CO-CHAIRMAN KRESS: I see. You estimate the order f magnitude.

MR. BAJOREK: Yes. In general, when you look at each one of those coefficients, two, sometimes it's only one; maybe it's two or three stand out and are an order of magnitude larger than the other ones, which say those terms should be dominating the process.

CO-CHAIRMAN KRESS: I understand.

MR. BAJOREK: So the critical thing was to make sure that those were scaled relatively well. If they were of minor importance, you kind of have to keep in mind that one of these facilities -- I think the idea is that you should get most of the things right, but it's virtually impossible to get all of the things simultaneously scaled correctly.

CO-CHAIRMAN KRESS: Yeah, we all know that.

MR. BAJOREK: As long as it was in a parameter of minor importance, we deem that as being acceptable.

CO-CHAIRMAN WALLIS: Well, probably three might be of minor importance because there's pressure change due to change in specific energy of the subcool fluid from heat transfer. Now, that's probably not a big contributor to pressure change. So slide three probably isn't all that important, is it?

MR. BAJOREK: I believe in both of these parameters the comparison between AP 1000 and the test is closer than what AP 600 and the test had been. So --

CO-CHAIRMAN WALLIS: Someone had some foresight.

(Laughter.)

MR. BAJOREK: There was some foresight there.

And as I mentioned earlier, in a lot of the periods and their subphases, we see much of the same story where the scaling groups stay within this acceptability range; the distortions are of two minor groups; or the test is more conservative for that process than what you would expect in the plant.

There is one exception, however, that starts to get our attention, and that was in the ADS-4 blow-down phase where we start from a relatively high pressure. The ADS-4 system opens. Entrainment starts to pick up during this period. The break flow or out the break, but the flow also leaving the system is fairly large. We may not be getting much flow from the CMT and the IRWST has not started to inject at this point.

So it's a period where we are losing a lot of inventory from the system, not necessarily getting much back in.

CO-CHAIRMAN WALLIS: This is a critical part in the process.

MR. BAJOREK: It is the critical path.

CO-CHAIRMAN WALLIS: The flow-down and all of that, really don't care.

MR. BAJOREK: Right.

CO-CHAIRMAN WALLIS: But when you get to the point where you have to lose pressure without losing water, that's when you worry about it.

MR. BAJOREK: So everything else up to this point has been a bit preliminary, but when we start to get to the ADS-4, this is where we've taken it very serious, and everything we talk about from here on out is really pertaining primarily to this critical period, especially the double ended guillotine break of the DVI line where you don't have as much mass coming into the system as you would for the one or the two inch gold leg (phonetic) break.

Westinghouse contends that during this period both APEX and SPES are scaled acceptably to the new conditions in the AP 1000. As we go through and redo the scaling, we find that SPES doesn't look all that bad. In fact, it looks more like the AP 1000 than it did the AP 600.

We disagree, however, with APEX. The mismatch in those resistances between the ADS-4 line and the DVI line creates a distortion for APEX while the pressures are high and if you make the assumption that the flow is critical during the early part of that ADS-4 period.

Once the pressure drops towards the end of that period, the flows diminish. APEX starts to scale acceptably. So we're --

CO-CHAIRMAN KRESS: APEX was meant for that period.

MR. BAJOREK: APEX was meant for the low part of the period. So we're saying close to the same thing in different ways.

Westinghouse in their report feels it's appropriate through the whole period, most of it if not the whole period. We aren't willing to go that far. We say it's only after you depressurize, the flow has gone noncritical, then we can start to believe APEX.

If you're going to use these data for code evaluation during the blow-down period itself, stay with SPES. Don't bring APEX into the picture.

Now, the problem does show up in the dominant dimensionless group that you get out of the scaling rationale. I'll refer to this one as pi 16. It's the relative flow rate between the CMT and a reference flow rate, which is chosen as the ADS-4 flow for this period.

Physically it represents how easy it is to get flow into the system versus flow leaving the system. So if I calculate --

CO-CHAIRMAN KRESS: And to get that pi group, don't you have to have an entrainment model?

MR. BAJOREK: To analyze it, yes, you would, and that's -- when INEL did their evaluation, okay, one of the things you could see in the report, and I did talk with some of the people who had done that evaluation, and they explained that one of the difficult features that they had was estimating the flow quality in the ADS-4.

In their report, they looked at the core exit quality, basically on the low end of things, and the flow quality of 1.0. They looked at AP 600 for both of those limits, and they found that the AP 600 scaled well for both APEX and SPES.

I found a couple of problems in some of

the numbers that they used with regards to the CMT, fixed those, redid that for the AP 600 and still agree. Both APEX and SPES would fit those susceptibility criteria for that wide range anywhere you pick that flow quality.

