early in this period, and this is probably pretty much --

CHAIRMAN WALLIS: Steam?

MR. PRELEWICZ: -- two-phase or single-phase liquid.

CHAIRMAN WALLIS: Oh, it's liquid?

MR. PRELEWICZ: It's liquid through the break, yes, through the PORV. You're putting in liquid through the HPI, and it's going out through the PORV.

CHAIRMAN WALLIS: The pressurizer is full.

MR. PRELEWICZ: Feed and bleed. Yes, pressurizer is full. Next slide.

That was the break flow. This is the HPI flow, which you can see again is fairly well predicted. My guess would be it's initially two-phase. This part is single phase, and when you start to get two-phase, you start to get some choking in the break or some flashing, and it drops down to a somewhat lower value. You see RELAP for a short time jumps back up again, but except for this one case where it looked like the break cooled for a short period, the prediction is quite good. Next slide.

This is the reactor coolant system pressure versus time, and you can see again, it's fairly well predicted. You can see a couple of glitches here in the RELAP5 pressure. We will see that those actually correspond to some recirculating flows in the cold leg, the start and stop, some recirculating flows in the cold leg.

CHAIRMAN WALLIS: Those are not physical?

MR. PRELEWICZ: Well, that's an interesting question. The data showed it, but it's really -- in the sense that we can induce this numerically, this same kind of behavior --

CHAIRMAN WALLIS: These glitches are in the calculation, not in the experiment?

MR. PRELEWICZ: Can we have the next slide? Maybe we can look at it. I'm going to get to the flow in a minute.

This is the -- There was no data taken on the flow rate. The instrument failed. So this is just a RELAP calculation of the cold leg flow. I may have gotten ahead of myself. I think it's the next transient where it actually goes into the recirculating flow. I don't think there is any on this one. Could I have the next slide?

Ah, yes, I was -- This is the cold leg which is the one with the pressurizer, and it -- I'm sorry, the one without the pressurizer. A-loop with the pressurizer keeps flowing.

CHAIRMAN WALLIS: So one cold leg is feeding the other cold leg? Is that what it is?

MR. PRELEWICZ: That's what is happening right here.

CHAIRMAN WALLIS: Well, it's a reflection of the other, just going round and round.

MR. PRELEWICZ: Round and round the circle, that's right.

CHAIRMAN WALLIS: Hey, you're not allowed to do that.

MR. PRELEWICZ: You're not allowed to do that. That's right. And we'll see that, despite this --

CHAIRMAN WALLIS: Hey, Vic, you got to fix that. In the tests for RELAP, put in a circular stagnant system there and let it run and see what happens.

MR. PRELEWICZ: Well, anyway, a short time after it stagnates here, and then it starts this recirculating flow pattern, and then it ends, and I think --

CHAIRMAN WALLIS: If you switch off the momentum flux, does it still do that?

MR. PRELEWICZ: No. This is not -- We don't think this is the momentum flux base.

CHAIRMAN WALLIS: Oh, it's something else?

MR PRELEWICZ: We think it's something else, yes. But anyway, those blips on the pressure curve correspond to kind of the start and ending of that behavior. Next slide.

We didn't have any data on the flow, but we do have cold leg fluid temperature, and this is the A-loop, the one with the pressurizer. You can see in the data that at this time there's a rapid drop in the cold leg temperature. One can infer that that's when the loop stagnated.

Now RELAP5 did not predict any stagnation. The data did show a stagnation, and you can see that, when the stagnation occurs, there is quite a bit of difference between the RELAP prediction and the test data. Next slide.

CHAIRMAN WALLIS: Wait a minute. This stagnation is just about when RELAP started recirculating, is it?

MR. PRELEWICZ: Yes. On the flow -- You want to go back a couple of slides?

CHAIRMAN WALLIS: It got the flow to zero, and then it started --

MR. PRELEWICZ: Right here. The flow first went to zero. It stayed there for -- actually, it stayed there for a while, and then it started this recirculating flow, and it stayed there. Then it went away.

CHAIRMAN WALLIS: Then it came back occasionally.

MR. PRELEWICZ: It blipped up. It didn't persist, but it did have a couple of blips of occurrences. That's correct.

MEMBER RANSOM: When you run into that, do you turn that over to the problem reporting and try to get it fixed?

MR. PRELEWICZ: Yes. We turn it over to the problem reporting. For PTS, a large reverse flow loss coefficient was put in so that it couldn't occur. And again, we did sensitivities. We ran with and without. So we had cases -- we call them with large k-factor and cases without large k-factor. So we handled it by sensitivity study and, I think, took the more conservative of the cases. I'm not really sure how they -- how the PRA people handled it. We gave them both cases.

In any event, could you go ahead a couple? This is the other -- This was cold leg temperature in the other cold leg, and you can see it also stagnates. This is the data stagnating here.

CHAIRMAN WALLIS: It looks as if the momentum equation is unimportant except when it predicts nonphysical results.

MR. PRELEWICZ: Well, it's probably a good point, and I think I tried to make that. RELAP is doing an energy balance, and that's what is important. If you are a little bit off on the HPSI temperature, you see it right away. You're a little bit off on the HPSI flow, you see it right away. If you mispredict the loop flow, it hardly shows up. So you are exactly right.

This is the cold leg B. This is the one without the pressurizer. RELAP5 does predict the stagnation, and these blips are basically backing up of the -- predicting the backing up of the cold water from the injection. The location where this is, is where there was a measurement, and it's actually upstream of the injection point. So this is backing up from that injection point occasionally after it stagnates.

CHAIRMAN WALLIS: This is again something that is not physical, or what?

MR. PRELEWICZ: I don't think the backing up is necessarily unphysical. The test data didn't show it. So in that sense, it didn't happen in the test.

Again, this period in here is the period where you had that recirculating flow. So it didn't back up when it was recirculating.

CHAIRMAN WALLIS: It certainly didn't want to do what the data showed, one way or the other. It either recirculated or it backed up.

MR. PRELEWICZ: Next slide.

This is the bottom line. This is the comparison of the upper downcomer temperature, RELAP, and the data. You can see again, corresponding to the recirculating, there's some blips in it.

CHAIRMAN WALLIS: It just looks like this $E^{-\text{TM}}$ or something.

MR. PRELEWICZ: Well, basically, this is -- If you look at the whole system, it's a big mixing cup. You are putting in cold. You are taking out hot, and the average temperature is going down; and by the time you get to the downcomer where -- In fact, this is about the elevation --

CHAIRMAN WALLIS: So a one-node model might not be too bad.

MR. PRELEWICZ: Well, that's what we found out in the first PTS study. When they couldn't run more than a dozen cases, SAIC came up with a six-node model that was basically a mixing cup, and it worked and was used to extrapolate the results from the other cases to the --

CHAIRMAN WALLIS: REMIX does something similar, doesn't it? It just has a few mixing cups here and there.

MR. PRELEWICZ: Yes, right. So in any event, you can see that RELAP, in spite of the momentum equation predictions in the loop, has done what I would call an acceptable job of predicting the temperature in the downcomer. Next slide.

This is the other end of the downcomer. This is the lower. Ones near the top of the heated section are the same elevation as the heated section in the vessel. This is near the bottom of the heated section. You can see, it's also reasonably good prediction.

I've showed a couple of data points, and they do have around the different azimuthal locations in the downcomer, although in this case it's just one pipe. So it doesn't make a lot of difference. It's all connected, but you can see that the data shows very little variation. Next slide.

The next test that we looked at was a small cold leg break, 10 square centimeters, 1.4 inch equivalent. Unlike the other tests, this test was started at a natural circulation condition. The pumps were not operating.

Again, it's a relatively small break. So it takes a while for things to develop. When the pressurizer dropped one foot after the break was opened, basically, there were several actions taken.

The steam generator level setpoint was increased. So the aux speed filled it up, filled the steam generator, and both of them actually up to 31.60. The HPSI was actuated, and a core decay heat power curve was initiated.

Again, during the test natural circulation is interrupted. We do get some loop flow stagnation, but there is no core uncovering. Next slide.

This is the sequence of events for the test, starting with the break opening. Then you can see, it took a minute or actually two minutes in the measure for the pressurizer level to drop and the HPI to be initiated.

There was flow interruption in both the hot leg and the cold leg, and you can see -- we haven't done the best of jobs, but in this case RELAP does predict the flow interruption in both of the loops.

There was later in the transient a complete loss of natural circulation flow, and you will also see that in both the RELAP prediction and the test data, there is some of this recirculating flow.

CHAIRMAN WALLIS: That starts when you get stagnation.

MR. PRELEWICZ: It's like the previous one. You go to stagnation. You sit there for a while. Then it starts up. But surprisingly enough, the test data did the same thing in this case. Next slide.

This is kind of the bottom line. This is the upper downcomer temperature, and you can see it is not as good in this case as it was in the previous case, and we will see again, you can relate this to the inflows and outflows, HPSI and so forth. But we showed a couple of downcomer temperatures.

This is again the upper downcomer, but we started with the bottom line this time. You can see that it is not quite as good, but still the trend is quite reasonable. Next slide.

Here you can -- and this is the comparison of the pressure. You can see that RELAP is a little bit high on the pressure. So if you go back to the first slide, of course, it's high on the temperature. So what's happening is it is not getting as much HPSI flow. So it's got a higher temperature. Next slide.

CHAIRMAN WALLIS: It's not being conservative. Is that right?

MR. PRELEWICZ: It is being nonconservative in this case. That's correct.

Again, this is the HPSI flow rate versus time. You can see that, when the HPSI flow is low -- I guess we're putting it the other way. When the pressure is too high, the HPSI flow will be low, and the temperature will also be too high, because you are not getting as much HPI flow into the system. Next slide.

This is the break flow. You can see we've done reasonably well predicting the magnitude of the break flow. Next slide.

Also, reactor vessel level versus time -- there is some lowering of the liquid level. Again, I'm always suspicious of these that measure delta P's, because other things -- they are not measuring the physical liquid level. They are measuring a differential pressure. Temperature changes or something else happens, you're not on, but you can see the code did a pretty good job of predicting the level. Next slide.

Here is cold leg A. This is the one with the pressurizer on it. You can see, there is an initial flow stagnation, and for quite sometime the flow basically stays stagnated. But the data, which is the triangle and the plus, you can see the data shows this recirculating flow pattern.

CHAIRMAN WALLIS: Right.

MR. PRELEWICZ: And the people who ran the test, B&W -- this was run, I guess, at their Alliance Research Center -- noticed this phenomenon and did some investigations. They attribute it -- Obviously, you have to have something to drive this. You have to have some kind of heat being put in unsymmetrically in one loop rather than the other loop -- one cold leg rather than the other cold leg.

They attribute it to asymmetries in the environmental heat losses, as the best they could come up with. Again, this was not the main thrust of their test. They were interested in those days in large LOCAs and small LOCAs.

CHAIRMAN WALLIS: I assume it's the pressure drop driving it around the circuit. It's not just the heat loss difference.

MR. PRELEWICZ: Well, if you were to take

-- There is an elevation change around the loop. So if you were to have someplace where you had more heat loss on one side than the other side, it could cool it off and drive some flow.

The thing that is surprising, though, is sometime later RELAP predicts the same phenomenon to occur, and it's kind of about the same magnitude. I guess it's limited in some sense by the friction.

The thing is, we can induce this numerically. So we are very reluctant to say anything about, you know, RELAP predictions of this phenomenon. I think the experimentalists were befuddled by it, and we can change the order of solutions matrix and --

CHAIRMAN WALLIS: Well, it's not just numerical, if it actually happened.

MR. PRELEWICZ: Well, it happened in the test.

MR. BESSETTE: See, in a facility this size the facility heat loss can be comparable or even more than decay heat. In this case, the cold leg started acting as a heat exchanger, losing heat just to the ambient.

MR. PRELEWICZ: You have to have something to drive it, basically. In RELAP we can get it to -- The co-developer set up some simple problems where they can get it to occur without any driving force. So we know that it can be predicted unphysically in RELAP by the order of the matrix solution. So again --

CHAIRMAN WALLIS: But you can't blame that for the actual data.

MR. PRELEWICZ: That's right. Next slide.

This one is even more dramatic. This is the B cold leg. You can see, this is -- flow stagnation would be here, and you can see that it took longer to get to the stagnation condition, and pretty much immediately both RELAP and the data show this recirculating flow pattern.

MEMBER KRESS: Does RELAP model heat losses?

MR. PRELEWICZ: Yes. We have heat structures on the loops, and they have --

MEMBER KRESS: Does this also do the outside?

MR. PRELEWICZ: I believe they have a heat transfer coefficient to the environment on the outside, yes.

MEMBER KRESS: Yes, but it's symmetrical.

MR. PRELEWICZ: It's symmetrical. That's right. In RELAP there is no reason to believe it's --

you know, there's no unsymmetry put into it.

MEMBER RANSOM: Well, you have to take that with a grain of salt. There's always a little asymmetry and round-off somewhere, you know, in these calculations.

MR. PRELEWICZ: That's correct.

MEMBER RANSOM: To trigger it. It can't drive it. It could trigger it.

MR. PRELEWICZ: So in any event, despite -- I mean, this is not the major influence. The major influence appears to be that we are a little high on the pressure. Therefore, we are a little low on the HPSI flow and, therefore, we are a little high on the temperature, despite all of this stuff.

Again, in the PTS analysis we saw this same phenomenon occurring, predicted in the RELAP calculations, and we handled it by doing sensitivity studies. We put in large reverse-K factors, and that got rid of this. It didn't happen with the large-K factors.

We ran with and without, and we've got the two results to look at. There are some differences in temperature between them. This does cause some mixing. So there is a difference in temperature.

MEMBER KRESS: Now where does the feed go in?

MR. PRELEWICZ: Pardon?

MEMBER KRESS: Where does the feed go in?

MR. PRELEWICZ: Into the cold leg.

MEMBER KRESS: Just one of the cold legs?

MR. PRELEWICZ: Both cold legs get -- All four cold legs have HPI injection.

MEMBER KRESS: Yes. Now when you model that in the code, is it --

MR. PRELEWICZ: It's pressure dependent. We have a table that will put in a flow proportional--

MEMBER KRESS: To the system average pressure?

MR. PRELEWICZ: -- a function of the pressure at the injection point.

MEMBER KRESS: Oh, at the injection point?

MR. PRELEWICZ: In that loop, yes, the local pressure at the injection point is what determines how much HPI flow comes in.

