MR. WU: As you may have noticed, the entrainment rate test has a lot of irregularities in the slug and oscillation. But the entrainment onset data is grouping very well. At least our data, the Maciaszek correlation predicted our data reasonably well.

And also Schrock and Smoglie's correlations also was predicted their small branch of data very well.

So we think we have the hope here to do some more research modeling to bridge these two models and to try to find the physics behind it.

What we did here is we followed Maciaszek's approach. Basically what his approach is, which is the wavy ring, the diameter, you go to the off-take diameter. And we think the liquid level goes far away from the break. The wavy ring is getting bigger and bigger, so we try to use importation flows theory to find that ring change.

So what we did is we used a mirrored distributed sink using potential flow to find the velocity distribution, allowing this X line.

Like Dr. Schrock pointed out, if we can find that somewhere the velocity goes to maximum, that means the pressure there is minimum, then we say, well, the bumps are supposed to -- the wave will crest -- is supposed to be at that location. So that's our rationale.

So we write -- we wrote this velocity distribution using potential for theory. And we tried to -- well, we kind of get the analytical solution. So we went to a numerical solution to check it.

The upper corner of the figure is the velocity at the -- the velocity on the interface versus over the velocity in the average velocity in the branch. And this is so a distribution, allowing the interface, go away from this interface.

We found the crest can never move into this break. That means when they -- this varies. This -- that should be -- all you can say is a liquid very approach to the break, then that mandates you go to the D. But when the level go away from the break, then maximum point is drifting away.

So we're trying to find the maximum point, velocity maximum point. That's the dotted i on the right side of the figure. And you say, well, that's when -- that's the limiting case is you go to wall. That means the diameter of that wave crest, you go to the diameter.

And the way it's drift away, the

asymptotic condition matches the point sink, mirror point sink, sink condition. That's one point -- the square root of 2 of h_b.

So that's -- basically you say, well, the wave crest diameter is equal to the -- A is proportional, directly proportional to the gas chamber height.

So if we put this number into the correlation originally Maciaszek developed, we found that the number is this term. When the h_b over d, that means the -- a gas chamber height versus the break side is getting very big, then this correlation approaches to what the Smoglie and Schrock's correlation, as it goes to the fifth power.

And when this h_b over d approach to zero, that means the level approach to the break, this term goes away. Then you get the one here. That means the correlation approach to Maciaszek's correlation gathers the one-third power and the diameter of the bottom.

So we thought that this is a nice approach to this bridge this small-break correlation and large-break correlation. And both of them proved right.

And then we -- we just have one adjustable coefficient, similar like what they did. With this coefficient, .5, and the theoretical value of this coefficient is .4. So we were very, very satisfied. It brings them together and both are satisfied.

However, when we look at this we still have a scattering. Again, make -- Kent, Mr. Welter pointed out, KFK data has a lot of scattering. Schrock's data and our data has risen in the group very well.

So if we take out these blue squares, I think this correlation is -- and we did the sensitivity analysis. The standard deviation of this, only Schrock's data and our data, it's like 30 percent off. By the way, Smoglie's data then, the error is standard. It goes to like 15 percent.

Well, this approach, like Dr. Wallis pointed out, is for the flat -- flat top without the confinement of a side confinement. And our approach didn't consider the side confinement.

So basically our approach, you say, well, the infinite place, the liquid velocity is -- the gas velocity is supposed to be zero. Then for our case gas is confined in the main pipe. And the infinite place is so that the gas velocities are supposed to not be zero. So we modified that.

Then we got a new correlation, is the same. But it has two adjustable parameters. I don't like it because if you get an x for parameter, you can fit everything. So -- but, nevertheless, what is necessary what's is a collapse of -- it's like a 20 percent standard dev- -- very well the data.

So as a summary of entrainment on the -- before we go further, I still want to go back to visit this flow regime transition.

And the red line, solid line is the symbol of Wallis' slug flow transition. And we use a -- since we don't know the -- which flow direction come, we say, well, all the gas flow in the branch coming from one side of.

So it's all this in this plot, our data follows this very well for all regime transition.

And also Schrock's data -- one group of Schrock's data also follow this line very well. And the way I checked it, it's the -- the diameter is the -- the break diameter is about 17 --

CHAIRMAN WALLIS: So I'm trying to figure this out. Which of these is this slug transition?

MR. WU: The red and solid line.

CHAIRMAN WALLIS: That one that goes through your data?

MR. WU: Yeah. And then I have a 20, 20 percent. And then a bracket dashed line is the Smoglie and Schrock correlation.

CHAIRMAN WALLIS: They seem to be just two different families that are completely unrelated --

MR. WU: You see here you have some...

CHAIRMAN WALLIS: -- on this plot.

MR. WU: Yeah. This plot doesn't have the diameter effect inside. Well, I show this plot as the -- one purpose is to say, well, if we treated this as a small break and this as a large break, I think anything should be between these two.

So if you run a sensitivity calculation in your code, you can treat this as two asymptotic conditions, like we just discussed for the theoretical. So anything else should happen between these two.

CHAIRMAN WALLIS: So the mechanism of a small break is this sort of potential flow sucking out from the surface. And the mechanism for the big break is sort of similar, but it's really a civility of the big-wave criteria.

MR. WU: Interface, because we -- we based on the interface wave a gross, that delta gross, so it's -- it --

CHAIRMAN WALLIS: The momentum of the gas and the -- it's a Froude number in both cases.

MR. WU: Yes.

CHAIRMAN WALLIS: But it's a different --

MR. WU: Yes, sir.

MR. SCHROCK: Now the coordinates on this graph seem to be the same as in an earlier slide where you showed the Berkeley data.

MR. WU: That's right, yeah.

MR. SCHROCK: And somehow magically now it's separated into two groups, which seems strange. I don't understand how you managed that.

MR. WU: No.

MR. SCHROCK: Coordinates are unchanged, but now the data seem to plot as two distinct groups.

MR. WU: No. It changed -- this to the Froude number in the main pipe based on the velocity in the main pipe, the superficial velocity in the main pipe, and the Froude number.

In the previous one, your model and --

MR. SCHROCK: Well, you don't put numbers on your pages, but I go back to one that's got a big -- three test results, onset of entrainment, -- that's quite a ways back -- has exactly the same coordinates as this one.

MR. WU: Yeah, that's right. We used the two group of --

MR. SCHROCK: FR1, the square root of rho g1 over delta rho. It's the same thing, but --

MR. WU: Yeah, this figure. Is that what you...

MR. SCHROCK: That's the one.

MR. WU: Yeah, that's the same -- same coordinates. Using this Froude number is based on the superficial velocity in the main line, not based on the velocity in the branch.

MR. SCHROCK: Well, look, you've got to define your terms and use notation to convey what you mean. You can't expect we're going to understand different interpretations for the same notation.

MR. WU: Well, this is a different approach. The one we go through -- went there the model development, that one, is following you and Maciaszek.

This one is just to show you the finding we found, to say, well, it's basically -- the horizontal 9 has a Froude transition for the larger break. It matches what our argument is, an entrainment happens, so for the larger break is like an interface, a wave,, instability on the interface.

And for the small-break case, maybe a potential for the large going up.

So it's -- eventually I want to say this is the two-boundary condition. One is to emphasize what I say, for small break and the larger break, it's a true asymptotic condition. And the real data should lie between these two. That's from --

MR. SCHROCK: Let me try one more time.

MR. WU: -- a larger point of view to argue my point.

MR. SCHROCK: Let me try one more time.

In engineering communications we have certain principles that have to be followed. And one of them is that you define your terms clearly. You set down the notation and define what the notation means physically.

MR. WU: Um-hum.

MR. SCHROCK: And then you don't use the notation redundantly. And I think what I've heard you explain is that FR1 on one graph is different than FR1 on the other graph.

MR. WU: No, no. We use only one FR1 here. We didn't use any other FR.

MR. WELTER: Sir, this is Ken Welter.

These are -- this is for the onset of

entrainment. The graph we showed you previously was for entrainment rate, so those are different datasets. This is for the onset of entrainment, this graph. The graph that we were previously discussing is for entrainment rate. So they're different datasets, but it is the same FR1.

MR. SCHROCK: This -- this one is onset of entrainment.

MR. WU: Yes.

MR. SCHROCK: The one that began this discussion is number 5, model improvement. Entrainment onset criterion.

MR. WU: Yes.

CHAIRMAN WALLIS: That's where it's the same FR1.

MR. WELTER: Could you go to the last slide that we were at?

CHAIRMAN WALLIS: I think we're mixed up here.

MR. WELTER: One more.

MR. SCHROCK: Well, I'm -- I'm trying to resolve in my mind what you've done that produced the result that --

MR. WELTER: Okay. That was wrong --

MR. SCHROCK: -- that our Berkeley data --

MR. WELTER: Is that right?

MR. SCHROCK: -- separated into two clear and distinct groups, which I never saw in our data.

CHAIRMAN WALLIS: Where are the two groups?

MR. SCHROCK: Well, it's the --

MR. KRESS: On this curve you've got --

MR. SCHROCK: It's the sort of ghosty dots.

CHAIRMAN WALLIS: "...ghosty"?

MR. SCHROCK: Yeah. Light colored gray dots. There's a set of them on each of those lines.

MR. KRESS: Down here and also down here.

CHAIRMAN WALLIS: Oh, those are Schrock's up there?

MR. SHACK: Yeah.

CHAIRMAN WALLIS: Well, I think that's a mistake.

MR. KRESS: There must be some mistake.

MR. SCHROCK: Well, is there a mistake?

MR. WU: No.

CHAIRMAN WALLIS: I'm really puzzled by these ghostly data. The Schrock data lie exactly on both curves, so that's pretty well. That's really strange.

MR. WU: You mean these lines?

MR. SCHROCK: Well, they always lie on whatever curve you choose.

CHAIRMAN WALLIS: Something is very peculiar.

MR. WU: Well, this -- this is a different --

MR. KRESS: It's a quantum effect.

MR. WU: This is based on the main line superficial velocity. It's not based on the branch line super- -- I just tried to present this from a different perspective, from the flow regime transition perspective. It's different from what we just discussed about the entrainment from the vertical.

CHAIRMAN WALLIS: Oh, I see what you mean.

MR. WU: Yeah.

CHAIRMAN WALLIS: It's these strange gray things, though. And Smoglie doesn't have any data. So those are the Schrock data, those square things, or those are the Reimann data?

MR. SCHROCK: No. Those are -- those are KFK data, Reimann and Kahn.

MR. WU: Square KFK data.

CHAIRMAN WALLIS: So the mystery is why there's some Schrock data on the Wallis line. That's the thing which is the mystery.

MR. KRESS: There you go.

CHAIRMAN WALLIS: And why this?

MR. SCHROCK: We never would have expected that.

(Laughter.)

MR. WU: Well, sometimes it has to agree with you again.

CHAIRMAN WALLIS: On the wrong line.

MR. WU: And this is -- we weighted -- we just -- what we did is your branch gas flow rate we are showing as coming from one side. And this data is a relatively larger break, and it's coming from -- that's -- we didn't do anything.

It's the same abiscus for the previous sets of data, but we just changed the perspective. We changed the velocity for -- from the branch to the main line.

What I would like to say this figure is, again, I want to say is one-fifth and one-third all here is for the flow regime transition. It's represented to boundary condition. I think the -- anything should happen between these two, and that was what we did to bridge these two together.

So as a short summary of this model

improvement for entrainment, the onset criteria, for Smoglie and Schrock's correlation, it's based on -- well, Smoglie did -- single-point sink, no interface effect, and the effect was far from a break or small break case.

For the Maciaszek, based on Wallis' interface instability argument, he uses a wave crest interface instability kind of option and chooses a crest, wave crest, as the basing and as the break diameter. And it is effective for the larger break or the liquid level is very close to the break.

For the new model we proposed, wave crest, this basing is a function of the onset height. And you -- and valid for both and it can be reduced to Maciaszek's situation and Smoglie and Schrock's correlation's case.

So that's what -- it was a challenge to us because we cannot come up with something without considering the previous contribution.

So I think we have the physical interpretation here, and it's -- the data is -- not much irregularity there because -- so we think this is a good model.

For the further improvement, improvement data, based on what we say is the velocity in the --

gas velocity in the pipe is different from the open kind of case of flat pipe. So we made a further improvement.

However, that made the correlation more complicated. And we have two adjustable coefficients.

And for slug flow transition, I don't know if we can use it a whole lot. We need to go do a further analysis. Until we know which side, how much gas is coming from which side, then we can revisit that kind of argument.

But for previous KFK data and the Smoglie data, they -- I show them as coming from one side, but the aperture is -- the break is so small, so basically the gas flow velocity in the main line doesn't contribute too much.

So we -- it is suggested one of the logical, we just jump -- tried to jump out of the loop seal, is there any other simpler option for us to take. That's it.

For the model improvement of entrainment rate, again we -- we have -- we follow the similar approach, argument of h over h_b, the actual gas chamber height versus the entrainment onset.

The rationale, as I say, any excess of this kinetic energy of a gas or that contribute to the pressure difference from the interface to the break, overtakes the gravity. That excess of kinetic energy is going to the liquid kinetic energy.

And when this liquid velocity and mass velocity is equal to zero, left aside, this equal to zero, that gives us the entrainment onset condition. Using this argument, we derived -- the equation quality in the branch is equal to this function. It's a function of density ratio. And the function for the h over h_b, plus there's another one, is the diameter effect of the break.

MR. SCHROCK: Is that derivation available to us?

MR. WU: Yes. Yes. It's simply, just put that k in front of this group, the right-hand group. Then we can straightforward again.

CHAIRMAN WALLIS: Then you must use some kind of a one-dimensional theory, or something, because --

MR. WU: Yeah. The --

CHAIRMAN WALLIS: Or does the k take account of two dimensionality, or...?

MR. WU: No. The only thing coming from this part, that's the -- say were the -- we are shown the -- a liquid of void fraction in the branch is a function of h over h -- 1 minus of h over h_b.

CHAIRMAN WALLIS: But these V_f3s, V_g1s, these are averages across the whole area. It's a one-dimensional --

MR. WU: Yeah, that's right.

CHAIRMAN WALLIS: -- approach.

MR. WU: That's right.

What --

MR. SCHROCK: What I asked is, is the derivation available to us? Can you tell us, are we going to have that derivation? Is it in a report that we're going to get?

MR. WU: I can do it right now here, if you --

MR. SCHROCK: Hmm?

MR. WU: I can do it right on the blackboard, if you prefer.

CHAIRMAN WALLIS: Now is this compared with data somewhere?

MR. WU: No.

CHAIRMAN WALLIS: The new --

MR. WU: It cannot solve that jump. So what we compare with Smoglie -- Schrock's correlation, for the D -- this -- this 9 can be treated as you have fixed the gas flow rate. And as you change the liquid flow rate to change the quality.

In such a case the h_b is a constant because that's based on the gas flow rate. And you see the diameter ratio is when this is about one-hundredths of the h_b should be, that's very close to Smoglie's situation.

The KFK correlation actually exactly is shaped like this. Unfortunately, we didn't put on that figure because it has the densi- -- has several. I don't know. Previous, last year we put on a figure.

This year we -- I can't -- in a final one, I will show you how this -- and also for Schrock's data, it's about 17 to 30. So this is a tenth of it. So it's -- the correlation goes through it.

When that break is getting bigger, then it's going up like this. It's more like our data case.

CHAIRMAN WALLIS: You said there was Smoglie correlation down the bottom there that we can't see?

MR. WU: Smoglie, no, we didn't put it here.

CHAIRMAN WALLIS: You said he was close to the bottom curve?

MR. WU: Yeah, that's right.

CHAIRMAN WALLIS: The .01h?

MR. WU: Yeah. It's the --

CHAIRMAN WALLIS: Smoglie is down there?

MR. WU: They have a data only in this -- in this shortened mix, very high quality data. And their correlation, all of the way we extrapolate it to zero quality. That was in Schrock's report, too, to mention to the KFK.

And this correlation doesn't express one thing -- let me -- okay. In our data we have a jump like this. What this give us the trouble is for one h liquid level you have two qualities. That means using there's -- like you said, before you mentioned, maybe it's related to liquid flow rate or gas flow rate explicit and beside the h_b.

And otherwise, only use the information of h, we can't gather this bump like that. And that's what we are working on, trying to see averages.

You will see later a behavior, see if we can -- and amazingly we -- we found these -- out of the turbulence here you will see -- in this region is actually -- I will say the ration occurs (phonetic). And the way it's flattened out is like a high gas, very -- no liquid flow rate. The oscillation disappear.

So the bump itself, it's coming from that. It was initiation behavior. And we try harder to get an average parameter to represent it. And we are still working on.

CHAIRMAN WALLIS: Are you sure there's a curve. Earlier where h over h_b was bigger than one.

MR. WU: Yes.

CHAIRMAN WALLIS: And here it's less than one. Are these different data or something?

MR. WU: No, no, no. Then we use the average h -- h in that previous --

CHAIRMAN WALLIS: In the other one. No, this is the h on the --

MR. WU: We are trying to say this is the high side.

CHAIRMAN WALLIS: So this is the h on the reactor side here?

MR. WU: Or 4 times vessel size.

CHAIRMAN WALLIS: Vessel size.

MR. WU: Oh, no, the steam generator size. That's the higher part, because it was originally -- when you see -- when you saw the experiment at lunch time, there was initiation actually occurs downstream of the branch.