AP 1000, however, it's going to be more of an important criteria because I think we've already moved APEX during this period. So it has potential distortion. As we talk about entrainment later on and if we want to revisit top-down scaling, if we go away from INEL's assumption that the flow quality in the text and the plant are similar, and we make one have a low quality and the other one have a high quality, then we start to see distortions potentially even in SPES through this period.

CO-CHAIRMAN WALLIS: So we change our M, zero, DOT.

MR. BAJOREK: yes.

CO-CHAIRMAN WALLIS: The rest of it is the CMT gravity driven flow, right?

CO-CHAIRMAN KRESS: Yeah, you get that pretty accurately.

MR. BAJOREK: So as I've been proceeding right now, I've tried to stay true to the assumptions and the methodology that INEL put together. I didn't think this was the best time to invent anything new.

CO-CHAIRMAN WALLIS: Now, this should show up in the code. I mean, if the code is modeling SPES and the code is modeling APEX, this distortion should show up in different predictions if it's important. if you just run the code with these numbers, I mean, M, zero, DOT is predictive by the code, and delta Y is predictive by the code and all of that.

MR. BAJOREK: Well, I think the code will predict a certain MDOT and a certain flow quality. The question --

CO-CHAIRMAN WALLIS: But then what happens? The way the transient develops will depend on the ratio of these two things up here.

MR. BAJOREK: But the question we would have is --

CO-CHAIRMAN KRESS: How good is that predictor?

MR. BAJOREK: -- how good is that entrainment.

CO-CHAIRMAN KRESS: And then you have to turn to the test.

CO-CHAIRMAN WALLIS: We could do a sensitivity test. You could vary M, zero, DOT in some ways, see if it makes any difference.

CO-CHAIRMAN KRESS: Yeah, you could do that.

MEMBER SCHROCK: You talked about the flow resistance of the ADS line in the beginning of your discussion. That discharge flow is determined by several things, one of course being the valve at the end of that line.

It isn't clear in my memory what the flow -- can you explain that in terms of this pi group? It's unrelated to this pi group, I guess?

MR. BAJOREK: Well, not exactly. For the CMT we used the resistance and the head that was apparent in either the one inch break or the double ended break to get the driving head, the resistance of the CMT line, to get the CMT flow rate.

For the ADS-4 flow, followed what INEL did, used a homogenous HEM critical break flow model, calculated the flow rate with that. Okay? The flow rate increase or the mass flux with the HEM model, and then calculated the flow rate for the larger sized flow area in the AP 1000.

MEMBER SCHROCK: And what is the source of the information on flow quality approaching the break for that? How does it relate to the entrainment that you described at the beginning of the discussion?

MR. BAJOREK: At this point it doesn't have a relation to the entrainment. Since we didn't know what the entrainment was, we said, well, it has to be somewhere between 1.0 and the core exit quality and looked at both ends of that range. We did not try to pick a flow quality that might be based on an entrainment model or some other estimate.

That's one of the questions that we're going to have for ourselves at the end of the top-down scaling, and we're going to try to address.

MEMBER SCHROCK: This parameters varies during the ADS operation, and at any point in time during the ADS operation it depends upon the amount of entrainment. There are other aspects that enter into it, such as whether or not there is a role for thermodynamic non-equilibrium in that critical flow process.

I don't see that this parameter addresses the question of what is the amount of entrainment, and certainly it doesn't address anything that.

MR. BAJOREK: No, it ignores nonequilibrium both in the flow and also in the energy of the flow itself. The top-down scaling essentially homogenizes everything. So those details don't come out on the top-down --

MEMBER SCHROCK: Well, homogenizing everything gets you off the hook on the nonequilibrium question, I suppose, in a sense, but it doesn't do anything for you in determining what is the fluid which is flowing in the ADS-4 line. That's the central issue, central question to get to.

MR. BAJOREK: Yeah. That's why when I finished the top down, which I think might be the next --

CO-CHAIRMAN WALLIS: This is a bit like a PRA, the case where non-risk informed application. You do this like a PRA. It reveals there are certain things. You now need to go back and think about some more.

MR. BAJOREK: yes.

MEMBER SHACK: But is that the conclusion I get from slide 11? You have the two critical flows at the two limiting qualities, and you still say it scales okay for either one of those. That's where you're going to get to basically.

MR. BAJOREK: pretty much, although I think I would have gone to slide number 12 to basically say that. Slide 11 is just a summary of where we wound up with those pi groups and is just an indication that when we looked at APEX, we're seeing numbers outside of that acceptability range.

It doesn't matter what I assume for my flow exit quality. So whatever kind of entrainment I go back and try to estimate, I'm still from a top-down scaling saying it's still out of range, and it doesn't matter whether it's the double ended break or the one inch break. I still have a problem on there.

SPES seems to fit things more acceptably.

CO-CHAIRMAN KRESS: But, once again, you know, when you look at the APEX one and say it's out of the range, that doesn't necessarily invalidate it to me because we've fixed that range sort of arbitrarily, and so it just tells you, well, maybe we ought to think about this one a little more, look at it a little more.