MEMBER KRESS: Okay. It looks to me like then a stagnant system like this which has these points on them, plus a bleed location, is basically unstable, and all you have to do is get a little bit of something to get it started. It could be numerical or it could be a real fluctuation in pressure.

The thing would keep driving itself due to the -- You will then end up with -- It won't restabilize itself, I don't think. But I would have to think about that.

CHAIRMAN WALLIS: Does this happened in the reactor?

MEMBER KRESS: Oh, probably not. It probably has something to do with the heat losses, like they said, being a predominant portion of it.

MR. PRELEWICZ: Well, it's an interesting phenomenon. I think the code developers -- we are still looking at it as something that we need to understand better than we do now. But it is interesting that it occurs in the test. I think that's -- It's interesting, but we are not ready --

MEMBER KRESS: I think the startling case is the unstable, and the recirculation is the stable. All you have to do is get the recirculation going, when you have the situation you have.

DR. MOODY: When you refer to code developers, who are you referring to?

MR. PRELEWICZ: Glenn Mortenson and company. Next slide.

This is just -- This is the secondary conditions, just to show you that we got a reasonable agreement on the secondary type. The bottom two are the liquid levels in the two steam generators. You recall that one thing that happened is that, when you turn the HPI on, you also set a level in the steam generators, and you can see we have maintained that level.

Also, the pressures are in reasonable agreement with the data. Next slide.

The last MIST test that we did was a larger small break LOCA, 100 square centimeters, equivalent to about a 4.4 inch break in the plant. Again, this same type of shift to a core decay heat mode. The aux feed fills up the steam generators and maintains a constant level control, 31.6 feet.

In this case, the cold leg is weighted, interrupting the primary flow, and the hot leg rises, also flashed and completely voided. Since this is a larger break, the low pressure injection was also initiated and also the accumulator, what they call core flood tank, injected into the system. Next slide.

This is the sequence of events. Again, measurements weren't real good. So we had to estimate some of these from the data. But see, we are not too far off on loss of loop natural circulation flow, around two minutes, both the prediction and the data.

Sort of another key event when low pressure injection initiated, that's kind of a function of the pressure. It's just again like the HPI. It's pressure -- So when the pressure gets to the level when the LPI can inject, it injects into the system.

There was one difference we will see, which probably makes the biggest difference in the temperature. There was a criteria for throttling the HPI flow when you got 75 degree subcooling. We never got that in RELAP, but it apparently occurred in the test, although apparently it was nothing automatic. The test operators were told when they saw 75 degrees subcooling to punch out one of the two HPSI pumps.

We did have quite a bit of difference between the measured and the RELAP. So it's not that the operators -- You know, there was a difference that could justify not -- the reason for not turning it on in RELAP again. Same with the other case, we ended the simulation at about 4,800 seconds. Next slide.

MR. ROSENTHAL: Dan, maybe you could skip to Slide 65.

MR. PRELEWICZ: Is that okay with the committee? The committee is the audience here.

CHAIRMAN WALLIS: Well, there is nothing new.

MR. ROSENTHAL: Well, Dr. Wallis, it's your meeting. I think people are starting to fade. The point that we wanted to make -- and you'll see it in -- Number one, we have a number of assessment cases. So we are broad in scale.

There's bumps and warts and wiggles in the RELAP stuff which we presented to you. You know, we are trying to be open about it. We seem to get the pressures and temperature in the downcomer pretty good, which is why we are doing it.

It's your choice. I think you ought to pick up -- skip a little bit, and then -- But I would like to do at least a couple of the ROSA cases, which I think the committee is familiar with, and that would give you -- It's your choice.

CHAIRMAN WALLIS: Yes. Let's skip to 65.

MR. ROSENTHAL: I'm sorry, Dan.

MR. PRELEWICZ: Oh, that's fine. Thank you. No problem.

This is the bottom line. This is the comparison that we are interested in, the downcomer temperature, the function of time. As I mentioned, the one departure here is when you have a difference between the throttling criteria. When one of the two HPIs is disabled by the operators, test data jumps up immediately.

In RELAP5 where we did not meet the 75 degree subcooling criteria, you continue along the line. So it kind of shows you, you get the -- The boundary conditions are really the most important determinant. Next slide.

CHAIRMAN WALLIS: This is an external downcomer.

MR. PRELEWICZ: This is an external downcomer.

CHAIRMAN WALLIS: Just squirting in from a pipe into a vessel?

MR. PRELEWICZ: Well, the HPI goes into the cold leg, which then goes to the downcomer. The LPI and the accumulator go directly in --

CHAIRMAN WALLIS: There's some sort of a plume in this vessel, although it's a vessel, not a downcomer. But there's some sort of a plume there, too.

MR. PRELEWICZ: In the vessel?

CHAIRMAN WALLIS: In the downcomer, in the external downcomer. There's some kind of a plume.

MR. PRELEWICZ: It's relatively small.

There's four cold legs coming in on the top.

CHAIRMAN WALLIS: So when you say upper downcomer temperature, it's all well mixed up there?

MR. PRELEWICZ: Well, again, I say upper. That's where -- It's at the elevation of the top of the heated section. So it is down several feet below. So it has a couple of feet to mix.

DR. BANERJEE: Do you have the flow rate, too, with the downcomer?

MR. PRELEWICZ: I don't have any plausible flow rate in the downcomer.

DR. BANERJEE: But were there measurements?

MR. PRELEWICZ: I doubt it, because it's hard to measure. There's cold leg. In fact, there's cold leg measurements of the flow rate. There's HPI measurements of the HPI flow.

CHAIRMAN WALLIS: If you've got all the cold legs, we should get the downcomer.

MR. PRELEWICZ: If you add the four together, it's got to be the downcomer flow in this situation where it's basically single-phase flow going -- or most of them. I guess the last one it wasn't. The last one gets some emptying. Next one.

This is again the secondary side. In

fact, if we want to move on, this is one -- We've gone from a two-hour talk to a three and a half hour talk yesterday, and now we are back to a shorter time today.

LOFT L3-1 is a one-inch small break LOCA. I think most of you are familiar with LOFT. This is a break where the HPSI pretty much keeps up, although they did turn it off for a while to try to empty the system.

The conclusion is pretty much the same as the others. If you get the boundary conditions right, you will get the downcomer temperature right. So maybe I can just -- We'll go quickly through this. Everybody is pretty much familiar with the LOFT facility. Next slide.

This is the noding diagram, just to show the level of detail. You can see it's a fairly detailed nodalization. Next slide.

Sequence of events: Again, in this case it's turning on and off of the HPSI, which we did at the same -- We turned it off at the same time and on at the same time. So the sequence of events is kind of boring. Next slide.

Break mass flow rate they didn't measure too far. You can see as far as they measured and stopped, it did pretty well. Next slide.

MEMBER RANSOM: Is that all Henry-Fauske and RELAP5?

MR. PRELEWICZ: Everything we did was Henry-Fauske and RELAP5, yes.

This is the HPSI flow. We are a little bit high initially. I don't know what happened with the test. It was lower the first time they turned it off, and after it came back the second time, it kind of was right. I wish there was some difference between the first and second time they turned it on. Next slide.

Primary system pressure: You can see, we're a little bit low. Next slide.

This is the upper downcomer temperature, and you can see again where it started off a little bit low, because we were high on the HPSI flow in that initial period, and we kind of stayed there. Remember, the HPSI slide, we were a little bit low. They turned it off at this point.

Before they turned it off, RELAP predicted a little bit low on the HPSI flow. Again, that was probably something different in the test that we didn't incorporate in the model. You can see again, we are low on the temperature. Next slide.

Why don't we just go to -- I think the rest of them are velocities and stuff. APEX-CE test: We did one of the tests that -- on the latest test here, the APEX-CE. Again, I think Jose covered this pretty well. Why don't we go to the next one?

This again Jose showed the configuration.

CHAIRMAN WALLIS: This has to do with the how much the plumes persist?

MR. PRELEWICZ: Well, the test -- The one we did was the PORV stuck open and then reclosed. Again, this was one that was kind of put in to be like a PTS transient. So this was APEX-CE 13, the stuck open relief valve from full power with subsequent reclosure, and initiated from full power steady state conditions.

ADS-2, which is the leftover from the AP600 days, on the pressurizer had an orifice put in scaled to stuck open PORV on Palisades. Pardon? SRV, sorry, stuck open. Again, two cooling pumps were tripped. High pressure injection was actuated. Flood power was shifted to decay heat mode, and the simulated SRV was open for an hour and was then reclosed, and 20 minutes later was the end of the simulation. Next slide.

This is just a comparison of the initial conditions, which shows that we did a pretty good job matching all the initial conditions, a little bit off on the pressurizer level but not real significant. Next slide.

This is the sequence of events. At time zero, the SRV was opened, the scram signal. HPI flow started, and again the pumps were tripped at the same time as in the test as in the simulation. We pretty much did all the events the same. So there is no timing difference in the events. Next slide.

This is one of the bottom lines, the pressurizer pressure. You can see, there wasn't a lot of a decrease. This is initial pressure. So it drops down, and this is sort of the important part. This is the reclosure.

You can see that RELAP5, as typified by maybe the MIT test, was a little bit slower at reaching the peak pressure, but eventually actually got up to the same pressure as the test data. Next slide.

This is the pressurizer level. You can see, basically what happens is that the flow, as we'll see, is mostly vapor. It won't quite fill up the pressurizer. The heaters are on during the test. So they help to keep vapor going out the break rather than liquid. Next slide.

Again, this is the downcomer fluid temperature. Not very much of a decrease in this case, but you can see that fairly good agreement again between the RELAP and the test data. Next slide.

This is the simulated SRV or ADS-2 vapor flow. You can see, while there's a lot of jumping around, there's reasonably good agreement between the test data and RELAP calculation. Next slide.

This is the liquid flow out of the simulated SRV. Again, you can see, while it's very noisy, there is certainly the same order of magnitude. Next slide.

This is the -- Again it shows you the secondary conditions reasonably well. This is the C-loop steam generator pressure. Next slide.

This is the other loop, the so called P-loop. In APEX-CE they keep the same terminology as AP600. There's loops going with the pressurizer in the other ones. Next slide.

This is the RCP inlet temperature, and you can see we are right on there. That's the -- I guess you would call that the cold leg temperature. Next slide.

I'm not sure this means very much.

Downcomer collapsed liquid level. It basically shows there was no emptying. Next slide.

So in summary, APEX-CE test 13 simulating the stuck open safety valve, the subsequent reclosure. The downcomer temperature is predicted with reasonable accuracy, and the temperature actually showed little dependence on azimuthal position in both RELAP and APEX measurements.

The pressurization was at a somewhat lower rate, but eventually the peak pressure from RELAP was actually slightly higher.

So the conclusion is that RELAP5 provides a reasonable prediction of the test data, which was the purpose of these calculations which will be turned over to the uncertainty people to be used to do uncertainty valuations.

If there's no questions, Don is ready to tell you about APEX -- ROSA-APEX -- ROSA-AP600, right.

DR. BANERJEE: What was the downcomer like in ROSA?

MR. BESSETTE: ROSA has an annular downcomer, about two-inch.

DR. BANERJEE: It's a true downcomer?

MR. BESSETTE: True downcomer, not like MIST.

DR. BANERJEE: And not like Semiscale.

MR. BESSETTE: Not like Semiscale either. They had -- Both MIST and Semiscale had that external pipe downcomer.

DR. BANERJEE: And ROSA was full height?

MR. BESSETTE: Yes, full height.

MR. FLETCHER: I am Don Fletcher of ISL, and the subject I am going to talk about today are the ROSA assessments that we've done for PTS.

There are five tests that we have looked at, two of them in ROSA-AP600 and three of them in ROSA-IV, which was the predecessor facility to ROSA-AP600. Next slide.

First the ROSA-AP600 tests: ROSA-AP600 is a 1:30 volume scale, full pressure representation of a Westinghouse AP600 passive safety reactor, full height electrically heated core. The facility has two loops that represent the two AP600 loops, including one hot leg, one steam generator.

In the test facility, there is only one reactor coolant pump and one cold leg per loop, as opposed to two in AP600. The pressurizer is located on one loop, and the core makeup tanks are located on the other loop.

The PRHR, the passive residual heat

removal system, is located on the same loop as the pressurizer. There are ADS automatic depressurization system valves on the top of the pressurizer and on the hot legs, and the IRWST is the in-containment refueling water storage tank, which is a large volume of water that is used to inject cold water into the primary coolant system after it has depressurized following the operation of the ADS.

DR. BANERJEE: ADS-4 was off the --

MR. FLETCHER: There are four stages of ADS. ADS-1, 2 and 3 are small valves on the top of the pressurizer that open in sequence to bring the plant down gradually in pressure. ADS-4, I believe there are eight valves in the plant, four on each cold leg -- on the hot leg, excuse me.

DR. BANERJEE: Directly on the hot leg?

MR. FLETCHER: They are directly on the hot leg, yes. Next slide.

This is a layout of the ROSA facility, ROSA-AP600 facility, showing the two loops and the orientation of the accumulators, the CMTs, the pressurizer and so forth. Next slide.

RELAP5 nodalization, which I know you've seen enough of by now. This is the nodalization that was used as a part of the AP600 evaluation study for the safety analysis. We have not changed the model.

The downcomer is an annular downcomer in the facility, integral in the vessel. The gap is two inches, and we have nodalized that region using six channels in the downcomer, all connected back together at the lower plenum. That is one of the regions -- It is this region that we have had difficulty with, with the downcomer circulation as a result of the momentum flux that was talked about earlier.

As far as the nodalization of the plant, we are pretty much modeling -- In this noding diagram, you see a noding that is fairly well representative of what we are using in the pressurized thermal shock models for the plants, four up and four down in the steam generator, approximately the same number of nodes in the vessel and in the loops.

Obviously, the passive safety systems aren't in the plants we are looking at for PTS. Next slide.

The first test is AP-CL-03, which is one that received a lot of attention in the AP600 safety analysis work. This is a one-inch equivalent diameter break on the bottom of the cold leg in the CMT loop with the reactor in full power operation.

Single failure is one of the two ADS-4

valves on the CMT loop hot leg fails to open. Next slide.

Sequence of events is shown here. The sequence compares rather well down through the point where the accumulator injection begins, and then after that the calculated sequence proceeds a little faster than it does in the experiment.

The loss of natural circulation in the pressurizer loop and in the CMT loop compare fairly well between the test and the data. Next slide.