CHAIRMAN WALLIS: So if you're going to

use this in a system-solving computer model, you'd have to somehow predict h over h_b, then you'd predict h -- x3 from that; is that what you'd do? And the problem with yours --

MR. WU: This is the traditional approach.

CHAIRMAN WALLIS: The problem with your curve is you don't know which one to pick. And the fact that it's going to curve up again, you get three xs for the same h or h_b.

MR. WU: Yes. So that's got to be related to the gas velocity or liquid velocity. That's what we are -- we are trying. Right now we only use this simply -- simple representative. If you don't consider the other, then you've got this -- you cannot find this bump, and you can't -- and that means use h over h_b and x as a correlation, you miss something important.

CHAIRMAN WALLIS: Well, my comment in all of this is what I saw in the experiment. It seems to me you need a dynamic analysis, so the rate of build-up of liquid in the plug which goes to the steam generator, when it comes back, you sweep some out the pipe, how long it takes to sweep that out depends upon sort of the length of the pipe to the -- to the air-water separator, or something.

All these things are very system dependent, aren't they? So you really need a system model in order to predict the entrainment.

MR. ROSENTHAL: Yeah. And why don't we let him finish the presentation, and then Steve can make some comments about our intent, how we can ultimately use this and track that.

MR. BAJOREK: One question on that last figure. The bump there, --

MR. WU: Yes.

MR. BAJOREK: -- does that include the -- both the -- with the block steam generator and without the steam generator? Is that all the data together?

MR. WU: Yes. Waves of -- but waves of the steam generator with a returning line, it's calmer, but it still have a bump.

MR. BAJOREK: Would you still get that bump --

MR. WU: Even Schrock's data has a small bump there. If we go back. Please, go back. Go back. I think go more, just go ahead. Go. Go. Go. Okay.

You see this, you called it ghostly. It has some...

CHAIRMAN WALLIS: This is the one where

the Schrock correlation has no relationship to his data, or not much.

MR. SCHROCK: I haven't gotten it figured out yet.

MR. WU: It's actually published in the left --

MR. BAJOREK: Well, you see the hump even more when you plot it in what you call h2, in the other one. That is when you don't use the average the hump is even more.

MR. WU: That's in your --

MR. BAJOREK: Yeah.

MR. WU: -- actually we tried to see which side we're going to use. When we use h2 we brought it down. But in this one we didn't know it.

In your handouts actually have a lot -- has a lot -- another figure. It's -- I use a steam generator side of the gas chamber, and it can bring it to about below one.

Well, we can go back.

MR. SCHROCK: Well, my recollection of our data is that they did not look like this against our correlation. I'll have to dig that out and refer to it to understand what's wrong here.

MR. WU: Shall I proceed?

As a summary, we built our database that actually covers all the branch separation cases. And we picked out the material related to the vertical branch entrainment. And we found the data is -- the correlation works for small breaks, but it doesn't work for the larger break.

We build our percentages relatively complicated in that like Dr. Schrock and Dr. Wallis pointed out. And it's amazing, we run a test of entrainment now, said the test, the correlation actually two ends meet -- it's -- there's not much irregularity there for entrainment onset case.

And in that length we varied the form to .7 to 4.7. It doesn't have much impact within the test range. And also the downstream structure or steam generator, with a steam -- with a steam generator and without a steam generator. That means we're being flooded.

It does have the effect because of the wave bouncing back and so of course the entrainment and that lower. But the gas flow rate direction from the downstream in this case has negligible effect, but we cannot quantify it. We didn't put a flow meter there. And that's what we are doing right now after this.

And for the steady-state entrainment case, a downstream structure or steam generator affects the entrainment rate. And the gas flow from downstream changes so the entrainment rate is substantial. And also we need to quantify how much a gas flow from the downstream side and get a better data.

And for the model evaluation, the model of Smoglie and Schrock, this is used in RELAP5, is effective for relatively small breaks that was evaluated from their experiment data.

Maciaszek's model works well for larger breaks. That's what our case.

And for the entrainment rate model, model of Schrock that is used in RELAP5, it seems it does not collapse our test data. Like Dr. Schrock pointed out, what h_b is going to use, we don't know what h_b is going to use because in the new phenomenon you have two levels there. And we use either one of them and we use the average of them, still can work.

So we think there is room to do some more work if we want to predict this phenomena using our system code.

In the model improvement for the entrainment onset model, we did a potential flow analysis. We found Maciaszek and Schrock, Smoglie's correlation can be interrelated if we consider a wave-crest size as a function of the liquid level height. And it's two asymptotic condition anything have, and it should be covered within this -- within this range. So it's one --

MR. SCHROCK: I'd like to make a comment about one of your conclusions. And that is that the correlation form that evolved earlier is okay for small breaks but not for larger breaks.

I think that that conclusion is misguided. And I say that because having seen the experiment in operation now I'm convinced that you're dealing with a completely different phenomenon that had been addressed in our work and in the work at KFK, totally different phenomena involved.

I do believe that if we tested with a larger diameter break on our apparatus that we would get consistent results with those already taken in that apparatus.

So I would not conclude from the combination of what you've learned from what we did, what was done at KFK, and what you've done in these experiments, that it is the diameter, the larger diameter of the break line that causes disagreement with the correlation.

The fact is if -- if you had the kind of surging, pulsating slugs of liquid moving back and forth in the test section with the smaller diameter breaks, you would not expect the results to agree with the correlation that we've developed for the stratified flow case.

MR. WU: So, well, the oscillatory effect only happened --

MR. SCHROCK: So your conclusion I think is wrong and for the reasons that I just stated.

MR. WU: The oscillation for the entrainment onset, you don't see oscillation. When you went to see the experiment for the onset, it's a little bit wavy interface. There's no oscillatory for onset correlation. There's some -- no such a complication or irregularity.

Only for the entrainment rate tests we observed this step phenomena. So you try to mix these two together to justify our conclusions, I don't agree with that.

MR. SCHROCK: Well, maybe you can make that apparatus produce a smooth stratified interface. What you showed us did not include that kind of interface, did not.

MR. WU: No. It -- for the entrainment

onset we don't have --

MR. SCHROCK: Yeah.

CHAIRMAN WALLIS: Even for onset it was not smooth.

MR. SCHROCK: No.

MR. WU: And it's a little bit wavy, but you don't see the jump like that. One side is substantially higher than the other side. And we measure, we use our probe with the measure to --

MR. SCHROCK: The onset that you demonstrated was distinctly pulsating. It was not a more or less continuous two-phase flow into the break line. It was a highly-pulsating flow.

MR. WU: No.

MR. SCHROCK: That's what I saw.

MR. WU: Onset, there is nothing happened. What we called the onset is the pulsating, everything stops. There's nothing being drawn into the branch. If you see the pulsing, that's still being entraining. That's in the process. It's not stopping.

So if that's the case, then we -- it's not our entrainment onset and measurement yet. Only when it stops, that's what our value of entrainment onset.

When you say something's been drawn into the branch, the entrainment is still there. That's not our entrainment onset condition.

So when you say, well, say later and there's some pausing and being pulled out, that's not the entrainment onset condition yet.

MR. KRESS: Well, you do have -- as you approach the condition of no entrainment, you do have wavy surfaces.

MR. WU: Yes, that's right.

MR. KRESS: And what he's saying is even then your entrainment is possibly not the same mechanism as his was. So when you stop that, --

MR. WU: Yeah.

MR. KRESS: -- you're stopping something different than what his is stopping.

MR. WU: If you have like 10 meters -- five meters of gas blowing over a surface you don't expect that surface is calm. There is a capillary wave which is being developed there. So that one, if you say that's the case, that we cannot make it a --

CHAIRMAN WALLIS: Well, I think the waves are coming from the reactor vessel.

MR. WU: Yes.

CHAIRMAN WALLIS: And you have this bubbling and frothing, and there's sort of a big plume --

MR. KRESS: That's right.

CHAIRMAN WALLIS: -- of stiff arising which is stirring up the surface. And that goes into the pipe, which is much bigger than these capillary waves.

MR. SCHROCK: You said you've simulated AP600, but in fact -- you say it's scaled to AP600 -- but in fact I think these big disturbance waves that are entering that horizontal pipe from the vessel depend significantly on the geometry of that entry.

You've joined two cylindrical surfaces with sharp edges. That doesn't exist in the reactor.

MR. WU: I agree.

CHAIRMAN WALLIS: Now when you're correlating your rate of entrainment, are you doing it with this one-inch bypass, and so on? You're not doing it with the closed end, because you get different answers.

MR. WU: We did close it. We opened it, opened --

CHAIRMAN WALLIS: But your correlation is for the open end with the bypass?

MR. WU: Yes. We did open. We did close it. And we did it with one-inch --

CHAIRMAN WALLIS: Yeah, but your

correlation that you're offering --

MR. SHACK: No, but it's for the steam generator. Sometimes you have the loop seal and sometimes you don't, right, but don't include the blind data.

MR. WU: Oh, we close the -- with the steam generator there, we close the three-inch and the one-inch. That's what these -- that's with the loop-seal case.

CHAIRMAN WALLIS: Yeah, but that's not what's being correlated. The data for entrainment do not include the one where you shut off the --

MR. WU: Can you go back? Go back to the --

CHAIRMAN WALLIS: You can't, because they're two different groups. I mean you can't correlate the same thing --

MR. WU: No. That one is blind flooded as dif- -- if we blind flood it, it's then coming from a different group. For the other case with the steam generator, we have three case. One is a three-inch and line open, one is one-inch line, and all of the line being closed. That's all the line closed --

CHAIRMAN WALLIS: But these data here are for the three-inch line open, or the one-inch line open, or something?

MR. WU: Go back.

Both -- all of them group with -- together. There's no effect --

MR. SHACK: Well, the peak -- the peak there is for the closed-return line, right?

MR. WU: No. You are talking about an entrainment onset or entrainment rate?

CHAIRMAN WALLIS: Apparently this is a phenomenon even with an open line.

MR. WU: So this case is --

MR. SHACK: But for -- are we talking about entrainment rate, because --

CHAIRMAN WALLIS: Yeah, this is entrainment rate here. Yeah.

MR. WU: Are we talking about the entrainment rate. If it's entrainment rate, this bump will come --

MR. SHACK: When I look at the one with the data on it, I mean I see that huge peak with the --

MR. WU: That's for the --

MR. SHACK: Isn't that really with the closed line?

MR. WU: Yeah, that's for the closed line.

Yes.

MR. SHACK: So he gets two -- he does get distinctly different results with the line --

CHAIRMAN WALLIS: Well, the steam -- he even has this awkward one with the open line.

MR. WU: I got a little bit like that, but what I -- when I did the conclusion I was the first to mention the entrainment onset correlation first.

CHAIRMAN WALLIS: So when we saw the experiment this thing was chugging like a steam engine, the thing there.

MR. WU: Yeah.

CHAIRMAN WALLIS: That was with the closed -- something was closed?

MR. WU: Closed the returning --

CHAIRMAN WALLIS: But it's not -- it's not ended. There's not a plug. You actually can go into the steam generator and come back again?

MR. WU: That's right. That's right.

CHAIRMAN WALLIS: So it simply means you close the valves in the three-inch and one-inch line.

MR. WU: That's right.

CHAIRMAN WALLIS: It's not as if you --

MR. WU: No, see -- okay.

CHAIRMAN WALLIS: -- block the end.

MR. WU: No. No.

CHAIRMAN WALLIS: So there's a big difference between having those valves closed and having them open.

MR. WU: That's right.

But that doesn't affect the entrainment onset data.

CHAIRMAN WALLIS: No. No, no. We're talking about rate.

MR. WU: Yeah. That was my conclusion when --

CHAIRMAN WALLIS: We should probably go on.

MR. WU: Yeah. For the entrainment com- -- go to the previous page, please.

So for the entrainment onset model, again the model of Smoglie and Schrock uses the RELAP. That is used in -- RELAP5 is effective relatively for small breaks. And Maciaszek models works well for the larger break.

And for the entrainment, we already covered that.

And the model improvement, we see the entrainment onset model. What we did is we bridge these two together. And we try -- we figured out a way to sink that wave crest. The maximum pressure point, it's a ring type. And that is a function of the liquid level. And the --

CHAIRMAN WALLIS: I think you should -- excuse me. You should do an experiment where you don't put the air in through the bottom of the reactor and bubble it up, but you put it in through the head. You have the same flow rate, but you wouldn't be bubbling it through the surface and disturbing the surface. You'd get a very different answer probably, or a different answer.

MR. WU: You mean...

CHAIRMAN WALLIS: Depending on how you put the air in.

MR. SHACK: Just do a genuine gas flow.

CHAIRMAN WALLIS: I mean the gas flow's more like -- it's just more like what Schrock did.

MR. SCHROCK: Yeah.

MR. SHACK: A separate effects test.

MR. WU: Yeah, we can run that. That -- yeah, we were -- originally we run this to simulate the prototypic. Yeah, we can run that. We put up a -- bring on that --

CHAIRMAN WALLIS: And you'd probably get a different group of data.

MR. REYES: Jose Reyes of Oregon State. Just a brief comment.

I think one thing that is happening with this data and what we've seen in the APEX test this morning during the 25 uncovery series is that this data matches our test.

And so we're seeing the same kind of dynamic behavior that's giving us this over -- an increase entrainment rate in their facility as we see in ours.

CHAIRMAN WALLIS: What you're -- he's correlating something which is very much like AP600 in terms of end condition.

MR. REYES: That's right. That's right.

CHAIRMAN WALLIS: Right. It really doesn't apply to a separate-effects type of thing.

MR. REYES: That's right. It basically is -- geometry is -- it's a realistic geometry to try to predict what's going on in a very specific case, the AP600.

MR. SCHROCK: Well, it's superficially realistic, but I mentioned the differences in the entrance into the horizontal pipe. Sharp edges versus a well-rounded entrance. It makes a lot of difference. And I don't think you want to sweep that under the rug.

MR. REYES: No, no. I think you're right.

There are some geometry differences between our facility and even in the air warp facility. We have upper internal structures, for example. So I know that changes some of the entrainment rate behavior.

MR. KRESS: Yeah. The real question is for this kind of phenomena of entrainment, have you used the right scaling parameters with respect to AP1000.

MR. REYES: Right. And --

MR. KRESS: You may have scaled the wrong things, because you weren't thinking of this phenomena.

MR. REYES: Yeah. What we measure -- so, for example, we do see a hydraulic jump in our -- in our hot leg, just like they see, because we do measure level on both sides. So we're seeing familiar phenomena.

Now the question is let's look maybe more closely at that to determine: Is that what we'd expect to see for the AP600.

CHAIRMAN WALLIS: Well, in your results for your APEX facility, you did see oscillations in that --

MR. REYES: Absolutely.

CHAIRMAN WALLIS: -- that relief line.

MR. REYES: There was a chugging behavior.

CHAIRMAN WALLIS: ABS-4 relief line.

MR. REYES: In fact, we put a transparent line in a portion of that.

CHAIRMAN WALLIS: And isn't that -- isn't that because of the slugs, and the pulses of liquid, and all that stuff?

MR. REYES: Right. You see -- you see -- you don't see a stratified smooth interface. You see a very wavy energetic interface.

MR. SCHROCK: Well, given that, it seems unlikely that an analysis based on the cartoon in page number 5 model improvement should succeed, that that would be very surprising and yet --

MR. REYES: Yeah. I think what we're seeing --

MR. SCHROCK: -- you're saying essentially that fortuitously it does succeed.

MR. REYES: Yeah. Yeah. I think what we're seeing is that we're hitting a limit like a slug. In essence, he's looking at a transition limit. And I think that might be what's allowing us to collapse the data at that higher point, which was a surprise, I think, even when Dr. Wu looked at --

MR. SCHROCK: I want to ask, once again, to have a copy of the derivation. Don't take the time to put it up there, but I'd like to see that, please.

MR. WU: In consideration for future effort, it's the test of liquid gas flows through the main line is more general case or more general or -- okay.

A test for the smaller main line for probably a noninnerflow case, because we are running only the intermittent flow case. A test of ward down -- downward break, branch and break, and also will have an effect of gas flow from the downstream and the effect of gas flow through the main line. And so we just think about the possibilities. It's not to say we are going to do it.

And one more phenomenon we would like to point out is the pool entrainment. In our case when the mixture level is way below the hot leg in that, it's about, say, six inches below the hot leg in that. Under the entrainment, pool entrainment, pool droplet, and since this hot leg is the ADS-4 line is very close to the inlet, some droplets go in through this ADS line and have been transported to the upper plenum.

So we think the pool entrainment there is one of the mechanisms, those with our inventory. And we have one still. Right now it's trying to use the existing model to predict this flow rate we measured.

And APEX was also run the data in last year and also found the entrainment down continues so when the mixture level is below the hot leg.

That concludes my presentation. Thank you.

CHAIRMAN WALLIS: You have no theory to go with this? This is just an observation?

MR. WU: We have some models selected from publication and we are trying to simplify it, because it's --

CHAIRMAN WALLIS: It looks like a very low flow rate, what, .01 kilogram a second. Is that -- that's about a pint a minute, or something.

MR. WU: Yeah. Yeah, that's right. But as it now running it goes... It's a mechanism.

MR. KRESS: Is that --

MR. WU: Those -- those are water inventory.

MR. KRESS: Is that kind of entrainment very important for the nuclears' side?