Pressurizer pressure measured and calculated as a function of time over the 8,000 second period. The obvious thing is we are doing well on the pressure down to about here, and then the code calculates a faster depressurization than is seen in the data.

This point here is where the ADS is fired on the top of the pressurizer. This knee here, as we depressurize the primary sufficiently that the CMTs stop circulating, and that results in that need right there. All in all, not too bad of a comparison on the pressure. Next slide.

This -- I show this only because the CMT behavior is fairly important as to how the sequence proceeds in AP600. We have the time. CMT circulation is initiated back here near the beginning of the transient, and then the CMT draining is fairly well predicted by the code, the timing of that.

We do see that in the calculation we are draining the CMT slightly faster than we are in the test during this initial period here.

DR. BANERJEE: Wasn't there a CMT refill that occurred?

MR. FLETCHER: Right here. The CMT refill was in the test. We have also seen them in calculations. They tend to be fairly spurious. We didn't see it in the calculation here.

CHAIRMAN WALLIS: That can't happen in full scale.

MR. FLETCHER: Pardon me?

CHAIRMAN WALLIS: That can't happen in full scale, I think we decided.

MR. FLETCHER: I guess I couldn't say on that.

CHAIRMAN WALLIS: That's where condensation sucks the water back in.

MR. FLETCHER: Right. There is a bit later on one of the other tests a pressurizer refilling from condensation that we see in the test data. I wanted to show that to you a little bit.

DR. BANERJEE: There was an oscillation in the pressurizer. Right?

MR. FLETCHER: Oscillations in the pressurizer because of the fluid going out of the ADS at the top. It was fairly oscillatory, and I really didn't want to dwell on that at this point.

DR. BANERJEE: It dumped right into the hot leg, though.

MR. FLETCHER: Yes, the pressurizer dumps into the hot leg, and there is an ADS-4 where the water comes in.

DR. BANERJEE: It was sucked out.

MR. FLETCHER: Right. The key point in the CMT draining is when you reach the 67 percent level, which is here, because that is the -- This is the point when ADS is fired. So it's important to get the draining -- the beginning of the draining at the right point. It's important to get the rate of draining at the right point, and then it's important to get to the time when the ADS is fired.

Then finally, it's important to end up with some CMT level down here at the end about the time when you get to IRWST injection, so that you don't starve the core for water. Next slide.

These two slides show the cold leg mass

flows on the pressurizer loop side. When we say P-loop, we mean the loop that contains the pressurizer and the PRHR system. The right slide shows the CMT loop cold leg mass flow response.

The black is the test data. The red is the RELAP5 calculation. The obvious thing here is that the code nailed the prediction here on the time when we loss circulation on the pressurizer loop. We didn't do too badly here on the CMT loop as far as the time when we lost circulation. Next slide.

One of the features of this ROSA test was the thermal stratification of cold legs. This is driven because on the pressurizer loop the PRHR system discharges into the steam generator outlet plenum, and that cold water flows toward the vessel.

What we see in the test is an extreme thermal stratification of that flow toward the vessel. The colored curves here represent the top to the bottom on a rake of thermocouples, fluid thermocouples in the cold leg between the pump and the vessel.

What we see on the dashed line, the black dashed line here, which is the RELAP5 calculation, is that RELAP5 happily makes the whole cold leg cold, and as a result the temperature going into the vessel in RELAP5 is fairly conservatively calculated.

CHAIRMAN WALLIS: You would think it would be closer to an average, since it's mixing there.

MR. FLETCHER: Well, the thing is there is no flow through the loop. The only thing coming down the cold leg is what is coming out of the PRHR. So it becomes -- It goes to the cold temperature, not to the average.

CHAIRMAN WALLIS: Well, should we conclude anything useful for the PTS from this?

MR. FLETCHER: Well, I think what we conclude is that there's some complex behavior going -- thermal stratification going on in the cold leg. RELAP5 cannot predict it, and yet I think you will see in a minute that the effect on the downcomer temperature is minimal.

What we have going on on this loop is that the PRHR system discharges into the steam generator outlet plenum. The cold leg comes off of that, and we've lost the circulation around the loop. So the PRHR flow is the only flow going toward the vessel.

CHAIRMAN WALLIS: So really, there's a countercurrent flow or something, too?

MR. FLETCHER: There is no countercurrent about it. The PRHR flow is the only flow experienced.

DR. BANERJEE: It's just flowing around

the bottom. Right?

MR. FLETCHER: It flows along the bottom.

CHAIRMAN WALLIS: And there is some stagnant fluid on the top?

MR. FLETCHER: That is correct. That is correct, but there is no place for the flow to return, if it comes up this way. So it's not really a circulation.

DR. MOODY: Would you professors mark him off for putting a zero on that left end of the scale? It's a log scale, right, on the bottom?

MR. FLETCHER: No. It's --

CHAIRMAN WALLIS: It's time. There is a zero time.

DR. MOODY: You go out to what, 10,000 seconds?

MR. FLETCHER: This is 10,000, 6,000. It's not log.

DR. MOODY: Well, you can mark me off.

MR. FLETCHER: I would have used zero, 2000, 4,000 and so forth, but I used the slide as it existed.

CHAIRMAN WALLIS: The thing is, if that cold water is running down, you wouldn't expect the water on the top to heat up the way it does.

MR. FLETCHER: Well, it's cooling down during this time period.

CHAIRMAN WALLIS: But it heats up?

MR. FLETCHER: The situation changes here because of automatic depressurization, and everything changes at that point.

DR. BANERJEE: But then the stratification comes back again.

MR. FLETCHER: Toward the end here, yes, we do have some stratification, and RELAP5 is underpredicting that. There is still some flow coming, PRHR, but the system is much more chaotic and, actually, I think the cold leg is partially voided during this time frame. That may be the reason for that. Next slide.

This is the other cold leg. What we see here is that there is, both in the test and in the calculation, some bleed of that cold water from the pressurizer loop cold leg, around the downcomer, and then out the break on the CMT loop. That's what we are observing there. Next slide.

The next four slides, these two and on the following image, are the downcomer temperatures at the top and bottom of the core on opposites sides. This is on the C-loop side at the top of the core elevation. This is on the C-loop side at the bottom of the core elevation.

The comparison between the measured and calculated temperatures, fluid temperatures in the downcomer, compare fairly well. We are doing very well here. We are doing sort of well here. The difference between these two is related to the discharge and temperature of the PRHR system, which I will show you in a minute. Next slide.

CHAIRMAN WALLIS: Why does it go wrong later on?

MR. FLETCHER: Pardon me?

CHAIRMAN WALLIS: Why does it go wrong? You say you're doing very well up to a certain point.

MR. FLETCHER: Right here, why does it go wrong?

CHAIRMAN WALLIS: Yes.

MR. FLETCHER: This is a difference in the IRWST injection time. So --

DR. BANERJEE: Which is data, and which is RELAP?

MR. FLETCHER: RELAP is the dashed line. I'm sorry, it's hard to see on this.

CHAIRMAN WALLIS: The data has more wiggles?

MR. FLETCHER: No. The one that has more -- I'm sorry. The one that has more wiggles is the data, and that is the solid line.

DR. BANERJEE: So the first bump there is RELAP toward the bottom when IRWST comes in?

MR. FLETCHER: This one?

DR. BANERJEE: Yes. Which is RELAP down there?

MR. FLETCHER: I can't see on that slide, to tell you the truth.

DR. BANERJEE: The bottom one is RELAP?

MR. FLETCHER: This is RELAP in here. This is the test data. And that's true in all four of the cases. So what we are looking at is 180 degrees apart in the downcomer at the top of the core elevation and at the bottom of the core elevation, and the results at all four of these are about the same. Next.

One of the reasons that we come down a little slower at the beginning of that cooldown is that the PRHR discharge temperature in RELAP is 15 kelvin higher than it is in the test. This has to do with the modeling of the IRWST and how the thermal response to the IRWST goes during the transient.

Of course, there is no IRWST in existing plants. So this really isn't pertinent for -- This difference is not pertinent for PTS. Next slide.

Then the reason why it goes bad is that we reach the IRWST injection point sooner in RELAP5 than we do in the test, and that's why behavior there looked like it was off in phase, but the magnitudes were more or less the same.

DR. BANERJEE: Well, except it's off by 1,000 or two seconds. Right? Somewhere.

MR. FLETCHER: Yes, we are off in timing. There is no doubt about it. We are off in timing. But we are off in timing because of the way the CMT draining has gone and so forth. We know why we are off in timing.

DR. BANERJEE: I think I remember it had some implication on core inventory. It may not be important for this, but --

MR. FLETCHER: Yes, it does have -- Yes. The core inventory -- it's critical to get CMT level -- the relationship between the CMT drain, the time the CMT drains and the time the IRWST comes on. It's important to have some overlap at that point. So it is critical for core level.

CHAIRMAN WALLIS: What does this tell us about thermal shock?

MR. FLETCHER: This tells us -- The only thing -- The purpose of these last two slides I've shown you is that the differences that we are observing in the downcomer temperatures are mainly caused by these aspects of modeling AP600. So I think, if we model as boundary conditions properly the IRWST injection time and the PRHR temperature, that we would do even better than what you have seen on here already, which I think is pretty good at this point.

DR. BANERJEE: Now you reran these, right?

MR. FLETCHER: We have rerun them.

DR. BANERJEE: Because the original problem was there was severe oscillations.

MR. FLETCHER: There is still oscillation in the pressurizer. This is --

DR. BANERJEE: No, no. The pressurizer, there are real oscillations. Right?

MR. FLETCHER: Yes.

DR. BANERJEE: Yes, but I mean, if I recall, there were some oscillations in the core.

MR. FLETCHER: In the core?

DR. BANERJEE: Yes, due to the fact that you were getting these bursts of vapor at the low pressure before IRWST came on.

MR. FLETCHER: No. Perhaps I have a slide back there that would answer your question, but the core level --

DR. BANERJEE: Your calculations won't show it, but I think the calculations that were done at the time of the AP600 seemed to show that. There was a problem with the stability of the code, and the vaporization. It had to do with the split between the heat going into vaporization and the heat going into heating up the liquid, some sort of partitioning function.

MR. ROSENTHAL: I think the thing that we are interested in is that we have a lot of production work where we have done hundreds of production runs for different scenarios. The code that we used is RELAP Mod 3.2.2. gamma. So by using the same code to do the assessment cases, we should be gaining some confidence that the -- well, I'll call it the production runs are reasonable, given that we are using the same code. That's why we wanted to redo it.

DR. BANERJEE: Maybe, but in this case I don't think RELAP really -- Even here, if this is really a question of whether you got the resistances right, inflow/outflow resistances -- If you got those right, you could do this with a hand calculation almost. You wouldn't need RELAP.

All it amounted to was what was losses in the IRWST line and to the ADS. So I don't think this proves very much. The other cases might be better. This was all momentum equation almost.

MR. FLETCHER: I don't recall -- I know we had some difficulties, but I don't know that it relates to this.

DR. BANERJEE: It relates to vaporization in the core.

MR. FLETCHER: You asked about core level. Here's core collapsed level for the calculation we are just looking at.

DR. BANERJEE: Right.

MR. FLETCHER: And the RELAP calculation is the triangles here. We are a little bit lower on core level. So we're a little bit high on PCT. The timing is different because of the CMT problems that we've had, but I don't see --

DR. BANERJEE: Well, maybe you fixed the problem in your -- but in the early days you've had a problem with stability.

MR. FLETCHER: Well, there have been many versions of RELAP. It is an ongoing development.

DR. BANERJEE: Maybe in this version, you don't.

MR. FLETCHER: And we've been careful here to use the same version that we are using in the PTS analysis, which is not the most recent.

MEMBER RANSOM: I had one question on the downcomer. You have six vertical stacks of volumes, I guess.

MR. FLETCHER: Yes.

MEMBER RANSOM: And, what, four are connected to the cold legs and two hot legs pass through it, I guess.

MR. FLETCHER: That's correct. That's correct. We connect them back together again at the bottom of the downcomer where it meets the lower plenum.

MEMBER RANSOM: To a single volume, I guess.

MR. FLETCHER: Yes. We are one-dimensional from there up through the core. So we have a two-dimensional or three-dimensional downcomer.

MEMBER RANSOM: And all of those volumes are cross-connected?

MR. FLETCHER: They are all cross-connected, yes.

MEMBER RANSOM: And momentum flux is ignored everywhere?

MR. FLETCHER: Right. We have turned off momentum flux in the downcomer.

MEMBER RANSOM: Did you do that anywhere else in the model?

MR. FLETCHER: No.

MEMBER RANSOM: Only in that downcomer?

MR. FLETCHER: Only in the downcomer which, by the way, was one of the suggestions that was made at the time of the AP600 study. So this model began from what worked on the AP600 study. Therefore, we have the multi-dimensional downcomer, and we've used the recommendations that were in place at that time.

CHAIRMAN WALLIS: The velocities are not very high, are they? So you wouldn't think the momentum flux would be a big contributor.

MR. FLETCHER: The momentum flux seems to be the biggest problem when the velocities are not high. It's when it's quiescent that the momentum flux seems to become a problem.

CHAIRMAN WALLIS: This is rather strange.

MR. FLETCHER: Yes.

CHAIRMAN WALLIS: When it's negligible, it's the biggest problem?

MR. FLETCHER: Yes. We do not have an

explanation. We are still looking. Shall we go on?

The conclusions for AP-CL-03 is that the complex system behavior and timing were well predicted with RELAP5. Coolant loop flow stagnation is excellently predicted. Experiments exhibit thermal stratification in the liquid filled cold legs. RELAP5 can't model it, but the code to data comparisons show that the effect on the downcomer liquid temperatures is minimal. Next slide.

CHAIRMAN WALLIS: I'm just wondering how, when all this is put together into a case for the way PTS is going to be handled, whether all these comparisons with ROSA-A600 are really going to be very convincing, because it's completely different system.

MR. FLETCHER: It is a completely different system.

CHAIRMAN WALLIS: What are you really learning that is going to be relevant to PTS?

MR. BESSETTE: Well, it's a case of the best available -- I mean, we will show you also ROSA-4. It's the only large scale facility data we have available that mocks up like the Westinghouse/ CE plant and has downcomer temperature measurements and so on.

So it's the case of the best available

data that we have. Now probably some of the ROSA-4 data, you might say, we don't have some of these AP600 questions in them, but these AP600 cases were really easy to generate, and they are not of no interest.

DR. BANERJEE: So the net result of this was that the stratification in the cold leg did not lead to a plume being formed in the hot leg. Is that the bottom line?

MR. BESSETTE: A plume in the downcomer?

DR. BANERJEE: A plume in the downcomer.

MR. BESSETTE: Is that what you --

DR. BANERJEE: Is that the bottom line, or what?

MR. FLETCHER: Yes, but, Dr. Banerjee, I don't think I'm trying to claim that no thermal stratification in the cold leg is of concern. I'm just saying here it was not.

DR. BANERJEE: Yes, okay.

MR. FLETCHER: When I saw Jose's presentation, I see that there's a lot going on in there that, obviously, this code cannot handle.

MEMBER RANSOM: I have a question, Don, that you may or may not know the answer to. But when they went to Mod 3, they put in a donored momentum flux formulation, didn't they?

MR. FLETCHER: I don't know the answer to that.

MEMBER RANSOM: As opposed to Mod 2. I believe that's correct. One of the reasons that you have trouble at zero velocity is, of course, things switch back and forth for minuscule differences. That's one of the dangers of that kind of thing.

MR. BESSETTE: So for integral system data, we have ROSA and we have APEX, which we are showing, and for B&W geometry the only data we have are MIST. So that's why we are emphasizing these three facilities.

MEMBER KRESS: I guess the question that comes to my mind is: For the TTS evaluation, the unique part of the new stuff was going to be a complete comprehensive uncertainty analysis to give you distributions at the endpoint.

I fail to see how I can take this information, which gives you some good feelings and confidence -- how do I convert it into a way to assess the uncertainties in the PTS results?

I fail to see that step, how you go from here to say, okay, now how am I going to use this information to say I have a certain level of uncertainty in the PTS results. That's the thing that bothers me most right now.

MR. BESSETTE: Well, I guess to do a sensible -- in doing a CSAU approach, let's say, CSAU type of uncertainty studies, you have to have some confidence that your base calculation that you are using to do sensitivity studies on has some validity, and how do you establish that is from code assessment, looking at comparison between the code and the data.

We show you a body of this information, and show that we can do a reasonable job of predicting temperatures and pressures.

MEMBER KRESS: You are saying somehow this database comparison will be fed to the PIRT people to help them in their --

MR. BESSETTE: You have to have some belief that your starting point is valid. If you do a sensitivity study on something that is questionable, then the sensitivity study --

CHAIRMAN WALLIS: Well, that's the first step. But once you've got that, then you have to do the sensitivity studies, and then you have to sort of get a real handle on the uncertainties for PTS.

MR. BESSETTE: Yes.

CHAIRMAN WALLIS: I'm not quite sure how you do that.

MEMBER KRESS: That's what I'm asking.

MR. BESSETTE: So this is kind of to show that RELAP has some validity, some believability to it and, therefore, the sensitivity studies are valid.

MEMBER KRESS: Well, we kind of thought it had some validity and some believability.

MR. BESSETTE: Not everybody would agree.

MEMBER RANSOM: I think the thing they are struggling with is even the CSAU has a provision for things that are not modeled and things that are not modeled correctly, biases.

MR. BESSETTE: That's right, biases.

MEMBER RANSOM: Yes. And so we've seen some things here which look like they would need some biases, and so how do you establish the magnitude of those biases then? I think CSAU did not give any real guidance on how to do these things.

MR. BESSETTE: No, and in fact we only applied one bias, as I recall, in CSAU. But the provision is certainly there for applying biases.

MEMBER RANSOM: Yes. How to establish the magnitude is the other thing.

MR. BESSETTE: Yes.

DR. BANERJEE: But ROSA-IV certainly would be closer to a scaled version of one of the plants.

Right?

MR. BESSETTE: Yes.

DR. BANERJEE: Are you going to show us some results from ROSA-IV?

MR. BESSETTE: Yes. Yes. In fact, the test he is going to show is the one you were mentioning earlier where the liquid hauled up in the loop seal clearing.

DR. BANERJEE: right.

CHAIRMAN WALLIS: Okay. So maybe you should move on through these tests, and then we'll get to the ones which are most interesting.

MR. FLETCHER: Okay. On AP-CL-09 -- next slide -- AP-CL-09 is the same break size, same location as AP-CL-03 that we've just seen. It's just there's multiple safety system failures. We starve the core for liquid from all sources.

I think you can slip through a couple here, Bill. Keep going. The sequence of events looks pretty good, the comparison between the calculation and the data. The thing we are missing, interestingly, is the order of loss of natural circulation.

In the test we lose it first in the CMT loop. Then we lose it second considerably later in the pressurizer loop, and it's the other way around at about the same times in the calculation. Next slide.

CHAIRMAN WALLIS: These things are very sensitive to delicate balances.

MR. FLETCHER: Yes, and that's exactly what we are seeing here. The pressure comparison looks pretty good. Next slide. But here is what I was saying about the loop flow stagnation.

In the pressurizer loop, the test shows that it comes down smoothly to zero. The calculation shows an abrupt stop in the pressurizer loop flow, and we see exactly the opposite on the other side. Next slide.

CHAIRMAN WALLIS: And all these wiggles, plus and minus wiggles -- what do they mean?

MR. FLETCHER: We have the ADS system firing out in here. We are looking at the -- We are looking at the flow in the loop seal of the cold leg.

CHAIRMAN WALLIS: So the flow is oscillating in the cold leg?

MR. FLETCHER: It's oscillating back and forth in the loop seal. We have blown the system down with ADS, and it's sitting there oscillating. We have wiggles in both the test and the calculation.

CHAIRMAN WALLIS: It's hard to see the

test, because you've written over it.

MR. FLETCHER: Yes. I know it's hard to see, and I wish I had them separately to show you, but they are both oscillating, although, clearly, the code is oscillating more in this time frame. Next slide.

CHAIRMAN WALLIS: So you are putting in slugs of cold liquid?

MR. FLETCHER: No, no. This is just water sitting in the cold leg.

CHAIRMAN WALLIS: But it's oscillating.

MR. FLETCHER: It is responding to the changes in pressure on both sides.

CHAIRMAN WALLIS: Isn't it banging to and fro in the cold leg? You're going to have to stand aside.

MR. FLETCHER: Where we are showing -- I will. This is the cold leg. The steam generator is up here, and the vessel is here. We have water in the bottom of the loop seal.

CHAIRMAN WALLIS: Oscillating like a manometer.

MR. FLETCHER: It's oscillating like a manometer, back and forth.

MEMBER KRESS: The time is too short for it to go very far.

CHAIRMAN WALLIS: You can't really see that because of the scale here.

MR. FLETCHER: It's not slugging. It's just water sitting there.

CHAIRMAN WALLIS: I thought it was more like a slugging oscillation in the cold leg.

MR. FLETCHER: No.

MEMBER RANSOM: Do you know if those are driven by pressure differences?

MR. FLETCHER: Yes. What's happening, the core is boiling. The core is throwing water up into the ADS system, and so there is pressure disturbances as a result of the slugging on the core side and in the hot leg side.

What we are just seeing here is the response in this loop seal of the water flowing back and forth. Next slide.

The reason we had the different behavior between the two loops, between the code and calculation, ended up being related to the thermal stratification. In the pressurizer loop we had thermal stratification in the cold leg, and then this water was seen to run over to the CMT loop in the test, and the CMT loop is where the break is.

As a result of that water flowing into the

CMT loop, it stopped the CMT loop from flowing in the test. In the calculation, we don't have the thermal stratification, and so we did not see that behavior. Next slide.

DR. BANERJEE: The calculation is quite a bit lower than the --

CHAIRMAN WALLIS: Yes, RELAP is way down.

MR. FLETCHER: Back up. It's down, because back on the previous slide we have lost natural circulation in the RELAP calculation at this point. So if the temperature plunges because the water from the PRHR system is the only flow in the loop, and so this is just reflecting a stagnant cold leg with water in the loop.

CHAIRMAN WALLIS: So that's the PRHR -- What's that temperature there your finger is on?

MR. FLETCHER: This is the RELAP5 calculation of the cold leg temperature.

CHAIRMAN WALLIS: Is that the PRHR temperature?

MR. FLETCHER: What it's saying is that, when the loop stagnates in RELAP5, the PRHR flow is the only flow in the cold leg, and it is quite cold. But we have a difference in stagnation behavior in the test. The loop is still flowing. So that's why it's higher. It's up there. It still has loop flow combined with PRHR flow, which is the reason why this is so high.

CHAIRMAN WALLIS: I just wonder if it's likely that this could be predicted in the PTS scenario where RELAP is predicting for some geometries and some reactors quite unreasonably low temperatures.

MR. FLETCHER: Well, the easy answer is there is no PRHR system in the PTS plants, but the more relevant question, I guess, is could the HPI geometry be different in such a way that it could cause these kinds of differences, and I think the answer is yes.

CHAIRMAN WALLIS: You've got sort of a cold stream of HPI flowing along the bottom of the pipe.

MR. FLETCHER: Right.

DR. BANERJEE; You've got a temperature difference between the top of the pipe and the bottom of almost 150 degrees.

MR. FLETCHER: Yes.

DR. BANERJEE: And that's being -- And that's while the loop is flowing still. Right?

MR. FLETCHER: Yes. Back one slide.

DR. BANERJEE: If I remember, there is

still flow there.

MR. FLETCHER: We still have flow here, and that's why the temperature is so high at the top of the pipe.

DR. BANERJEE: Yes.

MR. FLETCHER: So what we are doing is we are combining the hot flow out of the steam generator with a cold flow from the PRHR -- ahead one slide -- and what we see is that the hot water stays in the top of the cold leg. The PRHR water flows underneath it.

DR. BANERJEE: What is happening to the downcomer temperature?

MR. FLETCHER: I'm glad you asked. Forward one more.

CHAIRMAN WALLIS: I'm trying to get away from the other curves.

MR. FLETCHER: Yes.

DR. BANERJEE: Let me go back to it.

MR. FLETCHER: Okay. Again, we have the four downcomer temperatures. This is at the top near the top core elevation, the bottom core elevation on the C-loop side. What we see right here is the effect of the difference in loop stagnation.

There's a difference in the way -- There's a difference in the cooldown rates in the downcomer during this time frame.

DR. BANERJEE: Now the data is there. It looks like it's at about -- Let's take the lowest point.

MR. FLETCHER: Okay, 425.

DR. BANERJEE: Could you go back two slides to see what it looks like. Okay. Now that seems like it's the --

MR. FLETCHER: Back one more.

DR. BANERJEE: No, no, that's it.

CHAIRMAN WALLIS: Is it the average temperature?

DR. BANERJEE: No. It looks like the low temperature, which is -- At about 2,000 the hottest temperatures are up at 550, and the coldest temperatures are around 425.

MR. FLETCHER: I'm not sure we're comparing the right ones. The one where we looked at the 425 temperature was at the top of the core on the C-loop side. This is the P-loop cold leg.

DR. BANERJEE: Well, let's look at the P-loop side.

CHAIRMAN WALLIS: Ahead of the C-loop one.

MR. FLETCHER: Okay. Here is the P-loops -- or the C-loop side, and here is the temperature that is coming -- the downcomer. And you're right, it's a little above 425.

DR. BANERJEE: So it looks like it's seeing the coldest temperature and not the mixed mean.

MEMBER KRESS: Unless there is steam in there.

MR. FLETCHER: I don't think there is steam during that -- There is no steam before this point.

DR. BANERJEE: So let's look at before 2,000 seconds.

CHAIRMAN WALLIS: If you go to 4,000 seconds, it's sort of following RELAP rather than the other codes.

MEMBER RANSOM: Well, the interesting thing is that under 2,000 it looks like RELAP5 agrees with the highest temperature.

MR. FLETCHER: Yes.

MEMBER RANSOM: And then suddenly plunges down to the lowest.

MR. FLETCHER: The reason for that is that in RELAP5 this loop is flowing. In the test, it's not.

DR. BANERJEE: No, no. It's just opposite. Not this loop; the previous one.

MR. FLETCHER: Right. On the other one it's the other way around. RELAP5 is flowing, and so the downcomer -- or the cold leg temperature is hot, and the downcomer below that would be hot.

DR. BANERJEE: Let's focus on the previous loop for the moment where RELAP is not flowing, and the --

MR. FLETCHER: Back up one.

DR. BANERJEE: Okay. There you've got a temperature which is around, let's say, 400, a little bit above the cold temperature. Let's say 425 averaging. Okay?

Let's go to the two slides forward now to the downcomer.

MR. FLETCHER: C-loop side.

DR. BANERJEE: Okay. What's happening there?

MR. FLETCHER: C-loop side --

DR. BANERJEE: Around 2000.

MR. FLETCHER: Around 2000, we're at -- Well, it's got to be before this, because this -- It's got to be right here. So that's 425.

DR. BANERJEE: So it's seeing the coldest temperature coming out, and it's the same for the other side. It's not seeing the mixed mean, and I don't understand how it is agreeing with RELAP, because RELAP is showing much colder temperatures.

If you go back two slides -- Go back two slides, please. Yes. It's showing 350. So how the hell is -- Sorry. How is the downcomer coming up in temperature to 425 from there? It's showing 250.

MR. FLETCHER: Can I look into it and get back with you? I don't think I can do it standing up here.

DR. BANERJEE: Well, I think it would be nice to put the downcomer temperature curve superimposed on these, just to be able to overlay them. Then we can look at it and see directly.

MEMBER RANSOM: Well, they are different volumes. So one has to mix with the other one, I would guess.

DR. BANERJEE: Right, but if the flow is going toward the downcomer -- In the experiment it is clear. It looks like the bottom flow is going into the downcomer, and that's what you are seeing. In RELAP, though, it's not clear, because the flow is of the order of 350 when the downcomer temperature is up to 425.

MR. FLETCHER: Maybe what is happening, it's this cold in the cold leg. It gets into the downcomer, mixes with water from the other loops before it goes down.

CHAIRMAN WALLIS: There must be some other loop doing something.

DR. BANERJEE: But there are only two lops, right? The other loop -- Go to the next loop.

CHAIRMAN WALLIS: The next loop is even hotter water.

DR. BANERJEE: It's 400. No, that's hot, yes. This one is hot.

CHAIRMAN WALLIS: If we look at, say, 6000, all the water that is coming in is above 420.

MR. FLETCHER: The problem is very different after this point, because ADS is blown in, and we are at low pressure. It's a different -- and it's probably partially voided.