MR. WU: I think so. I think so because

that carry the droplets is not vapor going -- going through the break. So you actually know the water inventory faster than you just depressurize the vapor. So that actually should be considered, I think.

MR. KRESS: Yeah, that looks like it's such a low rate of liquid being lost that it wouldn't --

MR. WU: That's a per second --

MR. KRESS: -- wouldn't -- it wouldn't impact the rate at which you lose inventory by vaporization. It seems like it's very, very negligible compared to the vaporization rate in terms of mass. So it may not be important for accident sequences, it seems to me like.

MR. WU: We need to calculate the numbers to this 1,000, like a kilogram per thousand. You're right.

MR. BAJOREK: I think the gas flow right there may also be low.

MR. WU: Um-hum.

MR. BAJOREK: We've run into this type of a problem before at Westinghouse at hot-leg switchover, where you have a period where you may not be putting as much liquid into the vessel as you normally would and you have a period of time where boil-off and potential entrainment could drop that level. It's only two or three feet down to the top of the core. I think the gas velocities are also fairly low there. If that goes up the liquid entrainment --

MR. WU: Yeah.

MR. BAJOREK: -- would also go up quite a bit.

MR. KRESS: In the business of how suppression pools extract aerosols from steam rising up through it, one of the problems is how much liquid carryover you get, because it carries over part of it. And there's some data in that field. And a lot of it has to do with the bubble size that goes up through and --

MR. WU: That's right.

MR. KRESS: -- it's the --

MR. WU: A burst.

MR. KRESS: -- it's the film -- it's the film that breaks, that kicks up -- kicks up the stuff.

MR. WU: That's right. The burst.

MR. KRESS: And there's basically two populations of droplet sizes that's seen. But you might want to look into that field --

MR. WU: Thank you, sir.

MR. KRESS: -- to see.

MR. WU: Thank you.

And also I think if we want to do a thorough investigation, maybe we need to add the internal, because droplets, or some of them are deposited down in the re-entrainment, and so we need to see.

Thank you, sir.

CHAIRMAN WALLIS: Thank you.

Are we ready to move onto pressurized thermal shock? Any more questions or points about this program?

MR. ROSENTHAL: Yeah. I thought that the staff ought to make a summary statement about how we intend to use the work and --

NRC STAFF REPORT ON INTENTIONAL USE OF OSU WORK

MR. BAJOREK: Sure. I guess first this program initiated a couple of years ago. It was in response to, I think, largely an ACRS concern and also a co-development concern that the entrainment model, the face separation models in RELAP and other codes were deficient.

It was a problem in AP600 that was resolved primarily because there was so much other water in the system for the conditions, the power level of AP600, you wouldn't suspect entraining so much to challenge the top of the core.

It remains an important problem. With a high uncertainty in AP600 it will become more of a concern and problem in the AP1000 when the gas velocities go up.

Our long-term intent is to use this data and similar data to develop better models for TRAC and RELAP. Clearly we're not there yet.

In looking at the data, what we saw in the lab, there's still a lot of problems in our understanding of what are the true physics of entrainment and what's going on in this system right now.

It's not solely entrainment off of a very steady interface that is dominating the physics, but it's clearly related to system effects, dynamic oscillations in the hot leg.

They may be affected by geometry and scaling of the facility itself. The split between what goes down the hot leg from the vessel versus the steam or air that goes through the rest of it and the size of these waves relative to the size in the pipe.

It's not clear that we've really addressed that total scaling issue at this point.

Our long-term intent, however, is to

continue to use this data, to look at the data, to try to develop better models out of it; potentially to refine the facility; and to deal with and better understand the system effects before we get a model that's going to be put into TRAC and/or RELAP.

As Dr. Wu mentioned, the long-term goal does go beyond AP600. We've talked about that and the AP1000.

Your limiting small break usually is determined from a small branch line at the bottom of the cold leg. That type of an orientation.

If we're ever going to be successful with code consolidation and improving the codes, we're also going to have to understand the side-oriented branch. Practically that's important in several plants. There's not a whole lot of those that have side orientations, but there's a lot of experimental tests primarily in the ROSA facility that would be absolutely vital for co-development.

That unless we can get the side branch correct we'll be forever dealing with the compensating-error issue. So we need to be able to get the top branch, the side branch, and the bottom branch right in the long-run.

MR. SCHROCK: Well, we have data for the

side branch. But I think that, again, you'll find that if the upstream conditions in the actual system looked more like in the OSU mock-ups of the system, that the data would not be applicable.

I certainly wouldn't want to argue those data for anything that looks like this sort of churning, pulsating flow in that horizontal pipe.

CHAIRMAN WALLIS: Okay. Do you want a break?

MR. ROSENTHAL: I think it would be fair to the presenters, et cetera, if we could take a short break, if you wouldn't mind. I mean it's your meeting.

CHAIRMAN WALLIS: Well, we just got back from lunch. So I was thinking of having a break at about the time that was originally anticipated, --

MR. ROSENTHAL: It's your meeting.

CHAIRMAN WALLIS: -- halfway through, otherwise -- see, we're a little bit -- we are late. I mean you can get up and walk around, whatever. We don't have to sit here all the time.

MR. ROSENTHAL: I will.

CHAIRMAN WALLIS: Okay. I think that Jose's been dying to get up there.

PRESSURIZED THERMAL SHOCK RESEARCH

MR. REYES: Okay. Now I'll get into the pressurized thermal shock research. This presentation is to give you a -- I've actually combined three of the presentations to save a little time.

That includes the research objectives, a little bit of the prior work that's been done on PTS, and then a discussion of what test matrix was performed.

So I'll to jump straight into some of the -- does this go backwards.

So we'll talk about overview; give you a little bit about our research program, what's been done; and then I'll mention what tests have been performed and what calculations have been performed, and just a brief summary. So this is by way of an introduction to what you'll be seeing in more detail. So each of these areas will be discussed in detail by the different presenters.

CHAIRMAN WALLIS: And a lot of this stuff we won't see 'til tomorrow, right?

MR. REYES: Correct. Correct.

Now on the overview there are 10 slides on what's been done in the past. And I think this is an optional area, and I'll leave it to the discretion of the Chairman. We --

CHAIRMAN WALLIS: Does it matter? Does it matter to the present?

MR. REYES: I think we can jump 'til -- we can jump to slide 12, and we'll gain some time. Basically -- what it does is discuss what's been done in the past.

And then beginning on slide 12 there it discusses the results of my review of the previous work. Does that sound fair?

CHAIRMAN WALLIS: Okay. That's fine. Let's do that. Let's do that.

MR. REYES: That'll advance us --

CHAIRMAN WALLIS: I think that we were most interested in what you have done.

MR. REYES: Okay.

CHAIRMAN WALLIS: And then at the end we might see what everybody's done and tells us about the conclusions we should be drawing.

MR. REYES: Right. So let's -- we'll jump to page number 12, please. And so basically what I've done is I've gone through and looked at what's been done in the past. And of course I already had some familiarity. And this would be the results of my review of the previous research.

So I looked at integral system research

that had been done previously. Well, the integral system work really was related to calculation. So what we had were calculations performed by TRAC and RELAP for the Oconee and the H. B. Robinson and the Calvert Cliffs plants. So all we had were calculations. There was no integral system test data available specifically for the PTS scenarios of interest.

So as a result of the review of the prior work there was a need to benchmark the system analysis codes to determine their ability to predict loop stagnations, train the system pressure and downcomer temperatures. So we'd like to have some benchmark data for those codes.

We'd like to be able to integrate the separate effects test results with the integral system behavior. What we had were two sets of experiments. We had -- well, actually all we had were the separate-effects experiments. We didn't have integral system tests.

And I think what you'll see is that they do link together and that some of the separate LOCA behavior affects loop stagnation, which is an integral behavior. And so we'll be talking about that later on. So that was one of the motivations for the research.

Also there was an effort to examine the effect of core heat, heat transfer on downcomer fluid temperatures. The pre-separate-effects tests were -- essentially modeled the cold leg, loop seal, downcomer, the lower plenum, and then they had a stand pipe. So there was no core sitting behind the barrel wall to heat up the core barrel wall.

So heat transferred from the core barrel to the fluid is going to be examined also in this study. So that was another thing that we noticed that was missing from past research.

In the area of separate-effects testing we need to obtain some fluid mixing data for low-flow HPSI operation in a side injection cold-leg geometry. So we didn't find in the existing literature any low-flow HPSI for a Palisades-type geometry. So we actually have done some flow visualization testing, and we'll demonstrate some of that for you tomorrow.

We also saw the need to develop a criterion for the onset of loop seal cooling. In these plants you actually have a -- as John will show in a little bit -- you have a reactor cool pump with a lip on it that prevents the -- that keeps a layer of cold fluid on the bottom of the cold leg essentially.

And when that spills over it has a particularly important effect in cooling the loop seal and it affects the loop behavior. So we need a criterion for that.

Also we want to assess some of the advance CFD Code capabilities. We've seen a tremendous increase in speed. Back in '85 when we were trying to run SOLA-PTS and some of the other CFD Codes, it was painstakingly slow.

And the nodalization, we were able to get maybe 4,000 nodes in the downcomer, and it was taking 10 hours to run maybe 10 seconds of transient. So it was -- and of course at the time we needed to perform amounts of 200 transients for 7,200 seconds apiece. And you do the math and you figure, well, not in my lifetime, I don't think.

So -- but what we've seen now is the CFD Codes have been -- are much more robust now. They are -- the computational speeds are much better. And you'll be seeing some fairly-heavily meshed systems later on in the presentations.

Okay. So now we set up this research program here at OSU. We want to perform some integral system and some separate-effects tests to address the earlier research limitations. We've got -- we've had a very good cooperation in place. It's worked very well. From the NRC Research, Dave Bessette, Gene Rhee, Sarah Colpo, Chris Boyd. Those folks have been very supportive of what we're doing.

They have allowed us to -- it's allowed us to be able to work with Oak Ridge and with Consumers Energy -- I was misspelling it. Oak Ridge of course is had interest in where we put our thermocouples to measure our temperatures. And they have been helpful in providing input in that area.

Consumers Energy, the Palisades Plant, they've been very helpful in providing plant data. And they've also done some other work in having us have discussions with their operators so we know how operators realisticly respond to main stream line breaks and small break LOCAs. And we'll talk about that a little bit more later.

So this is by way of the structure of our research plan. And it might be hard to read on there, so I'm just going to talk about the big, the overall headings.

We essentially started off with a review of what had been done. Did a scaling analysis to see whether or not our APEX facility could be modified to give us behaviors or to produce a geometrically similar system to the Palisades Plant. That was the plant selected.

We found that it was geometrically similar, remarkably so, that the CE 2-by-4 design is very, very similar to the AP600 design.

So in scaling that cross-section flow airs, the volumes, we're essentially using a constant factor all the way around the loop, so it was very nice.

We did some facility modifications, and then we were able to perform our testing. We've had two types of tests, as I mentioned before, integral system tests, and then we also did some separate-effects test.

In the area of thermal hydraulic analysis we're using RELAP5, the NRC version, the Gamma version. And we're using REMIX and STAR-CD to do more detailed LOCA separate-effects types of analyses.

So what we plan to present to you is the summary of all this work in each of these areas and try to provide you with some result in each of these areas that will be helpful to the overall PTS reevaluation.

So I mentioned the scaling analysis. I won't get into a lot of details. We established that the degree of geometric similarity between Palisades and APEX was -- the plants are similar geometrically.

We developed a detailed scaling basis for looking at the -- for assimilating the onset of loop stagnation. So our flows, and our injection flows, and our cold-leg flows under natural circulation conditions are maxed so that we're able to get the onset of loop stagnation under the same conditions.

The onset of thermal stratification, the cold legs. This has been interesting. We've learned a lot from our tests here. Both the flow visualization and the APEX-CE test. We'll talk more about that.

We have also did some scaling in the area of thermal fluid mixing. And that also required doing some separate-effects tests in APEX. We did some very, very simple benchmark tests on those.

Now we developed scaling bases for comparing the main steam line break and a small break LOCA in our facility to Palisades. And we also identified which of the PTS PIRT phenomena would be adequately simulated in APEX-CE.

Facility modifications. The APEX design was modeled, of course, after the AP600. What we've done is we've added loop seals to this design to simulate a Palisades plant. We've changed the configuration of the cold legs to simulate the Palisades Plant.

We've eliminated all the -- in essence, all the passive safety systems of the AP600. And we've changed the logic. We've isolated all the logic of the AP600 to come up with a design that was similar to Palisades.

We've also added four safety injection lines on the cold legs in prototypic geometry, including the check valves on those lines, to simulate the inactive emergency core cooling system.

The types of integral system tests that we performed, we -- in all the tests we measured downcomer fluid temperatures and of course the corresponding system pressures. And we did a series of small break LOCAs and what are called excess steam demands on main steam line breaks, a stuck-open atmospheric dump valve test.

And in these tests we've tried to identify the conditions that lead to primary loop stagnation. And we've nailed those down pretty well, I think.

This is our test matrix just for the integral system test. We start off very simply with just a natural circulation flow benchmark test, making sure that all of our loop resistances were similar to the Palisades.

We did a stepped inventory reduction test which was reminiscent of the semiscale tests done back in the, I guess it was, late '70s, early '80s. We were able to duplicate that work. Again we're trying to characterize single-phase and two-phase natural circulation in our loop. And I'll show you those results later on.

And then, of course, we did the small break LOCA tests. We had a -- it's actually -- we did a 1.4-inch hot-leg break from full power conditions. And actually number 8 was a two-inch hot-leg break from full power conditions. So that test -- that's an old test nomenclature. So that was actually a two-inch break that was performed, number 8.

We did the stuck-open pressurizer 4 from full power; 10 was revised also. We did stuck-open pressurizer power with a combination stuck-open automatic atmospheric dump valve. So some of these have changed, and I guess we didn't catch it on this slide. Sorry.

We did do two main steam line breaks, one from full power and one from hot and zero power. And then test number 13 we still need to perform. That's one where we have an opportunity to do something a little bit different there.

We're looking at HPSI injection in a partly-voided downcomer. Now you've got level in a downcomer. And we're essentially pouring cold water into it. So it's a little bit different than what's been done in the past. And we do need to get a little bit of guidance on the best way to perform that test. But that's all that's left from our original integral system test matrix.

And we also performed some separate-effects test in APEX, APEX-CE. And these were steady-state HPSI tests. And these were similar to what was done at Creare in their half-scale facility. And we also simulated those in our transparent loop. We wanted to see the thermal stratification in the cold legs.

We wanted to study the plume development interaction in the downcomer. And we wanted to look at plume heat transfer downcomer walls. And so this was an APEX-CE, so we were at full pressure. We were injecting -- essentially it is a constant HPSI flow rate.

And these were done with no core power, so it was very similar to what was done at Creare. And we'll show some of the differences that we've seen from our data and what was done at Creare in the past.

Our test matrix, Tests 3, 4, 5, and 6, 3 was essentially a parametric study. And that was safety injection under natural circulation fluid mixing conditions. So we've looked at 16 different conditions there.

And 4, 5, and 6 were just like the Creare half-scale type test. We did it with one HPSI injection and then with four at two different flow rates. And the big difference there is we do see some of the effect of the core barrel stored energy release, and it plays a significant role.

And then in the flow bridge relation series, we're still continuing to do some of those. We're looking at onset of rear wall spillover and how to go about modeling that.

In terms of analyses, we're doing two types, of course. We're doing integral system analyses and we're doing separate-effects analyses. We're using RELAP5, the NRC, the Gamma version to do the integral system analyses.

We've performed actually five analyses there. One was a steady-state natural circulation. The other one was Test Number 2, which was a reduced inventory.

Then we've done two main steam line break analyses and one small break LOCA analyses. So Dr. Lafi will be presenting that later this afternoon.

In the area of separate-effects analysis, we used STAR-CD to do some analyses there. And this was kind of a very good experience for our students.

What we did, we said, here we have some folks with some good basic engineering background. We hand them the code and say, "You have a year to learn this code," and to try to get -- to benchmark it against existing data to see if it works. "I want you to report back to me all your difficulties, all your experiences, and how difficult it was to learn this type of code to get to a point where you feel proficient and able to use it to come up with predictions for a new geometry."

So they've got some feedback and some lessons learned there.

And we also used the REMIX Code for predicting some of our separate-effects test. That's one that had been used in the past in the previous effort. It's a regional control volume type of analysis technique that's used and had been used in the past to predict the downcomer temperatures and actually the -- all the way through the downcomer and out the exit of the downcomer. And we've got some calculations to show you there.

This mentions the tests that had been performed or analyzed using RELAP. Again, we have four there. And there was an additional one which was basically our benchmark -- a benchmark case. And that has the right nomenclature there with the two-inch hot-leg group.

So you'll be seeing -- you'll be seeing some of those calculations later today.

For the STAR-CD calculations, we did benchmark the code against the Creare half-scale test, MAY 105. You'll see that result.

And then we have also looked at OSU-CE-0003 as one of the parametric studies that included flow in the cold leg, a natural circulation flow rate.

For the REMIX calculations we'll be showing three of those today. OSU-CE Number 4, 5, and 6. And those are similar to what had been done in Creare, except now we are doing an integral loop with some of the heat transfer from the core barrel going to the plenum. And we see that it does make a -- it does impact the results quite a bit.