CHAIRMAN WALLIS: Well, how does it get so cold, though, later on? You're putting in hotter water.

MR. FLETCHER: How does RELAP5 get so cold here?

CHAIRMAN WALLIS: If you plot the downcomer fluid temperature on top of this, at 6000 it's down to 330 or something.

MR. FLETCHER: My guess is this is

saturation.

CHAIRMAN WALLIS: Way down below all of those.

MR. FLETCHER: My guess is this is saturation. ADS is blown here. We're down at atmospheric pressure.

CHAIRMAN WALLIS: It gets cold by boiling and evaporating down to saturation. That's how it does it?

MR. FLETCHER: The whole system has been blown down. We've opened up all the ADS.

CHAIRMAN WALLIS: Those magenta curves are all supersaturated -- superheated?

MR. BESSETTE: That's right. I think they getting the hot wall effect.

CHAIRMAN WALLIS: It must be in a steam area.

MR. BESSETTE: In the data, yes.s

CHAIRMAN WALLIS: Must be in a steam region.

MR. BESSETTE: So in the data the pipe is voided, and you are seeing wall temperatures.

CHAIRMAN WALLIS: Okay. Well, I don't know if this is relevant to our PTS discussion.

DR. BANERJEE: Only before ADS blows it

could be relevant.

MR. BESSETTE: I think what you are seeing is, because the downcomer temperature is being warmer than that cold leg temperature, it's showing that the water from that cold leg getting mixed with other water, and downcomer temperatures are actually warmer than the cold leg.

CHAIRMAN WALLIS: Okay. Well, I think someone has to do the job of tying this in with PTS, and what have we learned from this which is really giving us insight into actual problems.

MR. FLETCHER: Go forward. Keep going, one more.

I think this slide is the same as for the AP-CL-03, basically. The system behavior, timing are well predicted. The order that the coolant loops stagnate is reversed between the calculation and the test. Next slide.

The test exhibits thermal stratification that causes that difference. Next slide.

But the downcomer temperatures are shown to be well predicted. We are off by a maximum of about 25 kelvin on any of the four individual temperatures, and the average difference is about 5 kelvin.

DR. BANERJEE: That could be because it's -- At least, it looks like here it's a small downcomer.

MR. FLETCHER: Yes.

DR. BANERJEE: And Dave says both streams are mixing. RELAP is just lucky. It's very cold on one, very hot on one. So yo mix it, and you get about the right temperature.

MR. FLETCHER: I understand.

CHAIRMAN WALLIS: I guess we should keep going. Do you think we can stand keeping going until the end without a break?

MR. ROSENTHAL: Do you want to go over ROSA-IV?

CHAIRMAN WALLIS: Well, I'm not sure what we are going to learn. I mean, we want to learn anything we can.

MR. FLETCHER: Shall I hit the highlights on ROSA-IV?

MR. ROSENTHAL: Why don't you do the five-minute version?

CHAIRMAN WALLIS: Okay. Maybe we can get to five o'clock or something.

DR. BANERJEE: Do you have any rakes in ROSA-IV?

MR. FLETCHER: Like this? No.

MR. BESSETTE: Yes, we do. The same thermocouple rakes -- Well, maybe I'm wrong. I believe that --

MR. FLETCHER: Sorry. You know better than I do, I'm sure.

MR. BESSETTE: I could be wrong in my memory, but I believe there was the same cold leg rakes.

CHAIRMAN WALLIS: We said that ROSA-IV was more representative or something?

MR. FLETCHER: ROSA-IV is more representative of PTS, because it's scaled to a four-loop Westinghouse PWR.

CHAIRMAN WALLIS: So what do we learn from it now?

MR. BESSETTE: We avoid these complicating factors of PRHR and CMTs.

MR. FLETCHER: Right. But I do want to tell you we modeled it with a 1-D downcomer as opposed to the multi-D downcomer in ROSA-IV, which was the model that existed when we picked it up, and we did not change that.

Let's see. SB-CL-18 is a six-inch break. So it's the largest break. Slide 37 -- go forward four, Bill -- is a sequence of events. IT looks good down to the point where the accumulators start to inject, and then the code prediction goes much faster.

CHAIRMAN WALLIS: So what I notice here is on page 44 you seem to have a liquid temperature in the downcomer which is very different in RELAP than it is in the experiment.

MR. FLETCHER: Yes. This is the worst case we had to show you. Downcomer temperature, we're showing 90 degrees apart in the downcomer. The two trends are up here like this. Code calculation dramatically plunges.

What we have is we have a break flow difference that starts it all off at the beginning, and so we end up with too little water in the primary cooling system that, when the break finally uncovers, causes it to be pressurized too fast.

I don't think that issue is particularly pertinent for PTS, because we are modeling a break spectrum. But one thing that is significant is that we have a pressure that falls dramatically during that time period as the accumulators start to inject. It's a self-feeding situation. The accumulator starts to feed cold water into the cold legs, which are voided because this break is fairly large. That cold water condenses, takes the pressure down even more, and the accumulators --

CHAIRMAN WALLIS: That's what RELAP is predicting?

MR. FLETCHER: Yes.

DR. BANERJEE: This is just falling saturation?

MR. FLETCHER: No. What you really have is a model of the accumulator that says I have so much pressure, and I'll only inject when the downstream pressure is lower; and the lower the downstream pressure is, the more I'll inject.

DR. BANERJEE: And that temperature curve -- is it correlated with the pressure curve in Slide 42? Looks like the minimum is about the same time.

MR. FLETCHER: Okay.

DR. BANERJEE: The minimum comes at 500 seconds.

MR. FLETCHER: Well, yes, but look at the difference in the minimum.

DR. BANERJEE: Yes, but I'm saying that's RELAP.

MR. FLETCHER: This is RELAP, and this --

DR. BANERJEE: So if you look at the downer temperature, is it just saturation temperature at that pressure, what you are seeing?

MR. FLETCHER: Back to 44, I guess. I don't know the answer to that.

CHAIRMAN WALLIS: You have to look it up in the steam tables.

DR. BANERJEE: One point 5 MPA.

MR. FLETCHER: Which is -- 15 atmospheres is 200 psi, and we are --

CHAIRMAN WALLIS: This is liquid temperature of 330 k. You're darn cold.

MR. FLETCHER: It is. It's accumulator temperature, I think, is what it is.

DR. BANERJEE: Oh, that's accumulator temperature.

MR. FLETCHER: Here's the accumulator flow rate.

CHAIRMAN WALLIS: Way below saturation.

MR. FLETCHER: Here's the accumulator flow rate. Here is the flow. We overpredict it by a factor of two and a half as far as the flow rate of the accumulator, and it is all driven by the condensation model in RELAP5, the interphase condensation model.

It's particularly bad for the six-inch break, because the six-inch break is such that the plant tries to depressurize, but it kind of hangs up when it gets down to around the accumulator pressure, which is about 500 psi or 600 psi.

So for a six-inch break, the accumulator starts the flow, and then it's a self-feeding process where the condensation takes the pressure down even more. So you overpredict the accumulator injection rate.

CHAIRMAN WALLIS: So it quenches the whole system.

MR. FLETCHER: It does. Now if the break is much larger, then you don't have this self-feeding thing, because the pressure in the system is going to go down to atmospheric and stay there, regardless of what the accumulator is doing. So there is no self-feeding effect.

So I think this is probably the worst prediction we will see.

CHAIRMAN WALLIS: So you were telling us before, forget all the details, RELAP5 does a good job of predicting liquid temperature in the downcomer. Now we have an example where it doesn't.

MR. FLETCHER: Right, and I say on my conclusion slide the comparison is poor.

CHAIRMAN WALLIS: So we can no longer --

MR. FLETCHER: And I say it's --

CHAIRMAN WALLIS: -- believe our previous rather naive conclusion.

DR. BANERJEE: Don't say it's conservative, because you don't know how it will go somewhere else, you know. I mean, who knows. If this is wrong, it's wrong.

MR. FLETCHER: Well, it's conservative for this experiment.

DR. BANERJEE: The next one, it could be unconservative.

MEMBER RANSOM: Well, in this particular experiment it looks like your break flow is pretty poor, overpredicted.

MR. FLETCHER: Yes. Right. This whole thing is set up by RELAP5 predicting too much break flow during the early part of the transient, and that -- As a result of that, we depressurize too fast and, because we depressurize too fast, the accumulators get into the act and feed on the depressurization, and it becomes a runaway.

CHAIRMAN WALLIS: So we really better understand what RELAP is doing and why.

MR. FLETCHER: Yes, absolutely.

CHAIRMAN WALLIS: Which is just what to do if you don't have the experiment there to guide your thinking.

MR. FLETCHER: Well, we have seen these events over the years with RELAP5, and we always recognize that this is unphysical, and we try to point it out at that point.

DR. BANERJEE; How big is the cold leg in terms of time?

MR. FLETCHER: In ROSA?

MR. BESSETTE: It's eight inches.

DR. BANERJEE: Eight inch. I don't see any rake data here, though.

MR. BESSETTE: I believe they had the same rake of 5 thermocouples across the cold leg, but I could be wrong in my memory.

MR. FLETCHER: We will see if we can find out.

DR. BANERJEE: Can you sort of give us, if possible, a synopsis of the real data on this one in terms of temperatures, not RELAP5 calculations but actual temperatures and pressures found in the experiment, because in a way, what you are arguing is that the downcomer temperature is a mixed mean temperature of the temperature in the cold leg. You can directly check that from your experiment. You don't RELAP.

CHAIRMAN WALLIS: Well, I thought RELAP was picking out the colder temperature in some of the other runs.

DR. BANERJEE: Well, that was due to other reasons.

CHAIRMAN WALLIS: So again, I mean, you conclude different things from different tests here. I don't know how we generalize it to apply to PS for some other reactor system.

MEMBER KRESS: Well, maybe take this for an example. If this is a bias in the condensation model, you could extract how much bias this is in this case, and put that in the code and fix it.

CHAIRMAN WALLIS: If you can fix the code to cover these anomalies, then you have a better code.

MR. BESSETTE: Except we are not even sure about the bias, because if the -- if it all goes back to the break flow being off, then this could be resolved --

MEMBER KRESS: It could be real.

CHAIRMAN WALLIS: I'm sure you are reassuring my colleague, Peter Ford, that you are really on top of all this and predict what we need to know.

DR. BANERJEE: For some reason, RELAP has a big bump in the break flow between 350 and 500 seconds.

CHAIRMAN WALLIS: That's a wart.

MR. FLETCHER: Back up one. We probably should have started in at the beginning. We would have gotten through this a lot better. Back up one more. We are missing the break flow badly during this time frame, what I think is 150 to 250 or so.

DR. BANERJEE: Then again later, right?

MR. FLETCHER: Well, this is accumulator, is what that is. We're putting in so much water that --

CHAIRMAN WALLIS: We are not reviewing AP600.

MR. FLETCHER: We are not.

CHAIRMAN WALLIS: And yet a lot of these phenomena have to do with things like CMTs.

MR. FLETCHER: Sure. This is accumulator.

MEMBER KRESS: This is ROSA-IV. It's not AP600.

CHAIRMAN WALLIS: Okay. It's just -- Oh, okay.

MR. FLETCHER: This is accumulator.

CHAIRMAN WALLIS: It ought to be more relevant to our thoughts.

MR. FLETCHER: Yes. The accumulator gets so far runaway that it throws so much water up in the system that even the break flow goes up dramatically in this time frame. We are sure the accumulator response is wrong. Let's put it that way. It's obviously wrong.

CHAIRMAN WALLIS: Obviously wrong? I mean, if it condensed that rapidly, it could do this, couldn't it?

MR. FLETCHER: Well, it's obviously wrong as far as the comparison with data goes. We are way off.

CHAIRMAN WALLIS: Ah, so it is wrong, but not obviously. I mean, it's clearly wrong.

MR. FLETCHER: It's clearly wrong.

CHAIRMAN WALLIS: Obviously means that you knew ahead of time it was going to happen, and you didn't.

MR. FLETCHER: No, we didn't know ahead of time. It is this break flow difference here -- next slide -- that you can see the density difference here.

CHAIRMAN WALLIS: That's not very reassuring either.

MR. FLETCHER: There is the density in the cold leg, in the top, middle and bottom of the cold leg where the break is located. Here is the RELAP5 density, and it's this period right here. We are missing that, and then afterwards we miss everything.

CHAIRMAN WALLIS: Whatever you do, don't touch the screen with an open pen.

DR. BANERJEE: But if you go back to the break flow curve, isn't it underpredicting and then overpredicting?

MR. FLETCHER: Well, before you move it, Bill, we do have the density right on at that point. So go back one, Bill.

I agree with you. Doesn't it look like we are overpredicting and then underpredicting, and these two average out. But it's not working that way.

DR. BANERJEE: Why not?

MR. FLETCHER: I don't know.

CHAIRMAN WALLIS: I think we are going to have to move on. There are just too many questions here that may be specific to this experiment. You have to really know what is -- think about what is going on.

MR. BESSETTE: I think we have to spend more time, certainly, on this particular comparison.

CHAIRMAN WALLIS: Can we move on to the next one? Is it going to show something similar?

MR. FLETCHER: Oh, that was the worst.

CHAIRMAN WALLIS: That was the worst?

MR. FLETCHER: As far as the conclusions go, the comparison with the test data is poor. RELAP conservatively predicts the downcomer fluid temperature for this experiment.

CHAIRMAN WALLIS: But it's way off.

MR. FLETCHER: It is.

CHAIRMAN WALLIS: It's exceedingly way off.

MR. FLETCHER: I agree.

SB-HL-06 is the hot leg break in ROSA-IV. It's a two-inch break. HPI and aux feed fail. Loss of off-site power. So the pumps close down. This starves the core for water, and once the core starts to heat up, we open up the pressurizer PORV to depressurize the system. That's how the test goes. Next slide.

Sequence of events is shown here. The sequence of events compares very well, and then we end up with a heat-up in RELAP5, starting slightly before 100 seconds early in RELAP5 compared to the test data.

In the test, the core starts to heat up.

The PORV is open. In the calculation we have done, we've forced the PORV to open at the same time as in the test. So we did not open it early, as would be expected, which sort of biases the comparison. But we are going to have to bias it one way or the other. Next slide.

The pressure follows, and the calculation follows the test data well. When the PORV opens, we depressurize faster with RELAP5 than we do in the test. Next slide.

Again, we are missing the break flow. The red line is the break flow through this period throughout the beginning of the transient. That affects the way the pressure -- depressurization goes when the PORV opens, because we don't have as much water in the primer.

CHAIRMAN WALLIS: You seem to be predicting too much break flow later in the transient.

MR. FLETCHER: Too much break flow?

CHAIRMAN WALLIS: Well, the red line is way down low.

MEMBER RANSOM: It doesn't look very trustworthy.

MR. FLETCHER: But this is the time -- We are missing the break flow badly during this time frame. So by the time when the PORVs open out here at about 6000 seconds, we have much less water in the primer in the calculation than we do in the test.

DR. BANERJEE: It would be worth maybe showing us a little bit more average break flow for the experiment so we can see where it actually is.

MR. FLETCHER: Okay. A point well taken.

DR. BANERJEE: At the moment, we can't tell.

CHAIRMAN WALLIS: The bottom line is 53, is it? Again, we have a difference between --

MR. FLETCHER: Go ahead slowly, Bill. Loop flows stagnate at about the right -- a little early on one side, a little late on the other. Next slide.

We were asking about U-tube water holdup. We are doing okay on water holdup in the loop-A side, and the loop-B side we are draining out early, probably a break flow effect.

CHAIRMAN WALLIS: This is the steam tube?

MR. FLETCHER: Steam generator tubes.

CHAIRMAN WALLIS: Draining?

MR. FLETCHER: Yes.

CHAIRMAN WALLIS: Is that what he talked about this morning?

MR. FLETCHER: Yes. These are the differential pressures in the up-flow sides of the steam generator tubes in the two steam generator.

DR. BANERJEE: So it gives you the core--

MR. FLETCHER: It gives you the core pressure. In fact, we went pretty fast there. I think -- Go back.

CHAIRMAN WALLIS: Maybe we need to go fast. It's fascinating, but --

MR. FLETCHER: Could you show 41? This is back on the previous test, slide 41. This is where we missed the draining. The code has an overprediction of the water holdup.

DR. BANERJEE: So you get a --

MR. FLETCHER: We get a core level depression, and that actually pushes the water up the downcomer and is one of the causes for the break flow being too high.

DR. BANERJEE: So you would expect in this case that you would get with RELAP too high a downcomer temperature prediction.

MR. FLETCHER: Too high?

DR. BANERJEE: Relative to what you got before.

MR. FLETCHER: I went back on you one

test. This was the one that we had a lot of discussion on.

DR. BANERJEE: Oh, I was talking -- I'm sorry -- the other one.

MR. FLETCHER: Yes, okay. So if you go forward. I can't remember where we were, Bill.

DR. BANERJEE: You were on the holdup in the steam generator.

CHAIRMAN WALLIS: You were on 52.

MR. FLETCHER: Fifty-two. We were here. Okay.

DR. BANERJEE: So now you are getting a core level depression. So you are shoving stuff up the downcomer.

MR. FLETCHER: No. We are actually doing better than the data at this point. This is -- We are draining faster --

CHAIRMAN WALLIS: This is better than the data?

MR. FLETCHER: From the viewpoint of how much water is being pushed up the downcomer, how far the core is being depressed.

DR. BANERJEE: It depends how you look at it.

MR. FLETCHER: Well, in this loop --

DR. BANERJEE: There is no problem.

MR. FLETCHER: In this loop we are draining okay. In this loop we are draining early.

DR. BANERJEE: So what happens to the downcomer temperature?

MR. FLETCHER: Okay, go forward.

DR. BANERJEE: Which is the data?

MR. FLETCHER: The data is the red and green here.

CHAIRMAN WALLIS: This is the bottom line here.

MR. FLETCHER: Yes. This is the upper downcomer fluid -- the temperature at the top of the core in the downcomer, and we have two readings that are 90 degrees apart in the downcomer, and we see that we are below -- The RELAP5 calculation has lower temperatures in the downcomer.

CHAIRMAN WALLIS: Most of the time.

MR. FLETCHER: Most of the time, and this point we miss right here is a condensation event in the test in the pressurizer. We are bringing in accumulator flow. It is filling the system back up. A little of the cold water is getting into the pressurizer, and it is literally --

CHAIRMAN WALLIS: That would have a

shocking effect on the wall perhaps, that precipitous drop of temperature.

MEMBER KRESS: Too short.

MR. FLETCHER: Yes. Yes.

CHAIRMAN WALLIS: It gets zapped a few times with flips of temperature, conceivably.

MR. FLETCHER: We do see the same pressurizer refill event. We ran this out to 20,000 seconds, and we do see a similar event in the code out here at about 15,000 where the pressurizer refills.

The timing difference is because we are missing the inventory in the primary cooling system. So the timing difference played into it.

CHAIRMAN WALLIS: It's not clear to me, if you put the theory, all of the experimental codes into a PTS prediction, whether one would be worse or the other would be worse in terms of --

MR. FLETCHER: That is true. That is true.

CHAIRMAN WALLIS: Okay.

MR. FLETCHER: The summary of this test: Break flow difference led to faster depressurization. The timing of the cooling loop c circulation is well predicted. The downcomer fluid temperature is conservatively predicted.

CHAIRMAN WALLIS: Maybe.

MR. FLETCHER: Maybe? Next slide.

The final ROSA test is run in more of a separate effects mode to look at natural circulation under reflux condensation conditions. Here we've got a closed primary system. We have set the conditions on the secondary side so that we condense on the inside of the steam generator tubes, and then we start drawing liquid off of the primary until we see reflux cooling mode being entered.

Then we do this experiment in three separate steps of pressure, and then at each of the pressure steps we increase the power in steps. Next slide.

Here is the pressure. The first one is at 7 bar. The second one is at 3 bar, and the last one is at 1 bar. Next slide.

Then at each of those pressures, we increase power as shown here. Next slide. Next slide.

What we are seeing is that RELAP5, which is the blue line here, is overpredicting the water holdup in the tubes as compared to the data, significantly overpredicting the water holdup in the tubes. At the intermediate pressure, we are closer to the data, and then at the lower pressure we have even less water in the tubes than in the test.

This shows the RELAP5 velocities, the vapor and liquid velocities at the inlet to the tubes. What we see is that at high pressure RELAP5 never predicts any downflow of liquid out of the tubes into the steam generator plenum.

CHAIRMAN WALLIS: Do we have a PTS scenario we are concerned about where reflux condensation matters?

MR. FLETCHER: I would say, yes, it's involved in most of the LOCAs. I guess the question is how long does that exist.

MR. BESSETTE: I guess I would say the opposite.

MR. FLETCHER: You would? Well, and people are going to go through this period.

MR. BESSETTE: We pass -- In practice, we don't really worry too much about reflux condensation most of the time, because even at LOCAs we pass quickly from a situation of natural circulation to flow stagnation. But this is, as I say, the most severe -- one of the most severe tests of the interfacial drag and what-not in the code. So that's why we wanted to look at it.

MR. FLETCHER: Next slide. As far as the loop flow rate -- and this is the loop flow rate over at the cold leg -- we see that RELAP5 is overpredicting the loop flow rate at the higher pressures, about right at the intermediate pressures, and then is underpredicting the loop flow rate at the lower pressure.

What this means is that at the high pressures we have so much water in the tubes that it occasionally spills over the top of the tubes and finds its way down to the cold leg and circulates around.

Then at the low pressures, we have so much reflux cooling going on, on the up-flow side of the steam generator, that none of the water makes its way over and finds it way to the cold leg. So that explains the difference there.

CHAIRMAN WALLIS: Now is this going to be used to fix up RELAP to do a better job of reflux condensation?

MR. BESSETTE: Well, I think so. I think that we've identified this -- or at least the code developer -- The code developer people working for ISL know about this problem, and as I understand it, they are working on it.

CHAIRMAN WALLIS: Are they going to adapt RELAP5 until it does a better job, and then that will be a better RELAP5 to use for PTS? Is that the idea?

MR. FLETCHER: I would say no, not in that timing.

MR. BESSETTE: Not in that time frame, no.

MR. ROSENTHAL: I mean, RELAP5 3.3.3 --

CHAIRMAN WALLIS: Gamma.

MR. ROSENTHAL: No, no, no -- is a version we have now where we are continuing to spend some money on improvement, code bugs, code fixes, which will do for some period of time.

For the time being, we are working furiously with most of our effort into TRAC, and what we need to do is take the lessons that we've learned from this exercise and make sure that we are addressing them in TRAC.

CHAIRMAN WALLIS: So you are going to make no decision about the PTS until TRAC is operational?

MR. ROSENTHAL: No, no. So now let's -- So now we are really at the end, right? That is what are we going to do? We would like to move on with making decisions on PTS. I think you've seen the state of the art in how well we can do. We can apply RELAP over a reasonably broad number of experiments.

Now comes the question of how can you use this information, and what do you have to live with? Now my uncertainties I have in, let's say, a transient are going to be different than in a small break LOCA or a large break LOCA or in this perverse six-inch case in which my accumulators are floating on the system, and I don't -- and I think we have to think through how we are going to do it. But if we end up saying that we don't know those temperatures better than, let's say, 100 K, let's say, then I think we have to figure out how to use that fact in the overall uncertainties and move on.

DR. BANERJEE: Is there a sort of threshold of temperature below which you have to cool the walls to make this thing an important accident? Does it have to go below like 300 Fahrenheit?

MR. BESSETTE: There's no sharp cliff, but there is a certain -- Certainly, the further down you go in temperature, the more risk probability is going up. Certainly, when you are down -- I think most of the dominant events that we are seeing, the downcomer temperature is getting down to about 200 F, thereabout.

DR. BANERJEE: Okay. So let me try to understand this couple of parameters which haven't been really clarified.

Let's say that it's the beltline region which is at most risk, and it's specifically the welds. Now there is some temperature at which -- above which you don't worry too much, I presume, or do you worry at all temperatures? That's the first issue.

The second is, I guess, gradients in time and space -- right? -- because that determines stress. So what you are asking us to write or whatever, give an opinion on, is whether RELAP5, if I understand you, gives us a methodology for calculating at least the temporal gradients, because it cannot give you the spatial gradients. Right? And do this in the temperature range of interest. That's the real issue.

Now the temporal gradient issue still remains, because we don't know if these plumes come down or whatever yet. I mean, they do come down, and you don't know how important they are.

MR. BESSETTE: Well, that's right. You know, short duration fluctuations don't matter in the vessel wall. There are variations that occur in a ten-second time span, you know, oscillations or whatever don't matter, because of the time constant in the vessel wall.

DR. BANERJEE: So what other time constants would matter?

MR. BESSETTE: It's an order of 100 to 500 seconds.

MEMBER RANSOM: Wasn't that characterized as so many degrees per second.

MR. ROSENTHAL: You need to talk in the mike, Vic.

MEMBER RANSOM: I was wondering if they wouldn't characterize it as the rate of temperature decrease.

MR. BESSETTE: That's important, too, but every time you shut down, you go to a cold temperature. But you have -- you don't generate the thermal stress, because you cool down fast enough.

MEMBER RANSOM: That's the rate.

MR. BESSETTE: That's a rate, yes. When you are above -- We have transients that don't bring you above 300 F. You don't have to worry about those.

CHAIRMAN WALLIS: Doesn't the surface of the metal go essentially to the water temperature, because that is where the heat transfer is limited?

MR. BESSETTE: That's right. IT will follow the water temperature.

CHAIRMAN WALLIS: And so you might

actually develop a surface crack, but it wouldn't actually propagate across the whole vessel.

MR. BESSETTE: That's correct.

CHAIRMAN WALLIS: Still, you are going to stress that surface layer pretty highly if you chill it. In a very short time, you still stress it.

MR. BESSETTE: That's right, but in terms of vessel failure -- Well, see, the thing is -- So your thermal stress now is applying to a very small part of the vessel.

CHAIRMAN WALLIS: That's right. So you might actually grow some flaws, but you wouldn't have them zap across the whole vessel.

Well, I don't quite know what to think. I thought Jose was sort of mopping up all the problems with PTS and giving us a good handle on everything. But we seem to be converging. Now we look at all these other tests, and sometimes things work out; sometimes, they don't.

I'm not quite sure what I conclude on the RELAP comparisons we saw in the last three hours.

MR. BESSETTE: Well, I think, you know, some of the things we've shown you like this, the comparisons are bad. These liquid holdup comparisons are bad, but they don't really matter, I think we can argue.

CHAIRMAN WALLIS: Well, you have to have some definite questions you are asking, and then you have to figure out how, if at all, these things -- what we've seen here, answers those questions.

MR. BESSETTE: Again, as long as the focus is the pressure and the downcomer temperature, I think most of the comparisons have looked pretty good, with the exceptions -- with a couple of exceptions, which I think we need to do some more work on in explaining exactly why they deviate.

CHAIRMAN WALLIS: Well, in these days of realistic analyses, looking pretty good doesn't mean anything. You want to look at uncertainties and quantify them.

MR. BESSETTE: So like Jack says, if this is the best we can do, is it good enough? And you know, if you look at the pace of improved fidelity in thermal hydraulics over the past 20 years or so, it's hard to know how much we have improved. So there's not much expectation we are going to do markedly better in the next ten years.

DR. BANERJEE: Well, I think for single phase flow, that's not true.

MR. BESSETTE: No, of course.

DR. BANERJEE: You have come a long way.

MR. BESSETTE: But in the situations we are dealing with --

DR. BANERJEE: For the large break LOCAs and then you have a problem, because it's not going to be simple.

CHAIRMAN WALLIS: Come a long way because of CFD?

DR. BANERJEE: Yes.

MR. BESSETTE: Give us 20 years, and maybe we will have two-phase CFD.

DR. BANERJEE: Well, in 20 years? We will presumably want to resolve this before that. Right? Or not.

MR. BESSETTE: Presumably, we will want to resolve this in the next few months.

DR. BANERJEE: Right.

MR. ROSENTHAL: Well, I think we need to put our heads together within the context of we don't know what sequence we are in. Right? We have a multitude -- you know, 40 or 100 different sequences to look at, each with its corresponding probability. Then for any given sequence, I only have a certain fidelity with which I can predict pressures and temperatures. Then I have my fracture mechanics with its uncertainty.

I have my uncertainty on how much copper and phosphorus and sulfur is in the well. Unfortunately, we don't know that, and look where it all fits together.

In isolation I'm not sure if even -- you know, what is the dominant issue?

DR. BANERJEE: I just wanted to ask you, Jack or Dave, how many of these sequences are you dealing with all liquid, and how many two-phase, if you took a fraction? Is a quarter all liquid?