Okay. So this is an outline of what you'll be seeing. Okay. I wanted to show you the overall structure. We had integral system testing. We had separate-effects testing. And then we had modeling approaches or analysis approaches for each of those areas. RELAP for the integral system, STAR-CD and REMIX for the separate-effects test.

So we performed those analyses, and you'll see those today. We were able to modify the facility, and we think it scales quite well. We've got eight integral systems tests that have been completed. We have one test, number 13, lucky number 13, which remains to be performed.

We have four separate-effects tests which have been performed, and it includes one parametric study which has actually 16 separate conditions. And then we're right now continuing to do a series of flow visualization tests in our transparent loop.

And that's that. Any questions on what you're about to see?

So that's an overview of our research plan and what's been done. I think the next thing on the Agenda is to start describing working through this. So the facility, I think, description is next.

CHAIRMAN WALLIS: Now we're due to have a break after you stop talking; is that still appropriate?

MR. REYES: I'm sorry?

CHAIRMAN WALLIS: We're due to have a break after you stop your series of presentations. Is that still appropriate?

MR. REYES: Sure, that will be fine. We'll take a short break. So I have stopped talking.

What I've done is I've combined those three presentations into one. So I've talked about test matrix, what was performed.

CHAIRMAN WALLIS: Yes. Right.

MR. REYES: I talked about our research plan. And what I skipped a bit of was the prior work and the PTS research that's been done. But I did summarize the results of that or the areas that we felt we could contribute.

CHAIRMAN WALLIS: Are you going to give -- are you going to give John Groome's presentation?

MR. REYES: So now John Groome is ready to present.

CHAIRMAN WALLIS: Okay.

MR. GROOME: Would you like me to present?

CHAIRMAN WALLIS: Sure.

MR. GROOME: Okay.

CHAIRMAN WALLIS: And then what do you have to do after that, before --

MR. REYES: Well, then it's a separate presentation -- oh, I see. The break's after my second, okay. Yeah, the second presentation.

CHAIRMAN WALLIS: Your second presentation. We'll see how long John Groome talks. We may --

MR. GROOME: I'll try to go real fast.

OSU PTS TEST FACILITIES AND PALISADES OPERATIONS

MR. GROOME: Good afternoon. My name's John Groome. I'm the Director of Facility Operations on the APEX Test Facility.

I've outlined what we're going to talk about. And I'm just going to go fairly fast. And if you have any questions you can certainly slow me down to ask.

I'm going to talk about the APEX-CE Test Facility, some of the modifications that we performed to the facility, a basic description of the facility. I'll also show some slides of the flow visualization loop.

I'll talk briefly about the NRC meeting at Palisades. We traveled with NRC to Palisades, and we actually observed the operators perform main steam line breaks and small break LOCAs at their simulator.

And we learned -- what we tried to do -- the AP600 philosophy was hands off, the plant logic takes care of the plant during an accident scenario.

Palisades is more like a traditional plant where the operators actually interface with the plant during the accident. And so we tried to incorporate some of those operator actions into our tests.

And I'll talk briefly about some conclusions.

CHAIRMAN WALLIS: Are we only doing this work for CE plant?

MR. GROOME: Well, the facility that we've -- the APEX facility was modeled after the Palisades CE plant.

CHAIRMAN WALLIS: All right. But the conclusions are going to be applied to pressurized thermal shock in some other plants, or what's the NRC going to do?

MR. BESSETTE: Yes. Well, the reason we -- you know, the scaling was done to compare APEX to CE plants because the APEX configuration falls very close to the CE configuration. The other plants we're doing analysis on were Oconee and the Westinghouse 3 Loop Plant, Beaver Valley.

So -- but in terms of, you know, looking at -- some of these phenomena, of course, should be generic, like the interruption of loop flow, you know, flow stagnation.

CHAIRMAN WALLIS: Well, the method of injecting ECC is different.

MR. BESSETTE: The method -- the method of -- you know, the injection is similar.

CHAIRMAN WALLIS: It's different in different plants.

MR. BESSETTE: Yeah.

CHAIRMAN WALLIS: A side injection is rather unusual.

MR. BESSETTE: Yeah. You know, the plants will have any -- all configurations, from top to side to bottom.

CHAIRMAN WALLIS: I thought some CE plants have top injection, don't they?

MR. BESSETTE: Possibly.

CHAIRMAN WALLIS: I think so, yeah.

MR. BESSETTE: But basically you can find every configuration.

Now the other aspect is the general question of code assessment is part of the objective. So we look at different kinds of secondary side and primary side transients with steam line break and small break LOCA.

So, you know, we picked, let's say, the most PTS-significant types of transients to run as integral to the experiments.

Again I think, say, for a steam line break, phenomena are similar. Small hot-leg breaks, again the phenomena are going to be similar.

CHAIRMAN WALLIS: But you're going to rewrite some PDS rules, aren't you, for all plants? Isn't that in the offing?

MR. BESSETTE: Yes. Yeah, because the PTS rule applies to all the plants generically.

CHAIRMAN WALLIS: So you're going to have to show some sort of generic applicability of this work.

MR. BESSETTE: Yes, -- well, you know, the --

MR. KRESS: These methodologies, though, would show up in a Reg. Yeah, they would show up in a rule, wouldn't they?

MR. BESSETTE: So I think, you know, the -- what we do is we say, well, the phenomena are going to be -- the dominant phenomena are going to be the same for different plant designs. We're doing some --

we're also incorporating -- let's say part of the objective here is to assess RELAP. We've got the same down on phenomena, so presumably the assessment is going to be valid for those different plants.

Like I say, when we did the scaling eval- -- when, you know, Jose did his scaling evaluation, he did it looking at the geometric similartude of APEX with respect to CE plants.

Was that an answer?

CHAIRMAN WALLIS: But RELAP doesn't model this stratification, does it?

MR. BESSETTE: Some of these phenomena, you know, of course RELAP can't do.

CHAIRMAN WALLIS: That's right. So how can you test RELAP on phenomena you can't model?

MR. BESSETTE: Well, if we can show that the downcomer temperatures -- if it turns out that downcomer temperatures calculated by RELAP are similar to the experiments, then we can argue that -- if that's so, then we can argue that the phenomena it can't calculate it don't seem to be that significant.

If there are differences, I think we have to supplement the RELAP analysis with the CFD and/or REMIX.

CHAIRMAN WALLIS: Okay.

MR. GROOME: The APEX-CE Test Facility is geometrically similar to the Palisades Plant. It includes a reactor vessel with a 48-rod electrically-heated bundle. We have to two hot legs, four cold legs with reactor cold pumps, and we added high-pressure safety injection nozzles on a side orientation, similar to Palisades.

One pressurizer. Two inverted U-Tube steam generators, a feed-water pump. And we have a programmable logic controller that we actually use to model the Palisades Plant logic.

This is a brief summary of the instrumentation. We have thermocouples. We added approximately 50 thermocouples to the downcomer to measure the plume temperature distribution for the PTS work.

We have pressure and differential pressure detectors. Some of our differential pressure detectors are actually used to measure level and pipes in various tanks.

Primarily for our liquid flow we use magnetic flow meters. We use vortex flow meters for measuring of steam flow. Some of our tanks have load cells to actually get a mass.

And we installed Coriolis flow meters,

mass flow meters, on our four injection lines that we added to the plant.

Testing capabilities in the CE configuration include hot-leg breaks, cold-leg breaks, main steam line breaks, stuck-open pressurizer safety relief valves, and stuck-open steam line atmospheric dump valves.

OSU modified the APEX to simulate the Palisades' 2-by-4 PWR. Again we added four cold-leg high-pressure injection lines. We actually modified our cold legs to include a loop seal.

We looked at the Palisades Plant, and I'll show you a slide here in a minute, and we added a weir wall in our cold leg to simulate the Palisades' primary-cooled pump housing lip.

And what that does is it prevents the cold leg from completely draining. And we added again approximately 50 additional thermocouples and 12 loop-seal thermocouples to our loop and four mass flow meters to the injection nozzles.

This is an elevation view of the Palisades' loop. And you can see the -- I'll just point. This is the primary cooler pump lip here we're talking about. The cold-leg nozzle would actually inject -- would actually come off the screen here perpendicular that prevents the cold leg from completely draining.

CHAIRMAN WALLIS: So there's no loop seal in this --

MR. GROOME: Well, I'll show you a side view. So this is an artist's rendition of the APEX-CE configuration.

One of the things that's different, this is a planned view here showing the similarities between the two plants. Here's an elevation view.

One of the things that's different is our reactor coolant pumps were made specifically for the APEX, the AP600 configuration, and they mounted vertically to the bottom of the steam generators.

Typically on a PWR they're mounted vertically upright on the top of the loop seal. What we did is we dropped the pump vertically at the bottom of the loop seal. And then there at the flange right on the discharge on the vertical section or the horizontal section of the cold leg, we added a weir wall in the cold-leg pipe to simulate that lip of the Palisades' primary coolant pump.

We also built a flow visualization loop to help us understand the mixing in the cold leg. Again it was constructed of clear PVC pipe. The test loop includes a single cold-leg piping geometry representing APEX-CE, a high-pressure safety injection nozzle on the side with a check valve, a weir wall in the cold leg, and we have a 50-gallon salt water mixing tank that we use to simulate the difference between the hot and cold streams.

Our high-pressure injection pump is capable up to 20 gallons per minute and our cold leg flow pump is capable of 500 gallons per minute. Typically we ran the flow visualization tests at much reduced flows.

CHAIRMAN WALLIS: This salt water mixing is only for a separate-effects test?

MR. GROOME: Correct. It was just for visualization.

And here is a side view of the test loop. The green dye is actually in the salt water when we inject it. This is actually a post-test. You can see the weir wall right there. Right there's the weir wall in our clear test section.

If we had a pump here that simulated the APEX-CE, the pump would actually be installed down here. But we just took a -- we have a test pump there in the facility, and we just took a flow off of the pump that's mounted on the floor there to simulate natural circulation flow rates. And we could vary that parametrically up and down.

CHAIRMAN WALLIS: Are you going to show us this, or are you --

MR. GROOME: Well, you kind of saw it if you --

CHAIRMAN WALLIS: Yeah, it was there.

MR. GROOME: -- when you were there, but we didn't actually put on a demonstration. But we can do that for you.

MR. SCHROCK: Now what does the weir wall simulate?

MR. GROOME: The weir wall simulates the loop, the lip seal.

Can you make me go back there, Brandon, to where that picture was? One more maybe. Two more. There you go. There's the mouse.

So this is the lip here that I'm talking about that exists in the primary coolant pump casing. And right here projecting perpendicular from the screen is the cold leg nozzle.

And so what it does is it prevents you from draining, completely draining this cold leg if you were to open up a drain valve. In other words, in order to spill over into the loop seal you have to get by this lip.

And since our pumps are at the bottom of the loop seal we added this lip here on the horizontal section of our cold-leg pipe to simulate this lip of the Palisades' primary coolant pump housing.

MR. SCHROCK: In what way does it simulate it? It's got the same height restriction or --

MR. GROOME: The same -- it's the same elevation. It doesn't simulate necessarily the roundness of the geometry. It's just a vertical plate that's welded on the inside of the pipe.

And again this is a top-down elevation of the flow visualization loop showing the side injection nozzle there.

We also traveled to Palisades to -- we found out where Kalamazoo is. If everybody ever wants to know where Kalamazoo is, it's in Michigan. And --

CHAIRMAN WALLIS: It's a Covert operation.

MR. GROOME: Yeah, it's in Covert. The plant's actually in Covert, but you fly into Kalamazoo to get to Covert, which we had to look at a map for quite a while to figure out where that was at.

But we actually talked with the Palisades' operators trying to understand the logic that they do for their accident scenarios and when they train on the simulators.

We actually observed, I think, about four tests, two main steam line breaks and two small break LOCAs. And based on discussions with the Palisades' operators and our observation and understanding of the scaling limitations of the facility, we developed a set of test procedures for the APEX-CE tests that we performed as part of our NRC work.

And I'm just going to briefly just kind of -- Dr. Reyes wanted me to talk a little bit about just to give you kind of a feel for what Palisades' operators would do during tests.

We looked at some of their emergency operating procedures, their standard post-trip actions: Loss of coolant, accident recovery procedure, an excess steam demand, their functional recovery procedures, and some of their EOP supplements when we were developing our test procedures.

And this is just a general outline for Palisades for a small break LOCA, their general sequence of events that you would see.

They normally would manually scram the reactor whenever their second charging pump was started. They have three charging pumps that can vary the flow from anywhere from 30 to 150 gallons per minute.

They manually tripped two reactor coolant pumps at 1300 PSI, one on each loop. And they tripped a second pair of reactor coolant pumps whenever they approach less than 25 degrees subcooling margin. And typically that will happen about five minutes.

Depending on the scenario that they're running, typically will happen about five minutes after tripping the first reactor coolant pumps.

And the operator determines this by looking at T hot and temperature to core and pressurize the pressure. And they actually have a screen, and I don't have a viewgraph, but they actually part -- I do have a little bit of a viewgraph showing the operator trends as they depressurize.

And typically the reactor coolant pumps are not restarted during a small break LOCA, even if subcooling is regained. And that's because -- well, this assumes -- for a steam break inside a containment, they lose cooling water to the reactor coolant pumps.

And so whenever they're isolated they have about five minutes to regain cooling to the reactor coolant pumps, otherwise they have to go to a warm-up procedure that takes them about 30 to 40 minutes to warm up before they can open up the cooling water back to the reactor coolant pump. So they just go ahead and lose the second pair, and they don't immediately worry about restarting the reactor coolant pumps.

Monitor. They monitor the pressurizer and reactor pull, reactor pressure level. The small break LOCA does not adequately remove decay heat, so they use the steam generators to remove decay heat via the turbine bypass valve or atmospheric dump valves. The turbine bypass valves are limited to five percent. And then they manually control aux feed water to maintain the steam generator level.

There's no automatic steam generator isolation. And when the T hot approaches about 550 degrees Fahrenheit, they secure the main feed pumps. And note this is approximately after the test T hot or after the small break LOCA, the temperatures are approximately 530 degrees Fahrenheit immediately following the reactor trip.

The turbine bypass valve is -- the set point is 900 psia, which is approximately Psat for 532. So the turbine bypass valve will open up and start to dump steam also.

The main steam line break. They get their signal either on a containment pressure greater than four PSI inside a containment. They will isolate the main feed pumps and main steam. Auxiliary feed water and atmospheric steam pump valves are available.

They manually trip the reactor or allow it to trip on a set point, but they will get a power-to-flow set point scram.

They'll determine the affected steam generator and isolate on excess steam demand or tube rupture. So they have a procedure where they try to determine if it's a U-tube rupture or a main steam line break. They'll isolate the aux feed water.

And for our tests we were not conservative, and we assumed that it took them about 10 minutes to isolate aux feed water to the affected steam generator.

And they'll also isolate the atmospheric dump valve, turbine bypass valve, and the safety isolation valves. And they'll allow the affected steam generator to blowdown.

They'll stabilize the plant. They'll cut back on the charging pumps when the pressurizer level is gained to 40 percent if it's a main steam line break in the containment; and 20-percent pressurizer level if the break is outside the containment.

They'll maintain the normal steam

generator -- the normal steam generator level on the intact steam generator by using aux feed water.

When the steam generator pressure is less than 800 PSI, they'll close the main steam isolation valves.

The reactor coolant pumps are on unless the excess steam demand is inside the containment. And again what happens there is that the containment is isolated and they lose coolant water to the reactor coolant pumps. And the reactor would most likely trip on their power-to-flow set-point.

Palisades has a set of pressure and temperature limit curves that are available to the operator on a CRT screen. These curves are basically designed to help them avoid a PTS event.

This is a look at the pressure and temperature curves from one of their emergency operating supplements. There's three curves on the bottom there. You could perhaps read a little bit better from your notes.

The bottom curve is the saturation curve. The curve right above it here is the 25-degree subcooling curve. So if they got down to this curve here they would secure the sector of reactor coolant pumps during a small break LOCA.

And this third curve that's right above it that actually crosses over the 25-degree subcooling curve is their minimum-pressure temperature for reactor coolant pump operation. And this is just an abbreviated screen. This actually goes -- there's another page that actually goes all the way out to 50 degrees Fahrenheit.

The upper limits of these curves, there's a 200-degree subcooling curve. And there's this VLTOP curve which is their variable limit for temporary overpressure protection. I like to refer to this as the brittle fraction prevention curve here, so that when they're shut down this is the set-point that would actually open up their primary power-operating relief valves to avoid exceeding the pressure for the temperature that they're at.

Normally this curve is not -- the VLTOP curve, when they're operating, is not in play. They use a 200-degree subcoolant curve until it comes down.

And the operator -- I'll show you a screen here. This is from the actual main steam line break simulation. And this is just -- there's a wide variety of information on this CRT when you're actually looking at it. And we just pulled one image off. But this is their pressure and temperature limit curves.

Number 2 here and 3 are the hot and cold-leg temperatures. So what they're doing, as the main steam line break is progressing, the operator is trying to control pressure and temperature to maintain the plant within the two limits, the subcooling curve here and saturation curve, and their 200-degree subcoolant curve here on the top or the VLTOP curve.

The APEX plant operating procedures and the plant actions were generally realistic with the following very important exceptions. We did not allow -- for our test procedure we did not allow throttling of the high-pressure safety injection. So we just started our high-pressure injection safety, and we modeled the full flow during the whole entire test.