MR. BESSETTE: Well, for the risk dominant sequences, we're dealing with two-phase all the time.

DR. BANERJEE: All the time?

CHAIRMAN WALLIS: And CFD doesn't help you then?

MR. BESSETTE: It helps.

CHAIRMAN WALLIS: No, it doesn't.

MR. BESSETTE: It helps you the way we saw during Jose's presentations, but when you look at --

CHAIRMAN WALLIS: Not when you have two-phase flow.

MR. BESSETTE: No. But it gives you something more. It gives you more insight.

DR. BANERJEE: Why do you say the risk

dominant is two-phase? Sorry.

MR. BESSETTE: Well, because the sequences that are showing up as being risk dominant are all LCOAs, let's say, two inches and greater. So there you are always dealing two-phase.

CHAIRMAN WALLIS: Well, I'm worried how it's all going to come together, and it really ought to come together in terms of some global uncertainty analysis that someone is responsible for, and that's the University of Maryland that's going to miraculously get there in two months from now.

Is that where it is going to come from? Who is going to pull it altogether into a rational argument, where the uncertainties are properly handled?

MR. BESSETTE: Well, if you say whose job it is, of course, it's University of Maryland, but -- So the question I think you have is --

CHAIRMAN WALLIS: Well, the last time we had a presentation from them, our uncertainty increased instead of being decreased. So it's all going to come together in February?

MR. ROSENTHAL: That's the goal.

MR. BESSETTE: Let me say, we didn't try to exclude the others, and we knew -- and in fact, we had discussed whether we should have other disciplines here, and we had been asked to spend a whole day on the thermal hydraulics. So --

CHAIRMAN WALLIS: I think it's been very useful. The thing is, though, we would like to be able to say at the end of the day, yes, you guys are really on track; we can see you converging to something which is believable and will resolve the issues and will feed into the other analyses. I'm not quite sure that that is what we are going to say to you.

MEMBER FORD: Do you want to go around the table?

CHAIRMAN WALLIS: I think it would be useful to have some comments, yes.

MEMBER FORD: Because I've got some multiple questions.

CHAIRMAN WALLIS: We certainly need to hear from you.

MR. BOEHNERT: I think the presenter needs to be told what to do here. We've kind of morphed into subcommittee caucus here without --

CHAIRMAN WALLIS: So maybe we should finish this presentation. Thanks very much. Jack was going to summarize everything at the end.

DR. MOODY: Can I just ask one thing before --

CHAIRMAN WALLIS: I think we should hear from the members who haven't been so vocal up to now, and some of us have been expressing opinions all along. But then maybe some others would like to.

MEMBER FORD: But before we get into the around-the-table --

CHAIRMAN WALLIS: Maybe you should be first.

MEMBER FORD: Well, no, I'd like to hear from Jack, your point of view as to what your expectations are. I recognize that you are not overall in charge of the whole project. What do you think of the staff's --

CHAIRMAN WALLIS: You need to speak in the mike.

MEMBER FORD: Oh, I apologize. Jack, what is your thoughts on the staff's expectations for the February 5th meeting?

MR. ROSENTHAL: We are clearly not looking for a letter now. I think that come February -- I'm sorry. Jack Rosenthal. I'm the Branch Chief of the Safety Margins and Systems Analysis Branch in the Office of Research, Regulatory Research.

We are clearly not looking for a letter now. This was just for information. It shows you the status that we are. Come February, I think we will be looking for a letter from you, and I think that, as I see it now, that hinges on how we portray the -- how you show you how we've accommodated the uncertainties in all these various disciplines into a reasonably cohesive story.

MEMBER FORD: If you are going to go around the table, Graham, let me start.

CHAIRMAN WALLIS: Why don't you start.

MEMBER FORD: I guess, to a certain extent, this started off by my comments at the January meeting when I asked for what was the substantiation, data substantiation for the RELAP code.

Quite honestly, I've heard -- seen a lot -- I was really impressed by the number of comparisons between observation and the RELAP theory, in addition to the other codes that were talked about, and I was impressed.

I'm not enough of a thermodynamicist -- a thermal-hydraulics analyst to see the nuances between multi-phase and single-phase conditions as they relate to the dominant sequence. I didn't hear much about the adequacy of the scaling factors, and I'm assuming that, because I didn't hear that, it is not a major technical problem in that area, scaling from the test facilities to the real reactors.

I'm unclear as to the treatment of model uncertainties. I'm assuming that the parametric uncertainties will be dealt with in the overall treatment of the PTS system, but I didn't hear anything about the -- on the treatment of model uncertainties.

I've heard bandied around that the RELAP code is fine, because it gives a reasonable prediction of plus or minus 10, 20 degrees C between observation and theory. But I don't know whether that is an adequate criterion, because I don't know how that impacts on, for instance, the frequency of through-wall cracks, if you are plus or minus 25 degrees.

For instance, in your temperature during the transient, if that impacts on plus or minus orders of magnitude in the frequency of through-wall thickness, then that's not an adequate criterion.

I'm assuming that there is not a major technical difficulty in transferring the pressure, time, transients in the fluid into pressure, time, geometrical distance and strain rate in the material; because those are the main criteria that are going to tell you whether you are going to propagate a crack and/or arrest a crack.

CHAIRMAN WALLIS: Do you mean temperature, time?

MEMBER FORD: Temperature, pressure, time, strain rate. Those are the main criteria to determine whether you are going to propagate and/or arrest a crack in an irradiated body.

I was disappointed that I didn't see any material properties, and I'm told that that will be done by the materials guys. I'm just hoping it doesn't fall through the crack between the two groups.

Those are my -- and I really do thank the presenters for showing us a great amount of data between observation today. Thank you.

CHAIRMAN WALLIS: Vic, do have some comments at this time?

MEMBER RANSOM: I don't know. I have to admit some disappointment in the results. Certainly, going back years ago, I think if we had seen some of these anomalies, you know, the first issue would have been to try to understand them and eliminate them, if at all possible.

I'm talking about things like these recirculating flows, the need to turn off the momentum flux terms in some of the models, the break flow modeling which seemed to be inadequate. The stability is an issue in certain of the calculations.

I would find it hard to draw any conclusion from the kind of calculations we just saw. It seemed, from Jose Reyes' presentation, that maybe things could be put on a fairly solid footing from the standpoint of a conservative estimate, but with as many issues that seem to be on the table in the modeling, it's just not clear how to treat that. I'd have a hard time myself trying to decide what kind of conservatism to apply.

DR. MOODY: I know, if you talk to a fracture mechanics expert, they will tell you that their technology is pretty mature, and maybe has less uncertainty associated with it than the fluid mechanics, which gives you the boundary conditions. I can't answer for that, but I just wonder, when you do hit, John, the probabilities, are there large probabilities of uncertainty, or is there a large band of uncertainty in the probabilistic -- or in the fracture mechanics? Is that when it comes to propagating a crack?

I guess the boundary conditions are spatially varying in a time dependent temperature on the boundary of a piece of structure, and the RELAP -- Someone mentioned that the RELAP program had been worked to the state of the art. In other words, how well predictions were made is just about working it to the state of the art of RELAP itself.

Maybe the fracture mechanics show the large uncertainties in the boundary conditions from RELAP but don't translate into large uncertainties in whether you are going to fail or not. Is there any way to make a gross statement that that is true or not? And if it is not -- In other words, if the fracture mechanics showed -- are as sensitive to the boundary conditions as they are to the propagation of a crack or progressing toward a failure, then really you have -- there's going to be a large band of uncertainty in this whole matter.

It seems that the place to start is the -- This is just someone talking who doesn't have to put out budgets or anything like that and has unlimited resources. You want to go back and maybe do a modern version of RELAP with all kinds of improvements or something, make it about as up to the level as the single phase transients that we saw today or single phase comparisons that Jose presented.

I'm just rambling a little bit, but I feel a little bit weak. If someone were to ask me on the outside do you think you can predict this, I'd say, well, we can predict it within this much, and I hold my hands out about three feet apart. It would be nice if it was narrowed down.

I think somewhat of the weakness I feel is in the fluid mechanics, and that's really up for grabs at this point, what RELAP can do, and maybe it's being demanded to do, what it never was intended to do.

That's not very profound, but I just see a range of uncertainty here that, sooner or later, is going to be narrowed down. What did you say, in another 20 years we will be there?

MEMBER FORD: Could I make a comment on that? Fred, there are uncertainties, certainly, in the fracture mechanics side in terms of flow distribution, in terms of fluence -- change of fluence through the very thick vessel wall.

I think the question here is input to that model will be things such as thermal stresses because of these effects, pressurization stresses, strain rates. These are all things which will come directly from this code.

The question is: Is the uncertainty in these thermal hydraulic codes going to markedly change the distribution of the frequency of through-wall cracking? And that's the question that is in front of us, I think, right now.

If the uncertainties are so huge that the 95 percentile of that frequency is way up, 10^{-3}, well, forget it. Forget the 10^{-3} frequency of through-wall cracking. Then you just might as well shelve this whole approach. I don't think it's that, but just taking extremes.

DR. BANERJEE: I guess the problem I have is very different. I really don't understand what is required of these codes. If I had in front of me an expression which says, if you had crack growth rates, say, related to thermal stress and mechanical stress, whatever, in terms of fluence, some pre-factor or an exponent -- If I have that expression, I could work backwards and say at this temperature I require this accuracy. At that temperature I require that accuracy in terms of the gradients, you know, in thermal stresses.

I can calculate thermal stresses. At the moment I don't know whether from RELAP we require accuracy to 20 degrees Celsius to be accurate, 50 degrees Celsius or rate of change of 50 degrees in an hour or 50 degrees in a minute. I have no idea as to what is our goal here.

So in a way, we are saying that this calculation should be as accurate as possible, but it may be that -- You know, I think this is the state of the art. You are not going to get too much better than what we've got today. In two months, certainly not. So more or less, this is what where we are.

CHAIRMAN WALLIS: But, David addressed this question. I think it was in the second or third slide, where there is an iterative process, directly related to your question, Sanjoy, that he had -- I don't know if it was the fifth or sixth bullet he had there. There is an input from the PFM, the probabilistic fracture mechanics, how good do we have to be.

The question is -- The thing is, we haven't had the answer to that.

DR. BANERJEE: Right, and that is why we are sort of in a vacuum a little bit right now.

MEMBER FORD: That is correct.

DR. BANERJEE: So if you are asking -- not you are, but if we are asked to deliver an opinion, we don't really know what the accuracy required of the code is right now. That's where I have problems with it.

CHAIRMAN WALLIS: But if we did it today, then that thermal hydraulics box of Dave's right at the beginning of this morning -- you would put RELAP in it, presumably. What else would you put in there, knowing what you know from this other work? Would you put in something different from APEX, different from RELAP?

DR. BANERJEE: RELAP and REMIX, I guess.

CHAIRMAN WALLIS: REMIX didn't do a very good job. So --

DR. BANERJEE: Maybe it doesn't. I didn't know.

MEMBER FORD: But it's conservative, isn't it? That's what I remember.

MEMBER KRESS: It didn't appear to do a very good job when you compare it.

CHAIRMAN WALLIS: Do you guys know what you need to put into that box called thermal hydraulics in the overall slide that Dave showed this morning? You have to know what you need to know. You have to go after it in a systematic way.

MEMBER KRESS: I think we are asking the wrong question when we ask the question how good does RELAP have to be. I think the question we need to ask is how good is it. We need -- because that's what the whole thing is about, and we need to figure out how to translate what we have into the actual uncertainties in RELAP in predicting the PTS transients, and that's the only focus.

To some extent, these other data and other things we've looked at, like, for example, the MIST test, in particular, are somewhat irrelevant to that question; because they don't really apply that well to PTS transients in my mind. So they confuse the issue, and I'm not sure.

That's one reason I asked the question of how are you going to use this data and translate it into an overall uncertainty analysis, and I think that's my biggest question right now, is how are you going to do that.

A lot of these things that we heard are, in my mind, just things you are not going to use at all, a lot of the ROSA tests and the MIST tests.

I certainly think the work at OSU is right on the mark, and that definitely can be translated into some sort of useful interpretation of the uncertainties, and I think that should be the focus of a lot of it.

I'm not sure it covers the full range of tests and PTS sequences that you need, but I would certainly make as much use of that as I could, because that's good stuff.

We don't like compensating errors. So I think another big question in my mind was the mixing, and in the sense that you seem to get -- The mixing gets the right answer for the wrong reason. I don't think that can be tolerated very long. So you need to address how that can be dealt with, with using RELAP in the uncertainty analysis in a better way.

I don't how that is to be done yet, but it's, clearly, to me, the -- It showed that some of the 3-D effects are important, and RELAP can't handle 3-D as it is. So you have to deal with it in an uncertainty space somewhere. I don't know how to do that yet, but that's an issue with me.

I guess that's the major part of my comments.

MR. BESSETTE: One of the points that you just said was, when you look at a RELAP comparison between one of these tests, MIST or whatever, and you see some difference, like we've said, there is still the question of what does that mean in terms of the plant; because the facility is not the plant, and the model of your facility -- the RELAP model of your facility is not necessarily a facility, and there may be --

MEMBER KRESS: You are exactly right.

MR. BESSETTE: -- modeling errors you have made. I mean in terms of the code input. So the comparisons we have shown you themselves don't represent some sort of a bottom line.

MEMBER KRESS: Yes, and that's why I think I have difficulty figuring out how to use them.

MR. BESSETTE: So like when we did like CSAU, for example, they did not directly use comparisons of TRAC with an integral system with a LOFT test as being -- show crack versus LOFT data and saying this is the TRAC bias or uncertainty. We didn't do that at all.

MEMBER KRESS: Well, I see two ways you can use integral test data. One of them is, if they clearly show a bias that you can just put into your code like they did with -- I guess it was the Framatome people for the large break LOCA. But if you can clearly pick a bias out of your data and it's applicable to PTS, then you could almost apply it directly.

What I would be tempted to do with integral test data is back out of it the separate effects things that caused the differences in the results, and put my uncertainty then on those separate effects models that exist in RELAP and treat the uncertainty that way. But that's a tough job to do, and I'm not quite sure how you do that, but that's about the only way I see to use integral data.

You have to back it up in terms of what models are giving you those differences, and get some sort of uncertainty on those particular models.

CHAIRMAN WALLIS: If I look back at Dave's presentation on slide unnumbered, page 2, there's this analysis procedure, and there's something called thermal-hydraulic analysis, and it leads to pressure and temperature versus time. I guess it also leads to heat transfer coefficient.

That's all it leads to. Then if I look at the CSAU, I find that that's probably not good enough. I've got to do a quantifying of uncertainty, and I've got to select uncertainty representative scenarios. That's all it has to do.

So you have to figure out -- and I don't think this is a trivial exercise -- how all this information which is coming in from everywhere to us today, a lot of which was very interesting, fits into this purpose of getting the question of temperature, heat transfer efficient and uncertainty on those things versus time, which is what you need -- the information you need to hand to the next step in the process. That's what you need to do.

I don't think that this information transfer really cares whether or not there is mixing in the HPI line and all that. That is physics that goes into the output, but once you hand over something to the PFM people form the thermal-hydraulics, they don't care about whether there was mixing in the HPI line.

They just want to know what do I put into my analysis as conditions in the downcomer, and what's the uncertainty on those things I put into my analysis. That's all they need to know.

MEMBER KRESS: Either that or they need to know on the very high end of the uncertainty.

CHAIRMAN WALLIS: I think this is where maybe not enough effort has been put in yet. It's very tempting to say, oh, let's look at some more data and try to figure it out and try to figure out what happened in AP600, the ROSA tests, and there Jose has done some very interesting stuff, and I'm very pleased that CFD is predicting some of his results.

How do you take all that and use it in this engineering technical analysis of pressurized thermal shock? I think that's where you've got to be very disciplined and very rational and have your arguments really put together in a way which is convincing. But I don't know how that is going to happen.

MR. BESSETTE: Well, the approach -- you know, the approach we had been following is we take this -- We, say, write down a list of what are the most important factors that are going to affect my bottom line of pressure and temperature, and list those, and say, well, now how well -- So we came up with a list of about 12 of 13 parameters --

CHAIRMAN WALLIS: Eventually, someone has to predict these as -- hand over these pressures and temperatures.

MR. BESSETTE: So that shows us what we have done. So now we've got these 12 or 15 factors that we believe dominate the answer, that are the most important factors. Then we vary these.

CHAIRMAN WALLIS: That's right.

MR. BESSETTE: And generate some distribution or whatever. So that's what we've done. Then I think the question was posed of, well, how do you know -- So you are varying these using a tool, some RELAP, a base case calculation. How well do you know your base case calculation?

From that, I think you have to turn to assessment results. You know, when you do assessment results, you don't get a nice, tidy picture, this is my answer. It's ten degrees or something. You get answers that sometimes look very good, sometimes don't look so good.

There's a lot of different things you can look at in assessment. It's almost an open-ended task.

CHAIRMAN WALLIS: But if you can identify that this assessment is better if I get a better understanding of, say, whether or not I am going to exclude momentum flux terms or something like that, that's a lesson you've learned, and maybe this is something you have to feed into your black box that spews out these pressures and temperatures. You have to have uncertainty on something about whether or not you are going to include the momentum flux term or something.

You identify that. Then you put those in quantitatively into your uncertainty analysis.

MEMBER KRESS: Well, now you can work your approach in reverse. Take your ranges you have already decided on for your uncertainty. Put them in your code, the model of the test and see if the uncertainty range does back the actual result you get. That would be -- You know, that would give some level of confidence in what you are doing.

DR. BANERJEE: Do you have any measurements in the downcomer of temperature in two-phase conditions in a large enough facility?

MR. BESSETTE: Well, yeah. When we talk about two-phase, we mean -- What I was thinking of our meeting was that we got two-phase someplace in our system. Now in terms of what we are saying, do we have two-phase in a downcomer --

DR. BANERJEE: Or in the cold leg.

MR. BESSETTE: So a lot of times, most of these transients then, we are ending up with two-phase in the cold leg, and most of the transients will end up with steam in the top of the downcomer somewhere around the cold leg on up, and liquid below that.

DR. BANERJEE: Right, but the large breaks will be liquid coming into a relatively voided downcomer. Right? And the issue there would be whether this liquid is cold and this tongue of liquid coming down gives you a high thermal stress in some region that it cools the material rapidly, and also maybe spatial stresses.

Do you have any data of that type at all?

MR. BESSETTE: Yeah. So we looked at, let's say, an extreme of a large break where you are dumping in a lot of cold water, and you've got a lot of steam around. There, the first thing you have to be able to do is to have the condensation in the cold leg just about right.

I think, as you heard before, what we've seen in the LOFT or UPTF is that the condensation in the cold leg is sufficiently efficient to preheat the downcomer water to saturation. Now the other thing about -- If there are periods when you are putting in -- doing the accumulator injection, you would be putting in more water.

You would be putting in so much water that you soak up all the steam, and you still have some subcooling left, a little bit of subcooling left. That's accumulator exhaust. Then you would go back to low pressure injection, and you get -- Now you have more steam than water, basically.

So you heat up all the water to saturation. So what we've seen back from large break days is we get enough condensation in the cold legs to basically heat up the water to close to saturation, if not saturation.

CHAIRMAN WALLIS: Can you put some sort of uncertainty on that which is convincing? If the range of uncertainty is high, then you could end up with some much colder water.

MR. BESSETTE: Yes, I think we have enough -- we've done enough comparisons in the past.

CHAIRMAN WALLIS: So this direct contact condensation is well enough understood that you can predict?

DR. BANERJEE: It's probably incorrectly predicted in the codes, but you've got the experiments.

MR. BESSETTE: That's right. So there may not --

DR. BANERJEE: You may not need the codes.

MR. BESSETTE: You have to first look at what your code is predicting to see if it's -- because -- Then in terms of the details, it's even more complicated, because you got slugs of water that can move back and forth across the injection location, which is what happened in the experiments.

DR. BANERJEE: But what comes out in the downcomer? Are there any experiments for large break LOCAs where the downcomers were instrumented with thermocouples, and you knew the temperatures -- the large downcomer, not a small downcomer?

MR. BESSETTE: There probably were wall temperature measurements.

CHAIRMAN WALLIS: UPTF-- Did UPTF do that?

MR. BESSETTE: UPTF doesn't start with a very hot downcomer. You know, it starts off about a 300 degree Fahrenheit downcomer, not a 550.

CHAIRMAN WALLIS: Are we running out of things to say now?

DR. BANERJEE: I think you may have enough of a matrix of cases, if you piece it together, would support an argument of the type that you are making, that for the large breaks the water is pretty close to saturation, you know. Then you've got steam there.

You may have. It seems very reasonable to me.

CHAIRMAN WALLIS: Then you're going to argue that for the smaller breaks, it's mixed up -- For other reasons is well enough mixed. Right. Okay. Well, let's see if it all comes together.

MR. BESSETTE: So it's a very complicated puzzle that you have to piece together.

MEMBER RANSOM: Well, one suggestion I would have is: I know it's rate of cooling of the wall, which is important from a thermal stress point of view, and I would suspect that that is what they would want from this, not downcomer temperature.

MEMBER KRESS: It's both.

MEMBER RANSOM: Rate of cooling?

MEMBER KRESS: You have to have both.

MEMBER RANSOM: Well, it's rate of cooling, I would argue, regardless of what you say.

MEMBER KRESS: Yes, you have to have rate of cooling, but you have to have the actual temperature.

MEMBER RANSOM: Rate of cooling over time.

MEMBER KRESS: Yes, but you have to have the actual temperatures, too.

MEMBER RANSOM: So it's both a matter of how much cooling do you do over a long period of time and also the rate of cooling which produces stress.

I suspect, if you talk to the structural people, the wall has a time constant associated with it, a few hundred seconds or whatever, of which changes in temperature over that period of time are not very important.

One technique would be to do a time average, sliding time average of these results in which you wipe out the noise, you might say, which is unimportant from a thermal stress point of view. That would tend to predict a more rational behavior than, say, the sporadic type of oscillations that you see.

It might also provide a means of then establishing what uncertainty do you have in this integral rate of cooling of the wall, so that you could provide a bound, you might say, from this work. But it does seem there needs to be somebody from the structural side saying what do we need or is this satisfactory.

MEMBER FORD: But that is in their format. Item 6 in this uncertainty analysis is feedback from the PFM people as to what they require. That's not known, I guess --

DR. BANERJEE: If it's a time average of 300 seconds, it's very different from, you know, instantaneous value, because the meandering stream or whatever jet falling down plumes. Doesn't matter. I mean, over 500 seconds the average is a nice Gaussian distribution.

CHAIRMAN WALLIS: Well, just to give my feeling from experience with all this is that, if I were a consultant working on this problem, I would say I'm going to take some time to get all this data and stuff that you've showed us and learn about all the phenomena.

Then I'm going to take some time to condense this down into something which is usable for analyzing PTS. My experience would be that the second task is just as demanding as the first, and I'm not sure that you have a strategy or have done very much of the second task.

Maybe you've done a lot of it, and we just didn't hear it. But I hope you have, because that second task is demanding, putting it altogether into something which is actually usable to make convincing analyses which will stand up to examination.

That's what we are going to hear about in February?

MR. BESSETTE: Yes. So far it's taken up all our time to do task one.

CHAIRMAN WALLIS: Yes, but you know, I think you know what I mean there.

MR. BESSETTE: Yes, I know. That's what I had in mind for task.

CHAIRMAN WALLIS: Anything else we need to say?

DR. MOODY: I think it was the time constants. I want to go over that. When you have something like Sanjoy. You took an experiment, and you broke, what, a glass tube by throwing cold water into it?

DR. BANERJEE: Condensation shock. You do it every time, yes.

DR. MOODY: Okay. Was that water hammer that broke it or was it --

DR. BANERJEE: Well, it was just the shock.

DR. MOODY: Not thermal shock?

DR. BANERJEE: Not thermal shock.

DR. MOODY: Somebody took a glass out of the drier. Was that Dave? And you put cold water in it, and broke. Is that the rate of temperature change that does that, according to what Vic was talking about?

MR. BESSETTE: Yes. It's the same thing, of course. I put the glass on the counter, and I pick it up 20 seconds later, it won't break.

DR. MOODY: Because it's down -- because the temperature rate goes down, because the glass temperature has gone down.

MR. BESSETTE: The rate of change is important. The rate of change -- the time constant, the rate of change of temperature, and the absolute temperature are all three --

CHAIRMAN WALLIS: And also flaws in the

glass.

MR. BESSETTE: And the flaws in the glass.

DR. MOODY: What about a case where you have suddenly spitting on a hot glass with cold water relative to moving a boundary like the water in the downcomer or something, and steam above, if you're moving up and down this way? I guess wherever the boundary crosses a point on the wall, you get a transient -- or you get a gradient, a time gradient. Right? And you also get a space gradient.

What is it that makes it crack? Is it both the space and the time gradient, or what?

MR. BESSETTE: Let's see.

DR. MOODY: That would sort of put a bound on what you really got to get out of the thermal hydraulics, wouldn't it?

MR. BESSETTE: See, the fracture code tracks the stress continuously. Their time step is one second. So they track the thermal gradient and--

DR. MOODY: Spatial or both time and spatial?

MR. BESSETTE: So they update the conduction equation once per second, and so they track that, and at given time intervals they take these, let's say, snapshots of --

DR. MOODY: Profile?

MR. BESSETTE: They generate the stress field, and then they do the fracture calculation from the stress and temperature and --

CHAIRMAN WALLIS: I think there's some uniform conditions around the periphery, jets and plumes and things.

MR. BESSETTE: So they are using -- speaking on the topic of plumes, they use a single temperature boundary condition. So there is no axial, no circumferential.

CHAIRMAN WALLIS: No axial variation?

MR. BESSETTE: No.

DR. BANERJEE: And no radial variation?

MR. BESSETTE: And no circumferential, no axial.

DR. BANERJEE: I see. So it's just the wall is changing in temperature.

MR. BESSETTE: A single fluid temperature, a single heat transfer coefficient, and then that's the boundary condition for the conduction equation.

MEMBER KRESS: Strictly radial heat transfer.

CHAIRMAN WALLIS: Extremely idealized.

DR. BANERJEE: That's probably is not what is really happening, because you are probably getting a thermal gradient sitting somewhere.

MR. BESSETTE: Well, you see, the top of the core -- So the top of the core is about five feet below the bottom of the loop elevation. So where you are most likely to see these sharp thermal gradients in the fluid is up around the loop elevation.

DR. BANERJEE: That wasn't what Jose's experiment was showing. He saw a sharp gradient about halfway down from the nozzle.

DR. MOODY: Well, are we providing the wrong boundary condition with RELAP then or not the complete boundary condition that would be needed? See, maybe I'm still a quarter-lap behind, but I can see a cold level rising up on a flat wall that's hot. I can imagine where would that level go is right at that point. All of a sudden there is a very rapid time dependent change in temperature in the wall. But even at the same time, depending on how fast this level is moving around, there may or may not be a spatial gradient in the wall.

Maybe I'm asking the questions that don't really apply. I'm thinking more in terms of what happens in the wall, and I think we are really focusing on RELAP or a boundary condition. But maybe these kind of ideas help you focus on what do you really need out of the thermal hydraulics to give you the boundary conditions that are going to be the most appropriate to apply to a wall or a piece of metal.

MEMBER RANSOM: I think you're right, Fred. What the materials people ultimately want is the temperature gradient through the wall, because it is what is producing the stress. You know, it's the linear coefficient of expansion, the inner part of the wall is going to be in -- I guess we are cooling it off -- going to be in tension. Ultimately, the inner layers will rupture, and that's what causes the crack to propagate from the flaw that is presumed to be there.

I think that methodology is pretty well developed from the structural side.

CHAIRMAN WALLIS: Well, it is if you don't have some of these variations around and up and down. If you get this sudden -- this layer that Fred is talking about, then you've got something --

MEMBER RANSOM: Well, that is why it would be interesting to find out, but normally it's the gradient through the wall more than it is, say, the circumferential or the axial gradient.

DR. MOODY: If this was a wall, this

table, and you had a circle of cold on it just suddenly applied, then wouldn't the same thing apply as it tries to shrink and pull in?

MEMBER RANSOM: Yes, sure. It will.

DR. MOODY: Okay. So we can have both.

CHAIRMAN WALLIS: Any non-uniformity in temperature.

Okay, are we ready to call it a day, quarter to six? Okay, well, we will close the transcript and the meeting, and we will meet again tomorrow morning. We are going to recess until 8:30 tomorrow morning.

(Whereupon, the foregoing matter went off the record at 5:47 p.m.)