Isolation of the feed water flow to the broken steam generator was assumed to take 10 minutes.

And no effort was made to keep the plant within the pressure and temperature band, scaled, as required by Palisades' emergency operating procedures. So we essentially just let the plant behave as it would with no operator actions once we started the scenario.

The APEX-CE Test Facility includes all the key components needed to simulate the Palisades' thermal hydraulic overcooling behavior.

The transparent loop provides visualization of the fluid-mixing behavior in the APEX-CE cold legs.

The NRC meeting at Palisades in March and the emergency operating procedures provided valuable insight into operator actions during the main steam line breaks and small break LOCAs.

The Palisades' emergency operating procedures are designed to avoid a PTS event. The APEX-CE test procedures were based on Palisades' emergency operating procedures, discussion with plant operators, and actual observation of plant simulations.

The APEX-CE operator actions were generally realistic with a few very important exceptions designed to produce PTS test conditions needed to benchmark codes.

And I believe that's my presentation. Are there any questions?

CHAIRMAN WALLIS: Not at this time probably.

MR. GROOME: Thank you.

CHAIRMAN WALLIS: Thank you very much.

So you train your operators to simulate

Palisades or something, or do you put it in the computer ahead of time, or...?

MR. GROOME: Actually we did both. For the most part, for repeatability we programmed it in our programmable logic controller.

But actually during the performance of this test we had an equipment failure where we lost our main feed pump. And so we had to use our pump that we use for high-pressure safety injection for our main feed pump. We have that capability. And so we actually performed operator actions because of that equipment failure at this plant.

MR. KRESS: The operators, their actions are intended to keep you away from pressurized thermal shock --

MR. GROOME: Correct.

MR. KRESS: -- or at least minimize it. But your test, you're trying to see what happens here in a pressurized thermal shock.

MR. GROOME: Exactly right.

MR. KRESS: So you don't really want to do everything they do.

MR. GROOME: Exactly. That's what we did.

MR. KRESS: Yeah.

MR. GROOME: We looked at the actions that they performed during the test, because it was quite a bit different than the AP600. You know AP600, basically the operator's dead. Plant logic takes care of itself. There's no operator actions at all.

Palisades, there's operator actions that affect the outcome of the test. So what we did was we -- to understand that, we traveled to Palisades, read and reviewed their emergency operating procedures, talked to their operators, and incorporated some of those operator actions into the test procedures.

For example, you know, we assumed that it took a minimum of 10 minutes to isolate aux feed want are.

MR. KRESS: Um-hum.

MR. GROOME: But we didn't try to -- unlike Palisades' operators, they'll actually try to control temperature and pressure to keep the plant within the two bounds of the P and T curves. We did not do that. We let the test just progress after that point.

MR. WOODS: Could I -- I'm Roy Woods. I'm in Research, NRC. I just wanted to point out that what these gentlemen are talking about, we take the PRA contractors and the HRA contractors, and we've gone to each of the plants that we are analyzing.

And one of the main things we do when we go to these plants is go through some simulator exercises so our HRA people and our PRA people can see what the important human actions are and see how the training the plant operators get corresponds to the -- whether or not they'll actually do those actions, and whatever.

So you gentlemen went on the trip because you were analyzing Palisades. And we also have already gone to two other plants for the same kind of purpose.

So the fact that they saw these human actions and then chose not to simulate them, you know that's okay. I mean they were looking for one purpose and we were looking for a different purpose.

MR. KRESS: Yeah, that's what I get.

MR. REYES: Any other questions?

No.

SUMMARY OF INTEGRAL SYSTEM OVERCOOLING TEST RESULTS

MR. REYES: Let's proceed. What I'd like to do is just start off with our integral system tests and just give you the -- we'll start off with kind of the big picture.

For PTS we're interested in the system pressure and the downcomer temperatures, so we'll talk a little bit about that.

In the presentations that will follow we'll talk more about the details of how we got to those temperatures and what's happening specifically in the downcomer. So let's start with just an overview.

So we'll look at downcomer fluid temperatures, at some of the temperature and pressure extremes for all the integral system tests that were performed. And I'll just give you some conclusions based on the big picture.

So you'll be seeing several presentations looking at the specifics of the downcomer fluid temperature under different conditions. So that will -- that's to follow.

But in general the fluid temperatures were relatively uniform around the downcomer at about eight cold-leg diameters down into the downcomer. So we saw good mixing for all the integral system tests at 8D.

And for the most of the tests at 4D, four cold-leg diameters down, we saw good mixing. So that's just perhaps a rule of thumb that you can keep in the back of your mind.

MR. SHACK: Where does that put me relative to the beltline?

MR. REYES: The beltline for this particular plant, their beltline wells were right about five cold-leg diameters down. Their centerline, beltline -- well,...

Several of the tests that did experience axial thermal stratification in the downcomer.

So we saw a cold temperature on the bottom stratified all the way up to the top. But radially they were all relatively uniform.

Here's the six integral system tests that we performed. And this is just kind of trying to pick the extremes. The minimum downcomer temperature for that particular test and then in the column next to it what the minimum pressure was.

And again in terms of scaling, you might want to think of it this way: 360 psig would correspond to about 1200 psig in the Palisades Plant on a pressure-scaling basis. Okay.

So what we saw was an minimum downcomer temperature for the smallest break, the 1.4-inch small break LOCA, which was off of the hot leg, the minimum downcomer temperature is about 255 degrees Fahrenheit. We initially were at 420 degrees. It came down.

And the minimum pressure -- temperature -- the pressure at that minimum temperature was about

131. You can look at all the numbers there.

In terms of the case which produced the most -- the highest pressure at the lowest temperature, we're looking at the main steam line break at hot zero power.

And I think that's consistent with what we saw in the previous analyses that were done almost 20 years ago -- about 10 years ago.

So the minimum downcomer temperature is about 230 degrees Fahrenheit and about -- we repressurized essentially on that test, okay.

And what I'll do now is I'll show you the plots of each of those scenarios, the pressures and temperatures, so we can do a little bit of a comparison.

CHAIRMAN WALLIS: What's the last column there?

MR. REYES: Oh, thanks --

CHAIRMAN WALLIS: You actually observed stagnation for part of the time, or something?

MR. REYES: That's right, yeah. So if the cold leg experienced stagnation anytime during the transient, we identify which cold leg's that.

CHAIRMAN WALLIS: But they're not all at the same time then?

MR. REYES: Right. And we did see some asymmetric loop stagnation, and that was very interesting phenomenon. We can explain that. There will be a whole separate presentation just on loop stagnation mechanisms. We've isolated those, identified what causes loop stagnation for this design.

MR. SHACK: What are we really talking about when we say the "main steam line break" here?

MR. REYES: Right. In this test we were doing, it was the equivalent of a one-square-foot main steam line break.

MR. SHACK: Oh, one square foot.

MR. REYES: And the assumptions that were involved in that, we had -- we assumed a one-square-foot break on the main steam line. It was assumed to be inside containment. And so we used the operator or the -- the operator actions that would correspond with a break inside containment. So that requires isolating containment.

And when you isolate the containment what happens is you lose your component cooling water to the reactor coolant pumps. You lose your ceiling, so you basically trip your pumps. And so we followed that logic there.

So we performed two of these cases, one at hot zero power which essentially assumed that the plant had been scrammed about -- for a period of about 100 hours. And then full power, which assumes that an immediate scram going to a decay curve.

For the hot zero power case we essentially picked the -- we picked the power at 100 -- scaled power at 100 hours. And essentially that power varies very, very slowly at that point. And so for our test we just used a constant low power.

For the full-power case we went to a decay curve.

So we can see the two different scenarios there. For the full-power case, we're looking at pressure. That's in the solid black line there. The red-dash line is the case for the hot zero power.

We see that because we're initially at a lower power. We get -- so we wind up at a lower pressure. What brings the pressure back up in this scenario -- okay, the main steam break force drives the pressure down in the primary side -- what brings it back up is just the action of the high-pressure injection system.

Unlike Palisades in their scenarios where they would throttle and just keep bringing pressure down, we just let the system run and, given enough time, the plant would repressurize. So this would be -- this is a good benchmark case for RELAP Code, to try to see if it could match these curves. So again it's more severe than what you would see in the real plant.

Now this is for the same test, same pair of tests, what we saw for the downcomer temperatures. And this is at the eight-diameter location, 8 cold-leg diameter down into the downcomer.

And we see that the full power case, because we still have core decay heat being generated at a fairly substantial rate -- actually not only did it repressurize, but it also reheated.

For the hot zero power case we stayed fairly low in temperature.

We also did some of the small break LOCA tests. And so here's the three scenarios that we did. We did a 1.4-inch hot-leg break, a simulation of a 1.4-inch hot-leg break.

Then we did a large break, a two-point -- a two-inch small break LOCA.

And then we also did a stuck-open safety relief valve on the pressurizer, which was the smallest of the breaks. And so we can see -- an interesting phenomena for the 1.4 inch. That's the solid line that has kind of this jagged behavior. In that case the HPSI pumps are capable, can actually keep up with the break flow.

And so we see kind of a pressurizing and then we fill up the pressurizer volume. And then we would sweep all the liquid out again and repressurize. And so we saw kind of a isolated behavior for that one.

So if your pumps are able to keep up with the break-flow rate, you see kind of a repressurization in this kind of a jagged behavior.

When we went to a larger break, a two-inch break, we see the pressure basically just come down and it just keeps coming down.

MR. SCHROCK: How do you simulate the SRV of the actual plant? What valve do you have and how do you go about qualifying it as a simulation of the actual plant valve?

MR. REYES: Right. Yeah, that's a good point. All we do is we have a flow nozzle which is sized to the diameter, a scaled diameter. And that's -- it's well characterized, so we know the loss coefficient for that flow nozzle. So all we can do is characterize that. It's not -- it doesn't represent the geometry of the valve throat in the real plant. So that's a good point.

MR. SCHROCK: So you assume that critical flow behaves in the same manner as loss coefficients for incompressible flow?

MR. REYES: Come again? You said the critical flow?

MR. SCHROCK: Yeah. It's critical flow through the SRV.

MR. REYES: Right, that's correct.

MR. SCHROCK: And that's unrelated to a loss coefficient ordinarily. So --

MR. REYES: Right, right.

MR. SCHROCK: -- when you say you have the same loss coefficient, what's the significance of that?

MR. REYES: In terms of loss -- what we do is we characterize the flow nozzle for a range of conditions. So we look at critical-flow conditions, but we also look at essentially a subcritical flow.

For critical flow, of course we do have a -- what this allows us to do at least with a code like RELAP is specify what the conditions are at the valve. So we're not giving it a complicated structure at the valve to analyze, in essence.

So we don't -- to make the long answer short, we don't simulate the geometry of the actual SRV for Palisades. But we have -- but we know what our geometry is, and we can characterize it.

MR. SCHROCK: But the scaled leak flow is somehow demonstrated to be related to the, or the same as in the plant for their actual valve?

MR. REYES: The data that we have for their valve, they give a -- for a given pressure condition in their plant, they give a given steam-flow rate, and so we scaled to that.

So -- but they only give us that top limit, so we know that their maximum -- we're given pressure in their plant and what the flow should be for that plant, but it's only one value.

And then it does behave quite well as a -- it's very close actually to a perfect gas behavior.

For the same three tests the small break LOCA is looking at the downcomer temperatures. Again this is somewhere down below the beltline weld.

CHAIRMAN WALLIS: Are you going to show us the 4D ones, too?

MR. REYES: The -- oh.

CHAIRMAN WALLIS: Well, you said 8D. I mean this --

MR. REYES: Right. Right, yeah.

CHAIRMAN WALLIS: You measured the various Ds presumably.

MR. REYES: Well, we'll have several presentations looking just at the downcomer fluid temperatures. So I picked one in particular just to -- as a characteristic like --

CHAIRMAN WALLIS: So we're going to revisit that?

MR. REYES: Oh, absolutely. Absolutely. We'll spend quite a bit of time in the downcomer.

The downcomer temperatures for the small break LOCA, again looking at which would be -- gave us the lowest temperatures. A two-inch break of course because you're depressurizing gave us the lowest condition there, followed by the 1.4 inch, and then the smaller -- the small -- so we're just following a saturation curve there.

We did do one combination test, and this was kind of interesting. It was a stuck-open pressurizer and the safety relief valve followed immediately by a stuck-open or single stuck-open atmospheric dump valve on the main steam line. Okay.

So we basically have a break on both sides of the plant. And this is what we saw. Again initial immediate depressurization, and then it gradually tapers off, and then it just flattens off at a fairly low pressure.

In terms of temperature we see somewhat of an exponential-type decay which would go with a primary side depressurization. And then a relatively linear plot after that or trend after that.

The SRV is fairly small compared to the other breaks. They have a fairly small valve size that they use for that.

MR. SCHROCK: These are test data and yet you get rather sharp changes in the slope of the pressure curve. Not in this graph but in a previous one.

MR. REYES: In the previous?

MR. SCHROCK: Yeah.

MR. REYES: Right.

CHAIRMAN WALLIS: Presumably something happened to that point.

MR. REYES: Right.

CHAIRMAN WALLIS: TMI is low, though. Something happened. The valve opened or closed, or someone did something. A very sharp change in pressure.

MR. REYES: Right. Yeah. This test I

don't recall if we fed the steam generators at some point in the test.

MR. SCHROCK: So you've got about three, four, five, six of those.

MR. REYES: So we have the -- we have a sequence of events for each one of these tests. We have a lot of details we can provide you. But I want to give you kind of the big picture, the big picture being that --

CHAIRMAN WALLIS: And you're going to show us that RELAP predicted exactly?

MR. REYES: Yeah. We won't go there yet.

And this is one that we did not use to -- we have not benchmarked our RELAP against this one. This is a prechallenging test.

Okay. So what we saw overall was that the fluid temperature's relatively uniform around the entire downcomer at about the 8D location, and for most tests at the 4D location we saw that. So we're seeing good mixing up in those regions.

So plumes appeared to be relatively well mixed by the 4D axial location.

Test Number 11 resulted in the lowest downcomer temperatures while at repressurized conditions. And that was the main steam line break, one-square-foot main steam line break at hot zero power.

So that kind of gives you -- of the scenarios we performed, that gives you a feel for which one was, in essence, in terms of PTS probably the most limiting.

That doesn't mean that there are other pressures that could be of importance, though. We looked at one that repressurized. Others kind of tapered off to a lower pressure. But in terms of PTS I'm not sure what, what the limit is --

CHAIRMAN WALLIS: So these were mixed four diameters. And four cold-leg diameters below the cold leg everything is mixed out?

MR. REYES: Right. So we look at the temperatures all --

CHAIRMAN WALLIS: So pretty rapidly.

MR. REYES: -- the way around the downcomer.

CHAIRMAN WALLIS: It's a pretty rapidly-spreading plume, is it not?

MR. SCHROCK: These are diameters of the vessel?

MR. REYES: Cold-leg diameters. Cold-leg.

MR. SCHROCK: Cold-leg diameters.

CHAIRMAN WALLIS: You're never going to get eight diameters down.

MR. SCHROCK: My gosh.

MR. REYES: Yeah, yeah. So -- and when we talk about the plume, the characteristics of the plume, you will see that the injection flow rates are very low in this design. And so they're fairly -- they tend to be weak plumes that break up relatively quickly.

MR. SHACK: Oh, yeah. Is that -- I mean is that related to the wimpiness of the high-pressure injection system?

MR. REYES: Correct. Yeah. And then we'll look at some other conditions where you're able to preserve the plume a little bit further.

MR. SHACK: A very low flow rate out of these safety injection systems, right, relative to other systems?

MR. BESSETTE: Especially a CE plant.

MR. BAJOREK: Especially a CE.

MR. SCHROCK: So how does that work out? The circumferential spacing of the cold legs is how many Ds?

MR. REYES: The circumferential spacing of each -- what are their angles on our plant, John? Are we on 90s?

MR. GROOME: I believe we're 90, but I'm not -- I'd have to look to answer the question correctly.

MR. REYES: Yeah.

CHAIRMAN WALLIS: It would be good if you showed -- maybe you will -- show an unwrapped annulus and --

MR. REYES: Right. Right. And that --

CHAIRMAN WALLIS: -- an unwrapped downcomer with all the pipes and --

MR. REYES: Absolutely. Right, that'll show the configuration.

And we'll see that we've used -- well, we've used STAR-CD and we've used REMIX to try to benchmark those codes to see how well they predict our behavior with the hope that maybe they could be extended to other, other plant designs and conditions.

With that do we have any other questions?

MR. SCHROCK: Well, you've got uniformed fluid temperature, but what about the metal temperatures?

MR. REYES: Right. We do -- we have a region of the vessel which is measuring metal temperatures. And it's an outside wall temperature.

And it's mostly in the vicinity of the upper downcomer. And we do see a distribution of temperatures there.

Now our vessel wall, of course, is very thin. We're a half-inch-thick wall compared to Palisades, which has a half-inch of -- or quarter-inch of stainless steel with about six-inch of carbon-steel-based metal. So it's a significant difference in our wall behavior.

So we focused primarily on the fluid, fluid temperatures.

MR. WACHS: To answer your question about the separation, the peak diameter is that -- it's I guess --

MR. ROSENTHAL: You need to speak into the mic here. Identify yourself, too, please.

MR. WACHS: I'm Dan Wachs. And to answer the question about the separation of the cold legs, I believe it's about eight diameters between each one. You have about a 25-inch radius. I guess that's going to be 16. if you just pi times the diameter, divide by three-and-a-quarter inches.

CHAIRMAN WALLIS: They're closer together than you think, I think.

MR. SCHROCK: Well, what he's saying is

they're far apart in comparison to what the data show produces complete circumferential mixing. Surprising.

CHAIRMAN WALLIS: It seems very rapid mixing to me.

MR. SCHROCK: Yeah, right. That was why I asked. It seemed very rapid.

MR. REYES: Now we'll look at some cases where, in fact, part of it is because the flow rates are so low in this plant. Even on these low-flow rates there are some cases where we'll see that loop flow, natural circulation loop flow, acts to preserve the plume. And so we'll talk about that a little bit later. That's kind of an interesting effect.

CHAIRMAN WALLIS: So you're keeping all that exciting stuff for tomorrow, are you?

MR. REYES: Yes. That way I'll be sure you come back.

CHAIRMAN WALLIS: I have a question. Is this a good time to take a break?

MR. REYES: Sure, I think this is perfect.

CHAIRMAN WALLIS: Then let's do it. We'll take a 15-minute break, and we'll start again at 3:25.

(Recess taken from 3:08 p.m. to 3:25 p.m.)

MR. LAFI: Shall I start?

CHAIRMAN WALLIS: Yes, please.

NUMERICAL SIMULATION FOR APEX-CE MSLB AND SBLOCA TESTS USING RELAP5/MOD 3.2.2 (GAMMA VERSION)

MR. LAFI: My name is Abd Lafi, and I'm an Assistant Professor at the Nuclear Engineering Department at OSU.

My presentation will be focused on numerical simulation for APEX-CE main steam line break and the small break LOCA tests using RELAP5, Model 3.2.2, Gamma version.

The outline of my research will include objectives, input modifications, APEX-CE model nodalization, RELAP5 calculation matrix, RELAP5 run strategy, and then mention and discuss some comparisons between the tests that I analyzed.

These tests will include a one-foot-square main steam line break from hot zero power. This is OSU-CE-11.

And then the second test is one-foot-square main steam line break from full power. This is OSU-CE-12. And then two-inch hot-leg break, OSU-CE-08.

I will end up with some conclusion after each of these tests.

The objectives of all of these analyses is to assess the ability of RELAP5, Model 3.2.2, to predict transient overcooling behavior. Actually, in particular, I will focus on the onset of loop stagnation during the integral tests under considerations; and then I will discuss some finding about the general behavior or general trend of downcomer fluid temperatures and system pressures.

We use our version of the input -- and the reason I say "our version," is because the original input deck was developed up by our new -- this input deck was adopted by Science Tech to analyze some of the NRC tests that was conducted at OSU.

Now this was input related to the original APEX with the new APEX-CE geometry that's required and necessitated a lot of changing.

Also after I explain the modification briefly to the whole input deck, I adapted also some modification, according to the operating condition and the geometrical configuration of each test.

So the first modification was to isolate its own APEX, AP600 passive safety system and DVI lines. There were ADS systems, there were CMTs, accumulator, IWST, PRHR. All of these components were isolated.

And I isolated these components in addition to all the input related to these components.

Also elimination of all APEX AP600 safety system actuation logic. As you recall, with the APEX Test Facility, there was, for example, ADS, which were actuated based on the CMT level and sometimes CMT level plus time, as the case with ADS-4. So there will be no LOCA CMT, no ADS, too. So all of these logics were eliminated. This is just one example of these logics that we no longer use it.

Also with the new configuration we added the new seals, and a lot of piping associated with it, and also some heat structures, some tables, some -- also, for example, the loop seal and the changing of dropping the pumps down.

It was originally connected directly to the steam generator on one side and the other side directly to the cold leg. In this configuration we dropped it by almost 18.75 inch.

So this needed some changes in the pumps. Also the other side was connected to the loop seal.

In addition to this we added the high-pressure safety injection head curve. And the nodalization diagram that I used. This shows just the primary. The secondary is not shown in this diagram. As you see, there are loop seals and there are four injection systems.

RELAP5 calculation matrix, as I mentioned in the introduction, we analyzed almost five tests. But I want to present, since the topic was just focus on main steam line break and the small break LOCA, I will discuss three tests which is two actually for the main steam line break and the second one for this hot -- of the top of hot leg number one, a break which is called APEX-CE-08.

I have the result, and I can also offer a conclusion of my finding in the other two tests.

I adapted the same strategy that was adapted by Science Tech. Actually this strategy includes running RELAP, a steady-state case. And the purpose of this run is just to establish the initial condition for each test.

In these kind of runs, I introduced some control volumes and control runs and some time-dependent volumes. The purpose of this is just to bring the facility fast to the initial condition of each test. These additions will be dropped later.

Then I run usually each test for 1200 seconds until I see just some stable initial condition that fits or close to the real test. Then I stop. This is 1200. From experience I found that sufficient to reach stable initial condition.

Sometimes you reach it within 400, 500. It's just because I introduce what I mentioned just before, introduced some time-dependent volume that accelerate the calculation.

I run another -- after actually the steady-state test, I initialize and I zero the time just out in the steady-state case to make the 1200 second is just zero. So the initial point or the time equal to zero will be the initial condition at the 1200 second.

Another -- I didn't mention this, but I run another one which is called null transient. I just run the transient for short time, just to see whether whatever I adapted in the control of the steady state, the time different in that I added, does not affect the transient case. So to see whether the transient case will hold. And that's why we call it null transient.

The real transient comes after, which is called restart run, sometimes runs, not run, because sometimes -- actually all the time I monitor the kill the condition. If I see some abnormal condition, I stop RELAP, look to the problem, fixing it, and then I run restart run to continue.

The first test is called RELAP5

calculation for all OSU-CE-011. And some brief description of this test. It was simulated, one-foot-square main steam line break conducted at a constant power.

Steam generator number one, the power-operated relief valve was open to simulate the main steam line break. And then upon the initiation of the break, the reactor coolant pumps were tripped and the power brought from 100 kilowatt to the 54.8 kilowatt.

The pressurized heaters were allowed to cycle on and off based on the pressure of the collapsed liquid -- pressurizer liquid level. In this test we turned it off when -- the test turned it off when the pressurizer liquid level reached 16. And then it turned on when the pressurizer collapsed liquid level reached 26-inch.

The auxiliary feed water was maintained for the broken steam line for 10 minutes, and it was isolated from the intact steam generator.

This is a brief description of the test. And the sequence of events will be discussed along with the RELAP sequence of events when I come to the comparison.

The steady state. As I said, each test I run steady-state analysis to initialize the input deck to start with the correct initial condition that match the real test.

The code was run for 1200 second, time-dependent for volumes and some controls that were added, as I said.

I run it for 1200 second and the results, the calculated versus much of initial condition, as you see it, is almost similar exactly. The power 100 kilowatt. Pressurizer pressure 370 for both. The hot-leg temperature almost the same. The cold-leg temperature. The steam generator 1 and 2, 272 psig, which is the case with the calculation.

Pressurizer level, steam generator water level, and the steam generator feed water temperature, the steam generator feed water mass flow rate, all of these almost even. The cold-leg natural circulation flow is almost comparable. There is an -- I put 15.3. As I recall the test, it was 15.29.

So this is the transient case comparison between the pressurizer pressure. The red line is the test. The dotted line is the RELAP calculation. It shows the comparison. The general trend is acceptable, except faster depressurization with the RELAP calculation. I would connect this, the impact of this on other calculated parameters.

The general trend of the broken steam generator was almost an accurate agreement. This is the pressurizer level. And the high pressure injection system is almost for the first part.

(Comments off the record re pointer.)

MR. LAFI: This chart comprises all the four high-pressure injection system flow rate RELAP calculation. As you see before this point is almost comparable except with this, because here the high-pressure injection system comes into play when the pressure reach 360 psig.

That's why I initiated almost at 160 seconds at the beginning, but when it reach the 360 it initiated when it drop below 360. When it reached 360, the high-pressure injection system flow rate will be zero.

So the reason for this discrepancy is due to the pressure prediction with RELAP reach the 360 later, different from the real test. But the general behavior is acceptable.

CHAIRMAN WALLIS: I would think the integral under the curves has to be the same because this is -- maybe not.

MR. LAFI: What? What is it?

CHAIRMAN WALLIS: No, it's not. No, it's not. Okay, that's all right. Forget that question.

MR. SHACK: The pressure's not the same.

CHAIRMAN WALLIS: No.

MR. LAFI: Shall I continue?

CHAIRMAN WALLIS: So we conclude that the comparison is pretty good? Is that what you conclude?

MR. LAFI: I think so, yeah. The comparison between -- this is -- because the high-pressure injection system is pressure system dependent. Okay

There is impact in this area on the end of the temperature, for example, but for the most part it's acceptable.

The break flow rate, the general one, is -- looks acceptable. The maximum flow rate comes immediately after you initiate the break. And then in the test it seems to reach a cutoff area, which is corresponding to almost 120 cubic feet per minute, while in the test and the RELAP prediction it's almost 150. This cutoff, it sounds, the test they used vortex flow meter. And this is -- reach zero and reading.

I don't know whether the RELAP adapted some cutoff in this area or not, but it sounds similar behavior. It reaches a certain point and then at a drop zero. I will make sure about whether there is anything adapted.

MR. SCHROCK: Well, the difference is quite large at certain times.

MR. LAFI: The difference in the --

MR. SCHROCK: And one has to wonder, is there an error in the stagnation state that's causing that?

MR. LAFI: Actually I will mention the stagnation first, but it sounds to me the opposite. The stagnation is affected by whatever discrepancy I saw earlier.

So if -- because here, if you look to this, -- by the way, the stagnation or the onset of stagnation happened in the main steam line break -- in this test happened in cold leg 2 and 4.

The stagnation didn't occur in cold leg 1 and 3, which are both in the same side of the plant. And the reason for this, I tried to find some cause in the calculation. I plot the hot leg number 1 against the steam generator number 1, the cold side of the steam generator against the hot leg, which is the hot leg side of the steam generator.

If you look to the hot leg, the steam

generator number 1, the test data, the red color, all the time it's below this hot leg number 1. That means still there is natural flow from the primary to the secondary. In other words, still the steam generator is acting as a sink to the primary.

This is the same situation, even little bit different. If you look to the hot-leg temperature prediction for RELAP, this one, this scale, against the steam generator RELAP, number 1 RELAP calculation, all the time also -- even the difference is not as significant as in the real test -- all the time you see the hot-leg temperature is higher than the steam generator temperature.

This is -- it makes sense that I can conclude that because of not having the stagnation in cold leg 1 and 3 -- by the way, this is just a plot for hot leg 1 against steam generator 1, just to represent the behavior of cold leg 1 and cold leg 3 corresponding to the steam generator number 1.

This make me convinced that the reason for this not having a stagnation, still I have a flow from the primary to the secondary. If I go to the hot leg number 2 against the steam generator number 2, just to find a reason why we had stagnation in cold leg 2 and 4, if you look to this, whether RELAP or whether the test, you see the steam generator 2, the first part here is almost -- at almost 100 or 200 second you see the hot-leg temperature is higher than the steam generator temperature.

After that you will see the steam generator, whether the test or the steam generator in the RELAP calculation, you see is higher than the temperature of the hot leg number 2.

This make me feel that now at this moment the steam generator is acting as a heat source to the primary. That's why it develop some potential to reverse the flow. That's why we conclude that the stagnation is due to this situation.

And if you go to the plot of the flow rate for the cold leg number 2, you see the stagnation happened almost at 500 second or so. It's actually subjective. For the test maybe you can consider it at this point, while for RELAP you can consider it later.

But the general behavior and the stagnation occurred really in the RELAP calculation. So RELAP predicted the stagnation like what happened in the real test.

This is cold leg number 2. I said stagnation happened 2 and 4 -- and also on 4. This is the test against the experimental data.

CHAIRMAN WALLIS: The stagnation means no flow rate; is that right?

MR. LAFI: Yes. The stagnation --

CHAIRMAN WALLIS: So the red is never really zero unless there's an error in the plot. It jiggles around as a negative and it crosses -- I guess it crosses very, very briefly there. Does that --

MR. LAFI: Yeah. We --

CHAIRMAN WALLIS: Is that stagnation 4 long enough to really make any difference?

MR. LAFI: I consider -- I don't know. I consulted the experimental team. They think that the stagnation or when the flow meter read like negative value, that means is it reverse or...

MR. REYES: The flow meters that we have now installed, the electronics do allow us to calculate or measure reverse flow.

CHAIRMAN WALLIS: Yes.

MR. REYES: -- reverse flow. Whenever it says --

CHAIRMAN WALLIS: You're worried about stagnation because it leads to the maximum or the minimum temperature of the cold fluid going into the vessel; is that --

MR. REYES: That was the -- the original

assumption was that --

CHAIRMAN WALLIS: That was the idea.

MR. REYES: -- was that if you stagnate the cold legs you get stronger plumes in the downcomer.

We're going to show tomorrow a little bit of -- that's not always true.

CHAIRMAN WALLIS: So there's nothing really magic about stagnation. It's not necessarily the worst case.

MR. REYES: Correct, not for this plant.

CHAIRMAN WALLIS: It looks as though there's quite a difference here. That in the test the flow is getting very low. This RELAP is giving these other bursts of flow in the two directions.

MR. LAFI: Yeah. It's isolated. But if you compare it to this, for example, --

MR. REYES: Excuse --

MR. LAFI: You can't compare the previous one to this one. I say there is no stagnation in cold leg 1 or cold leg 3. This is true; there is no stagnation. While in this...

MR. SCHROCK: That spike is the test data.

MR. ROSENTHAL: What's the accuracy in your flow meter? Are we just looking -- should we be painting this with a paint brush, with a... You're talking about being off by two, three gpm.

MR. LAFI: Yeah, but I think if you take the average -- this is my thinking -- that RELAP calculation isolated actually from positive to negative.

CHAIRMAN WALLIS: Well, should we care about it?

MR. LAFI: At least the stagnation occurred, but at different time. Even if you consider the stagnation here, but I think -- but this will contradict the temperature against -- the hot-leg temperature and steam generator temperature will plot.

So that's why I thought the mechanism behind the stagnation is whenever the steam generator -- actually not exactly, because even in the test the stagnation occurred not at exactly when this steam generator exceeded the hot-leg temperature, that there is some time in order to develop some potential to reverse the flow.

That's why actually almost when the temperature in RELAP, the temperature difference between the steam generator and the hot leg reach almost 80 degree, then the stagnation occurred. This is what I saw even in the test, almost there is a

60-degree difference then the stagnation occurred.

MR. ROSENTHAL: Can you flip back to slide 20; would you mind, 20, if you -- that's good. So you see if you go out about 1800 seconds you will see that steam generator 2 RELAP versus --

MR. LAFI: This is --

MR. ROSENTHAL: That's good.

MR. LAFI: This one?

MR. ROSENTHAL: Yes, please.

-- about 1800 seconds --

MR. LAFI: Yes.

MR. ROSENTHAL: -- is a difference of like 100F. So that's --

MR. LAFI: The difference --

MR. ROSENTHAL: Okay. Now -- I'm sorry.

MR. LAFI: You say that --

MR. ROSENTHAL: No, between the blue --

MR. LAFI: Yes.

MR. ROSENTHAL: -- and the top --

MR. LAFI: And the top.

MR. ROSENTHAL: -- is about 100F.

MR. LAFI: Yeah. This is the difference between the RELAP -- that's why there is discrepancy between the RELAP prediction of the steam generator temperature in both calculation and the test.

But there is in both, the test and the RELAP prediction, the case occurred when the steam generator temperature exceeded the hot-leg temperature.

There is difference between RELAP prediction for the steam generator temperature and the test. But this does not mean that there is a case when the -- this difference, whatever happened, for example, in real test, when the temperature difference exceeds 60 or 63 degree or almost -- I think 63 degree the stagnation in the test occurred.

A RELAP calculation, and this is almost here, when at 500 something, between 420 and -- almost 80 degree between the steam generator and the hot leg. So this is where I saw stagnation, or at least I considered the stagnation.

But if you talk about the discrepancy between the RELAP prediction for the steam generator temperature, I say there is a discrepancy.

Again I'm talking about -- I'm looking for the cause of stagnation.

And if you look to this, also the steam generator -- RELAP prediction for the steam generator, not as good as the test, but all the time during the test the steam generator temperature did not exceed the hot-leg temperature. That's why we couldn't get stagnation in both the test and the calculation.

CHAIRMAN WALLIS: So we can go on now?

MR. LAFI: Yeah. This is just the stagnation, and this is another stagnation in cold leg 1 and cold leg number 3. And actually this is supported by the fact that the steam generator during the stagnation was full. And this is the plot of the liquid volume fraction --

CHAIRMAN WALLIS: It's always liquid. It's full of liquid; is that right?

MR. LAFI: Full of liquid, yes.

CHAIRMAN WALLIS: Or is it full of vapor? Which is which?

MR. LAFI: No. This is liquid volume fraction.

CHAIRMAN WALLIS: Liquid?

MR. LAFI: Yes.

CHAIRMAN WALLIS: Okay.

MR. LAFI: In RELAP they call it voidf.

The portion regarding the downcomer temperature prediction by RELAP. I saw within 2,000 second RELAP prediction for the downcomer temperature is in good agreement with the test.

And also I didn't notice this is the case at 8 diameter in the downcomer and the same position in RELAP. I plot different spot at 1.3 diameter; 2 diameter; 3, 4, 5 diameter; 'til 8 diameter. And I saw the temperature profile. There is no significant -- or actually there is no stagnation -- no stratification.

This is the cold leg number 1, and the same case with cold leg number 2.

As conclusions, the trend of the pressurizer pressure is similar for the OSU-11 test and RELAP5 prediction, although the depressurization RELAP5 calculation was faster. This is what was indicated in the first figure that I showed you.

RELAP5 successfully predicted the general trend of the broken steam generator, starting with the maximum flow rate, gradually decreasing to the cutoff area, similar to what we notice in the test.

The steam generator pressure, the broken one, was almost in a very good agreement. The flow rate through the cold legs, the main steam line break, the high-pressure injection system, and the downcomer temperature almost in good agreement.

RELAP successfully predicted the stagnation. Noted the same exact point. If we have, for example, the pressurizer pressure here for exactly and the injection system, which we say is system-pressure dependent, then we will have everything exact, but this is the problem with the RELAP prediction.

CHAIRMAN WALLIS: How big is the cold -- is the injection nozzle?

MR. LAFI: The injection nozzle? The high-pressure injection nozzle?

MR. REYES: I think it's about 1.3 inches.

CHAIRMAN WALLIS: How big?

MR. REYES: About 1.3.

CHAIRMAN WALLIS: It's this size hole?

MR. LAFI: Yeah, it is.

CHAIRMAN WALLIS: It's dribbling in at .1 gpm. It's hardly got any velocity at all. This is scaled from a real plant?

MR. REYES: So the maximum flow rate, it goes from about 1.1 gallons per minute per cold leg to zero.

CHAIRMAN WALLIS: What?

MR. REYES: The maximum is 1.1.

MR. BESSETTE: It comes in at a low velocity in the plant. It's about a -- something like a foot a second in the plant.

CHAIRMAN WALLIS: The figure we have here is -- yeah. It's one foot a second in the plant?

MR. BESSETTE: Something like that, yeah.

CHAIRMAN WALLIS: I thought it came in gangbusters, hundreds of feet a second. It came really in. I mean it's got several hundred PSI driving it, isn't it, or is this not?

MR. BESSETTE: You see, it comes in at a fairly large -- it comes in -- in the plant it comes in at about a seven-inch pipe.

CHAIRMAN WALLIS: Well, this must be a very different plant from the kind we used to -- we did -- you know, Creare did experiments with cold-leg injection and stuff trying to simulate fast. I think we had a fairly small scale, but the water still came pouring in through that injection nozzle at a pretty high velocity.

MR. BESSETTE: It will. In the B&W Plant it comes in at about 20 feet a second or so.

MR. REYES: Right.

CHAIRMAN WALLIS: So it's a completely different beast?

MR. REYES: Right.

CHAIRMAN WALLIS: Okay. All right.

MR. LAFI: The hot leg number 2 and the steam generator number 2 temperature histories indicate that the steam generator became a heat source at almost 180 second into the test in both the test and calculation.

Loop flow continued for another 320 until we reached the thermal potential, enough to reverse the flow. So the difference at that time it was in the RELAP calculation 80 degrees between the hot leg and the steam generator. And then the primary loop stagnation occurred.

Hot leg number 1, steam generator number 1 histories indicate that all the time hot leg number 1 exceed the temperature of steam generator number 1. And this varies in -- there was no stagnation.

It can be concluded that the action of steam generator number 2 as a heat source was the cause of stagnation in cold leg 2 and 4, given that the steam generator was full as indicated by liquid volume fraction, the one that I showed you.

By comparing the steam flow rate out of the break we can find the following: That the maximum is almost -- happened exactly at the time when you -- when we initiated the break.

The flow experienced some sharp drop at 120 cubic foot a minute for the test, while for the calculation it was 150.

There was similar gradual decrease in between. Further assessment for the parameters controlling the break flow in RELAP5 is being conducted because there are some parameters that affect the flow out of the break.

CHAIRMAN WALLIS: This is just a steam flow, is it? It's not a two-phase flow?

MR. LAFI: This is the steam flow.

CHAIRMAN WALLIS: So you would expect to be able to predict it quite well?

MR. LAFI: Actually I am trying to play with the -- because here there is some parameters -- this is what I expect for --

CHAIRMAN WALLIS: I'm sorry to -- when you say "cfm," that means that's some condition? I mean it's not a mass -- usually it's a mass flow rate that you want.

MR. LAFI: This is part of --

CHAIRMAN WALLIS: Because I don't know what the condition is and we're valuating the cfm at. I guess you can do cfm. Was it standard cubic feet per minute, or something, or is it... What is it, velocity times area; without --

MR. LAFI: This is volume --

CHAIRMAN WALLIS: -- any reference to

density?

MR. LAFI: -- actually cubic foot per minute, right?

CHAIRMAN WALLIS: So it's volumetric load.

MR. LAFI: Is it 120, it was.

MR. SHACK: But is it reduced to a standard condition, or is it just v times a?

CHAIRMAN WALLIS: Velocity times area? It must be.

(Comments off the record.)

MR. LAFI: Converted to mass flow rate?

MR. REYES: The flow meter rate, I believe, is the standard.

CHAIRMAN WALLIS: It's just velocity times area?

MR. REYES: The vortex. That's it.

MR. LAFI: Is the vortex flow meter --

MR. REYES: So the vortex flow meter is standard.

CHAIRMAN WALLIS: It's kind of strange, because I mean if you were dropping the pressure and you can get sort of the same velocity, but a lot less mass flow rate -- no. Maybe you can -- that's going to be all clear when we read the report?

MR. LAFI: That test is 12, which is

similar to 11.

CHAIRMAN WALLIS: I think the ACRS has a preference for never using cfm or gallons per minute as a unit-to-flow rate, because different gallons and different pressures and temperatures. If you use mass, then it's clearer what you -- what's going on.

MR. SHACK: Sometimes gallons are nice, but...

CHAIRMAN WALLIS: Well, gallons of cold injection are quite different from gallons of hot ejection in terms of mass flow.

MR. SCHROCK: In your detailed comparisons you have some poor results for hot leg -- or for steam generator number 2 temperature. And then you have some poor results for the collapsed liquid level beyond 2,000 seconds. But those poor predictions don't seem to be reflected in your summary conclusions.

MR. LAFI: Actually the poor prediction for the pressurized level actually -- in the first portion it was good comparison, while in the -- almost 1, 3, 16-inch in the test, that was -- after it reached the 26-inch the pressurizer heater turned on for --

MR. SCHROCK: It what?

MR. LAFI: In the real test, when the pressurizer level reached 26 amps, the heater -- the pressurizer heater turned on.

For RELAP this 26-inch -- and I can show you.

MR. SCHROCK: I don't understand what the heater on or off has to do with the level.

MR. LAFI: So you're asking me about the poor prediction of RELAP for the pressurizer level?

MR. SCHROCK: Yeah. I just looked at your comparisons of test data against predictions, and I see it made poor predictions of collapsed liquid level beyond about actually 1500 seconds. And it made poor predictions of the steam generator number 2 temperature.

But, as I listened to your summary descriptions, it seemed as though those rather poor predictions are not reflected in your summary.

MR. LAFI: I -- my --

MR. SCHROCK: Are they regarded as insignificant, or what's the -- what should be --

MR. LAFI: Actually --

MR. SCHROCK: -- interpreted from that?

MR. LAFI: -- I expect, my conclusion that the general run of RELAP predictions and, of course, all acceptable agreement with the first.

Consequently, I don't expect from RELAP to match exactly what happened in the test.

MR. SCHROCK: Well, the difference in pressurizer level of 70 and less than 50 is a significant amount of water.

MR. LAFI: Yeah.

MR. SCHROCK: And so I would think that would have some -- if I didn't know anything else about the test, I'd suspect that there's something in the calculation that needs to be made better in order to get reliable predictions from that code.

CHAIRMAN WALLIS: Well, that's the problem with all of these comparisons. We don't have a criterion for saying what's good enough, and what you have to do, and how you're actually measuring the goodness of RELAP with all these various wiggles, and squiggles, and lines, and curves, and things. I mean --

MR. SCHROCK: Yeah. But I keep --

CHAIRMAN WALLIS: -- that's the always the problem.

MR. SCHROCK: -- noticing these things and I mention them when I notice them.

CHAIRMAN WALLIS: Yeah. Well, I think you really ought to -- really the NRC should start off with some kind of an intellectual roadmap which says how do we make these comparisons, what are we looking for, and --

MR. BESSETTE: The thing about pressurizer level, and it may -- it may be due to this difference in the HPI flow between the -- see, pressurizer level in this case is an effect of something else. So this --

CHAIRMAN WALLIS: The extra water has to go somewhere.

MR. BESSETTE: Yeah.

CHAIRMAN WALLIS: So that's a good, simple principle.

MR. BESSETTE: So it looks like it goes back to this difference in the HPI calculations.

CHAIRMAN WALLIS: Because this is the only -- pressurizer is the only place which can accommodate extra water.

MR. BESSETTE: Yeah, right.

CHAIRMAN WALLIS: The rest of it's solid.

MR. ROSENTHAL: And let me point out that 50 percent versus 70 percent of the pressurizer volume is a much -- it looks like a lot, but the pressurizer is, what, 10 percent or something of the total system volume, so it really isn't that big of a deviation.

MR. BESSETTE: So I mean it's got to relate back to a difference in --

CHAIRMAN WALLIS: I think we have something similar with the next one, too. We have a similar difference with the pressurizer level and come back to that.

MR. BESSETTE: It can only be due to a difference in the RELAP calculation of the injection or the system temperature.

CHAIRMAN WALLIS: As long as RELAP is conserving mass.

(Laughter.)

CHAIRMAN WALLIS: Maybe it's conserving gallons of something. We're in trouble.

MR. BESSETTE: There you go. Conserving.

CHAIRMAN WALLIS: Okay. We should go on, I think.

MR. LAFI: The next test is CE-12, which is similar to one-foot-square main steam line break initiated from 610 kilowatt from full power.

Steam generator number 2 power-operated relief valve was open to simulate the break. And then upon initiation the break, the same thing, the reactor coolant pumps were tripped. The power and state of test 11, it was kept constant at low pressure -- lower power. Here it converted or switched to a decay mode. And this decay was included in the input.

The pressurizer heater were tripped upon the collapsed liquid level of the pressurizer, were turned off -- switched between on and off. Again 16 under 26.

The auxiliary feed water was maintained for the broken steam generator, which is the case of 11, for 10 minutes. And it was isolated from the intact one. And this is the sequence of events of the real test. And again the RELAP Code was run for steady -- was run for steady-state for 1200 second. And we established the initial condition, which was almost similar to the initial condition of the real test.

The mass, the auxiliary -- the feed water mass flow rate is higher in this case. And this is almost -- the pressure is different. In the previous test it was 272, this one 232. Almost -- the other parameter is close to each other, so this make me satisfied that I will start my transient case.

So the comparison, also the behavior of the pressurizer pressure not exactly but similar to what I saw before, the depressurization rate and RELAP prediction is faster, especially in this area.

And the steam generator pressure of the broken one, RELAP prediction just in good agreement trend-wise with the test.

This is the pressurizer level.

CHAIRMAN WALLIS: So you got the same problem as with the previous one?

MR. LAFI: The same thing.

CHAIRMAN WALLIS: Except the HPI prediction is okay. Look at that one after this. It looks as if you're predicting the injection rate right. Where is the water coming from or going to? Maybe it's a question of getting the temperature right.

MR. LAFI: Can I -- could I just one...

CHAIRMAN WALLIS: You're not -- you're not losing water, are you, from this?

MR. LAFI: Actually I'm not losing water in this test.

MR. ROSENTHAL: Well, then something's hotter.

CHAIRMAN WALLIS: Something's hotter. This is the steam -- the water is more -- expanded more somewhere.

MR. ROSENTHAL: Someplace.

CHAIRMAN WALLIS: Yes. Okay.

Well, maybe we should move along. But I'm not sure we learned -- what did we learn from that?

MR. LAFI: This is --

CHAIRMAN WALLIS: What are you testing, that RELAP conserves mass, or something?

MR. LAFI: The high-pressure injection system RELAP predicted well, compared to the test data.

CHAIRMAN WALLIS: Presumably, unless there's one of these traces which is invisible. I mean there are eight traces, and I can't see eight. I assume they're all on top of each other.

MR. LAFI: Yes. This is the RELAP prediction, the solid line. This one. You cannot recognize, but this is RELAP.

The stagnation occurred in this test in cold leg 1 and 3. In the previous test it occurred in 2 and 4. Now 2 and 4, no stagnation. This is 4, no stagnation.

And 1 and 3, you will see some kind of a stagnation and resumption of the flow in both test and RELAP prediction. So RELAP in this situation, this case, it predicted what we saw in the test, stagnation, and then followed by resumption of the flow.

And when I tried to look for the reason, it sounds the same reason, the same mechanism, when the steam generator becomes a heat source, you would have stagnation. When it goes back to the normal situation, the flow will be resumed or will resume.

This is similar to what I saw in cold leg 3, stagnation and resumption of the flow in both tests and a RELAP prediction, although at different times. And this is the reason again. This is supported by the plot of hot leg number 1 against steam generator number 1.

You will see that the steam generator number 1 for the test. And this is the hot leg number 1 -- what is it -- for the test. This one.

So when the steam generator higher in temperature than the hot leg, then you will have the stagnation. Whenever you have the hot leg exceed the steam generator temperature, then the flow will resume. This has happened in this point and this point with RELAP prediction.

So at this point the hot leg temperature, also predicted by RELAP, exceeded the steam generator temperature. That's why the flow was resumed.

And these spots is corresponding to the

time of occurrence of stagnation and resumption that I showed you.

Even, again, the steam generator temperature is not exact between RELAP prediction and test, but all the time this condition hold. You have heat sink, steam generator as a heat sink. You would have stagnation. When it comes back it will go to the normal flow.

For steam, for not having stagnation in hot leg number 2 and number 4, this is the reason that hot leg temperature all the time exceed the steam generator temperature.

Again, again, the temperature of the steam generator not as exact -- as exact or similar to the test.

This is supported also by being in the steam generator at that time. When the stagnation occurred it was full. There is no voiding.

The temperature profile for the downcomer. This is at eight diameter. And it match the test to this portion exactly, while after that it match the trend of the temperature profile.

This has happened also with the cold leg, because here at RELAP the downcomer was divided into sectors, so each -- when I say cold leg 2 downcomer it is corresponding to the sector that is in the cold leg number 2 side. So this is the temperature profile in the downcomer corresponding to the cold leg number 2.

And again I tried all of the cold legs, and it seems the cold -- the downcomer temperature is well mixed and there is no stratification.

I plot some data at 4 and at 6 and at 8. There was no stratification. But when I plot the downcomer temperature, even it does not show, there is some almost 20-degree or maybe 30- --

CHAIRMAN WALLIS: It seems to me the conclusions from this experiment are much like the conclusions you drew from the previous experiment.

MR. LAFI: Exactly.

CHAIRMAN WALLIS: So maybe we don't need --

MR. LAFI: Except -- except the resumption, and actually --

CHAIRMAN WALLIS: So maybe we don't need to read through all the conclusions.

MR. LAFI: Okay.

CHAIRMAN WALLIS: Is there something new in the conclusions?

MR. LAFI: I think there's no significant --

CHAIRMAN WALLIS: It's very similar to the last conclusion.

MR. LAFI: The only -- what? The only difference is I think the resumption of the normal flow. This is what happened in this test.

Now the last test is the OSU-CE-08, which is a break. That is located at the top of the hot leg number 1, which is two-inch break.

Again this test, not all the reactor coolant pumps were tripped at the same time. Two of them, called pump 1 and 4, were tripped. And then the second and fifth were tripped based on subcooling.

The pressurizer heater also allowed to cycle on and off based on the pressurizer low level.

The sequence of events for this test will be explained in the comparison.

A steady-state test was run like before for 1200 seconds.

CHAIRMAN WALLIS: You've got flow rate stagnating all of the cold legs --

MR. LAFI: Yes. Yes.

CHAIRMAN WALLIS: -- at the same time?

MR. LAFI: No. At different times.

CHAIRMAN WALLIS: But they -- you don't have it stopping. Does it -- so I guess that, in your sequence of events, cold leg 1 stops. There seems to be a long period when there's no flow in any of the cold legs, right? You take away that thing, will you? That thing between 1841 and --

MR. LAFI: This is not RELAP prediction, by the way.

CHAIRMAN WALLIS: It seems to me between 4723 and 5326, we have no flow in any of the cold legs, because none of them are restarted yet; is that right?

MR. LAFI: For the real test, tell --

CHAIRMAN WALLIS: They all stagnated at the same -- they're still all stagnated -- at 4723 they are all stagnated?

MR. LAFI: From 1841 until 4,723.

CHAIRMAN WALLIS: They are all stagnated?

MR. LAFI: Yes.

CHAIRMAN WALLIS: So there's -- what's cooling the core, just the HPSI dribbling in? The HPSI's over, too, isn't it then?

MR. LAFI: Let's see, HPSI at that time --

CHAIRMAN WALLIS: It's finished.

MR. LAFI: -- if it is injecting.

CHAIRMAN WALLIS: So there's nothing happening. It's just sitting there. Where's the heat going? It's going out the break? It's just boiling it? Is the pot boiling it out the break and there's no circulation through anywhere?

MR. BESSETTE: That's right. The break is big enough to take out the decay heat.

CHAIRMAN WALLIS: Okay.

MR. BESSETTE: And the HPSI is on the whole time.

CHAIRMAN WALLIS: HPSI's on the whole time?

MR. BESSETTE: Yeah. Or starting at 40 seconds earlier.

CHAIRMAN WALLIS: So you don't want to close the break and repressurize.

MR. LAFI: HPSI all the time except if it reach above the 360 psig there's no HPSI.

MR. BESSETTE: If you did close the break, at some point those generators would become active again.

MR. SCHROCK: Well, why have they got all these ADS things?

MR. LAFI: They're calculated versus measured initial condition, as shown in this table. The pressurizer pressure behavior trend was predicted by RELAP but, as you see, there is some -- at the first portion it was acceptable.

Here it reach a certain plateau for both of them, the test, and the RELAP prediction. And then it goes -- it decrease in both tests and RELAP prediction.

CHAIRMAN WALLIS: Well, now the pressure in the system is determined by the heat generation rate and the flowing out the break, isn't it? And the pressure it takes to drive that flow right out the break to carry out the heat essentially.

MR. LAFI: So that's --

CHAIRMAN WALLIS: You've have a certain amount of heat making a certain amount of steam and it has to go out the break, so the pressure is big enough to get that right out the break. I'm saying that it looks simple enough. You ought to be able to predict the pressure pretty well.

MR. LAFI: Actually even this -- this will reflect, this discrepancy between RELAP prediction and the test will reflect on the flow rate of the break. You will see big difference --

CHAIRMAN WALLIS: Yeah, that's right. You ought to be able to predict that pretty well, or is it --

MR. LAFI: No, it's not very well.

CHAIRMAN WALLIS: Is it because you can't predict the liquid carry over out the break just like what we talked about this morning, or what is it that's difficult about the break flow? It's a two-phase flow out the break? It's a two-phase flow.

MR. LAFI: It should be two-phase.

CHAIRMAN WALLIS: So the difficulty is because you can't predict the two-phase flow very well out the break, but you have these deviations here?

MR. LAFI: Actually what I know, that maybe the critical flow model at the break, this led to this problem because, as I understand, Henry Foskey's particular model is adapted by this version of RELAP. This is -- so I am thinking to look for that parameter that control, for example, the discharged coefficient or...

I will show you the break flow later.

This is actually the feed water flow. This is just -- I used whatever the test used. And this is the feed water mass flow rate RELAP and the test. And the injection, since the pressure is different, the injection now funnels because, as I said, the HPSI is system-pressure dependent.

So if you look to the top here is the test results, while the lower is the RELAP prediction.

CHAIRMAN WALLIS: So those four RELAP5 are all in that one bottom curve, are they?

MR. LAFI: Actually four for RELAP. This is --

CHAIRMAN WALLIS: The fuzzy curve is the four tests, right? That bottom curve is -- all the RELAP5 are on top of each other; is that right?

MR. LAFI: Yes. The level one is four RELAP prediction while the top is four HPSI. The test --

CHAIRMAN WALLIS: This is presumably because you have the pressure system pressure wrong?

MR. LAFI: Exactly, different.

CHAIRMAN WALLIS: Right.

MR. LAFI: So it behaves -- if you look, the pressure goes like this and down, it's different from the test. That's why this is a discrepancy.

CHAIRMAN WALLIS: They don't cross at the same point, but they...

MR. LAFI: As I told you, the break flow is not predicted except at the beginning, but the behavior reached maximum, then go down and then oscillate.

MR. SCHROCK: What is the test measurement of break flow?

MR. BESSETTE: But how is the break flow measured?

MR. REYES: The break flow --

MR. BESSETTE: It goes --

MR. REYES: -- on --

(Simultaneous discussion held among others in the room off the record.)

MR. REYES: We are using a separator system. This is all --

MR. BESSETTE: So he runs it through the separator, and he measures the -- you measure the liquid flow --

MR. REYES: The closed end and cfms.

MR. BESSETTE: And the vapor flow.

MR. REYES: Correct.

MR. SCHROCK: And you get these kinds of oscillations.

CHAIRMAN WALLIS: I don't know which is the test and which is the RELAP.

MR. SCHROCK: The liquid coming out of the separator.

MR. KRESS: Well, I can tell you which. This is the test and this is the RELAP.

MR. LAFI: The problem is the test --

CHAIRMAN WALLIS: So we have a question

now. We say that RELAP is predicting more flow out the break, about twice as much as in the test, so I gather from this curve. When I go back to page 58 --

MR. LAFI: Yeah. It's overpredicted --

CHAIRMAN WALLIS: Overpredicted the break.

MR. LAFI: Yes.

CHAIRMAN WALLIS: We go back to page 58. RELAP is holding the pressure up higher.

Do you think if it's predicting more flow out the break it would depressurize faster? It doesn't seem right.

MR. BESSETTE: It seems peculiar.

MR. SHACK: Yeah, something's wrong. Yeah.

CHAIRMAN WALLIS: Something seems strange. I don't know if it's wrong. It's just strange. I mean --

MR. LAFI: What's this conflict?

MR. BESSETTE: Could you flip back to the pressure comparison?

CHAIRMAN WALLIS: This --

MR. BESSETTE: Page 58.

CHAIRMAN WALLIS: RELAP holds the pressure up.

MR. LAFI: RELAP within 1,000 seconds --

CHAIRMAN WALLIS: In the early part.

MR. (SPEAKER): Oh, in the early part.

CHAIRMAN WALLIS: The early part up to about 5,000, RELAP is predicting a higher pressure than reality. And yet RELAP's also predicting a higher break-flow rate, which is consistent with having a higher pressure.

But if you look at -- you'd expect the higher flow out the break to depressurize faster. That's why it doesn't seem to make sense.

MR. HAN: How about HPI in comparison?

CHAIRMAN WALLIS: HPI is being predicted pretty well.

MR. LAFI: Yeah. It follows this one. Look, it follows this --

CHAIRMAN WALLIS: I guess this is the first time we're able to see something we can latch onto which we can get cause and effect and try to figure it out. I'm not sure we really need to pursue it, but it does look a bit odd.

So it's something for you to think about this. Can we leave it at that.

MR. SCHROCK: I have a question about your initial conditions. The RELAP prediction of initial conditions seems to me to be impressively good with one exception, and that is the steam generator number 1 and 2 water level, seems to be off by quite a bit, not just in this particular experiment but in the others, too.

Is there an explanation for that?

MR. LAFI: Actually I noticed this. Even if I start with the same volume of the steam generator level, like the test, it leads me to higher volume. And I couldn't find out what's the reason, but this is what happened in many cases.

For example, if I see the initial steam generator 15 and I set it as 15, it run --

CHAIRMAN WALLIS: To 27.

MR. LAFI: -- for a few seconds and then it goes to 25, or something.

CHAIRMAN WALLIS: And you can't even blame Bill Gates for that.

MR. LAFI: No.

(Laughter.)

MR. LAFI: As I said, the stagnation occurred in all cold legs, similar to the test but at different times.

And even I can't conclude, because it sounds to me subjective whether I consider the stagnation in the -- for example, in the test, it is clear for RELAP. I don't know what I --

CHAIRMAN WALLIS: You have to stand by the mic or you -- we lose the transcription.

MR. LAFI: It sounds to me subjective to determine which is as far as that. I will -- but I thought without the test, I will choose some point, but this is what happened. RELAP predict the stagnation, but at different time.

Not predicting the stagnation at its exact time is due to other discrepancy in other factors.

CHAIRMAN WALLIS: I guess what really matters here is what difference does it make to your assessment of pressurized thermal shock if you have these kinds of differences. And I have no idea.

How accurately do you need to know this sort of -- is it stagnated, or is it close to stagnation, and all that, in --

MR. LAFI: Actually --

CHAIRMAN WALLIS: -- order to assess pressurized thermal shock?

MR. LAFI: It seems the stagnation -- I found no stratification in the cold -- in the downcomer temperature after stagnation. And this is what we noticed in the test. Also the temperature in the downcomer is uniform during the entire test.

CHAIRMAN WALLIS: Everywhere?

MR. LAFI: Huh?

CHAIRMAN WALLIS: It doesn't stratify vertically, or anything; it's uniform everywhere?

MR. REYES: There are some tests where we see vertical stratification. And as far as the timing of when stagnation occurs, in this plant we -- because of the low injection flow rates, we see a relatively good mixing under stagnant conditions.

In other plants stagnations are important because if you have high injection flow rates under stagnant conditions you may see more penetrating plumes. So the timing becomes an issue.

Tomorrow I'll be presenting. We'll look at this scenario again and go --

CHAIRMAN WALLIS: See, I have no criterion for deciding is this good, or bad, or indifferent, or what shall I conclude, or --

MR. REYES: Right.

CHAIRMAN WALLIS: -- why should I worry, or should I.

MR. REYES: Tomorrow what we'll do is we'll look at loop stagnation mechanisms. That'll be the first talk. And we'll come back to this, what was causing stagnation in this particular test. And we'll relate that to some of the separate-effects tests and what we were seeing there.

MR. LAFI: This is cold leg 4. And actually what I discovered through a RELAP calculation that the mechanism of stagnation in this test is different from the mechanism of stagnation in your tests, as I will show it to you. This is -- again stagnation occurred but different time.

This is cold leg 3. And if you notice this, the hot leg temperature number 1 against steam generator number 1 temperature is almost higher, the hot leg temperature higher than the steam generator temperature, except it reach a point when they are the same.

And at this point, when I discovered the steam generator voided, empty. And that's why I conclude that the mechanism of the stagnation according to RELAP calculation for this test is the voided of the steam generator. This is supported by this figure.

CHAIRMAN WALLIS: Now this -- wait a minute. This is TF 143 is a thermocouple in the hot leg?

MR. LAFI: Yes. 143, yeah, in the hot leg.

CHAIRMAN WALLIS: And it has these enormous dives that go off the picture and the one picture before that. Is that real, or is that a glitch in the instrumentation? Why do those things go down to the bottom of the graph there?

MR. LAFI: This one, this figure or --

CHAIRMAN WALLIS: Yeah. There's -- the color I can't describe.

(Comments off the record.)

CHAIRMAN WALLIS: Whatever you call that.

MR. LAFI: TF 143?

MR. SHACK: Teal.

CHAIRMAN WALLIS: Teal. Teal, or something.

CHAIRMAN WALLIS: Yeah, Teal.

Why does it go down to -- is that a real thing, or is that a...

MR. LAFI: With the temperature profile?

CHAIRMAN WALLIS: The temperature plunges. It comes back.

MR. SHACK: The measured thermocouple response.

MR. SCHROCK: Right there.

MR. LAFI: This one?

MR. SHACK: Yeah.

CHAIRMAN WALLIS: And it's in a hot leg. Why does it do that? Does it suddenly sees a slug of cold liquid?

MR. LAFI: Is this the --

MR. REYES: I don't -- I don't believe that's --

CHAIRMAN WALLIS: If you see something you don't like, you don't believe it?

MR. REYES: No, no. There are -- there were two thermocouples that we were looking at earlier. One was giving us spikes in the high direction. And, of course, we want to look at both of those, but --

CHAIRMAN WALLIS: So --

MR. REYES: So the --

CHAIRMAN WALLIS: Give them a break and let them have low ones, too.

MR. REYES: That's right. We think there might be some noise problem with --

CHAIRMAN WALLIS: It's a noise problem. It's not a real thing?

MR. SHACK: Just put a bigger averaging in the circuit.

MR. SCHROCK: Somebody put a little ice water in there.

MR. LAFI: This condition, again, occurred with hot leg number 2 and steam generator number 2. And this is when the stagnation occurred when you have the hot leg temperature as equal to the steam generator temperature, which is corresponding now to the voided of the steam generator.

This is steam generator number -- what is it? The -- this one 225, which is the steam generator number 2, this one. And this one's steam generator number 1.

So this is the time when the stagnation occurred. I didn't, and I doubt RELAP can predict what is happening in the other location. But this is what I connected the stagnation cause because of the voidage of the steam generator going from volume fraction 1 to zero.

And the downcomer temperature profile is acceptable, except RELAP overpredicted the downcomer profile.

And this is the cold leg to downcomer, which is the sector corresponding to the area when the cold leg number 2 connected to the downcomer.

As the conclusion, RELAP predicted general behavior of the system depressurization, the high-pressure injection system, feed water, and the break-flow rates. Just in general for the break-flow rate. We see -- we saw some significant difference.

By comparing the break flow rate one can notice that the maximum break-flow rate at the beginning of the test was 12 ga- --

CHAIRMAN WALLIS: So this is a two-phase flow, not the break?

MR. LAFI: Out of the break, I suppose.

CHAIRMAN WALLIS: It's a two-phase flow?

MR. LAFI: I suppose two-phase flow.

CHAIRMAN WALLIS: What's a gallon of two-phase? I don't understand the break flow of gallons per minute.

MR. REYES: You're looking at the liquid flow as the --

MR. LAFI: This is the RELAP prediction liquid.

MR. REYES: Liquid?

MR. LAFI: Yes.

CHAIRMAN WALLIS: The beginning of the test it's all liq- --

MR. LAFI: Because the mass flow rate for... However, RELAP5 overpredicted.

CHAIRMAN WALLIS: This break flow in the two-phase is still measured in gallons per minute?

MR. REYES: Basically what we have is a separator with a loop seal. And the magnetic flow meter on that loop seal measures in gallons per minute.

CHAIRMAN WALLIS: So you're measuring the -- okay.

MR. REYES: So I think what he's comparing there then is just that flow meter liquid --

MR. LAFI: Comparing not after leaving the break.

CHAIRMAN WALLIS: So it's the liquid flow.

MR. LAFI: After separating the liquid from the two-phase.

CHAIRMAN WALLIS: So this is the liquid flow out the break?

MR. LAFI: Yes.

CHAIRMAN WALLIS: Then the steam flow isn't counted?

MR. LAFI: No. This is what -- the data I think -- after I think the separation, right? Yeah, it depends.

MR. REYES: So in RELAP were you comparing just the liquid?

MR. LAFI: The mass -- the mass flow rate for the liquid RELAP. That's why I compared this to

--

CHAIRMAN WALLIS: So the steam isn't counted in some way?

MR. LAFI: There is control volume. It occurred in RELAP to calculate the mass flow rate for the vapor, for the steam.

CHAIRMAN WALLIS: So you have a phase separator?

MR. REYES: Right.

CHAIRMAN WALLIS: You measure the water and steam flow rates?

MR. REYES: Separately.

CHAIRMAN WALLIS: And you measure them both in gallons per minute?

MR. REYES: No. They're -- the magnetic flow meter is in gallons per minute. The vortex flow meter is in the standard cubic feet per minute.

CHAIRMAN WALLIS: Standard cubic feet per minute? Standard cubic feet per minute?

MR. GROOME: Well, most flow experts do not measure mass. Only Coriolis measured mass. So the raw data is in volumes. If you want mass, there's --

CHAIRMAN WALLIS: It drives me up the wall. And graduate students get always very confused by all flow meters because they have these stupid measurements, like standard cubic feet per minute which no one understands. People are always misunderstanding.

MR. REYES: I agree.

CHAIRMAN WALLIS: Okay. Sorry.

MR. LAFI: RELAP5 predicted flow stagnation in all cold legs at different times, as was the case during the test.

The stagnation cause in this test is not similar to that of the main steam line break tests. It is believed that the cause of stagnation here is the voiding of the steam generator tubes.

RELAP5 prediction for the downcomer temperature profile is in good agreement with the test. RELAP5 is one-dimensional cold. Therefore, studying the stratification that occurred during the test in the cold legs and the loop seals was not possible.

I think this is the end of my presentation.

CHAIRMAN WALLIS: Thank you.

That's the end of the day's presentations, Jose?

MR. REYES: That's correct.

CHAIRMAN WALLIS: So we're finished ahead of time. And we're going to go and look at the experiment now?

MR. REYES: We can do that for a short while.

CHAIRMAN WALLIS: Yes. I think that would be very appropriate, while it's cold and we can get in there.

MR. REYES: That'd be fine.

CHAIRMAN WALLIS: Then we're going to see it tomorrow when it's hot and running?

MR. REYES: Hot and running.

John has guaranteed it.

MR. GROOME: Well, I don't know. We're going to be in gallons per minute.

(Laughter and comments off the record.)

(Whereupon, the meeting was adjourned at 3:05 p.m. on July 17, 2001, to resume on Wednesday, July 18, 2001 at 8:15 a.m. in Corvallis, Oregon.)

CERTIFICATE

This is to certify that the attached proceedings before the United States Nuclear Regulatory Commission in the matter of:

Name of Proceeding: ACRS Thermal Hydraulic Phenomena Subcommittee

Docket Number: (Not Applicable)

Location: Corvallis, Oregon

were held as herein appears, and that this is the original transcript thereof for the file of the United States Nuclear Regulatory Commission taken by me and, thereafter reduced to typewriting by me or under the direction of the court reporting company, and that the transcript is a true and accurate record of the foregoing proceedings.

Nancy Palmer

Nancy Palmer
Official Reporter
Neal R. Gross & Co., Inc.