MEMBER SHACK: Two, point, oh, two, you're --

CO-CHAIRMAN KRESS: Yeah, at 2.02 you're not good, right.

CO-CHAIRMAN WALLIS: It's not necessarily no good. If you run the code and if it's APEX, it tells you something about the code. And if you run them on the code for AP 1000, then you've got some more confidence even though these numbers are different.

You're still modeling the same phenomenon, but you haven't modeled exactly the same kind of a trace versus time.

MR. BAJOREK: That's true.

CO-CHAIRMAN WALLIS: The balance of things.

MR. BAJOREK: But when this number gets larger and larger, it tells me that maybe you aren't modeling the same transient anymore. Okay? If it's two or three --

CO-CHAIRMAN WALLIS: Then you should perhaps run the code with modeling the real APEX and then a virtual APEX which has a bigger ADS-4 so that it comes back to one or something. See if it makes any difference.

You can do an awful lot of things with the code with numerical tests, and you learn from that.

MR. BAJOREK: The conclusions that we get out of taking a look at the top-down scaling as a whole.

One, by and large, in many of these periods the tests are still very valuable, and it can be used to help benchmark those codes for AP 1000 usage.

The ADS-4 period gives us some concern,

and it does go back to what flow quality do you have in that ADS-4 line, and if you're off or if you were wrong for some reason, what's its potential effect on the AP 1000 itself?

In looking at these scaling groups, okay, varying the quality, we didn't do it explicitly, but if we varied the break model, varied other things, one of the things is that they are sensitive to some of your assumptions.

Quality was one of those. We could jockey those numbers around, depending on what that quality assumption was. So even though top-down scaling left us feeling like this isn't too bad, it left us a couple of questions saying that quality in that line and things that would affect that quality in the line need to be looked at in more detail.

To do that, we said, well, we need to set up a simple model where we can make some parametric studies, varying quality, other things in the system, to try to get on a first order approximation on AP 1000 and how it gets affected by some of these parameters.

Dr. di Marzo is going to show you this calculation. It's valid from the beginning of the ADS 1, 2, 3, and transitions us into the IRWST.

Do you want to sit here in the middle?

MR. DI MARZO: This is Marino di Marzo.

What I have tried to do here is to basically look at the single node type system, and first I formulated this model, if you wish.

MEMBER POWERS: It's not a handout. It's different.

MR. DI MARZO: And then I had to build some confidence in myself that this thing had something to do with what I was trying to describe. So I picked the DVI guillotine break as a start, as Steve mentioned to be the most severe transient.

And then I used the ROSA AP 600 test of that particular transient to see if I was close. Again, it's one node. We'll see with fixed parameter. So it doesn't even -- the qualities do not change during the transient like Dr. Schrock alluded.

And so I made a judgment there, and you will see the result as to how good that is.

Then I asked several questions. The first question I wanted to ask was: of all the non-dimensional groups that are used in the model, which one is relevant and which ones are not relevant? I mean, what is very important during this portion of the transient.

Then I compared AP 600 and AP 1000, which is kind of similar to what was done top down, and finally I start to run some sensitivity analysis, and the first one I run was changing the ADS quality and see how that impacted minimum vessel inventory, which has been the figure of merit throughout the AP 600 certification effort.

Then I'll draw some conclusions from what I'm looking at.

Now, this here is the set of assumptions used in deriving the model. The first thing is that the quality is fixed at each port. It can be different at each port.

Remember you have an ADS 1, 2, 3 and 4, which is considered one part. Another port is the break vessel side, and the third one is the break of the CVI line on the DVI line side. So you have essentially three outlets for the system. Each one has its own quality, and that's kept constant throughout the process.

The reference of the system is at the enthalpy at the average temperature during your transit, and you will see from the analysis how this is justified.

The specific heat of the liquid is

artificially doubled to account for metal masses that are in contact with the liquid. This is pretty standard. We've done that on many, many occasions.

The accumulator clearly comes in as a soup cool leaking (phonetic), and that represents a sync (phonetic) to the system. You will see that in the equation. PRHR also is a sync and will be modeled as a function of time because it was impossible to take it as constant as it decays, as you go through the transient.

All parameters unless otherwise specified are taken as constant at this average value in order to make this analysis simple enough that you can scrutinize the effect of each variation on the answer.

Now, here are the submodels that have been used to characterize mostly the flows. The AF is the ADS flow. It's the flow that goes out ADS 1, 2, 3, and 4. Obviously as the transient progresses, the cross-sectional area of that port keeps increasing when the activation is timed in this particular transient. So at each time that an additional valve opens, the cross-sectional area changes.

The flow is critical. Quality is considered to be equal to one to start, and in that we use the Henry Fauske, and then when the quality is considered to be less than one, we use basically the homogeneous HEM model.

The break vessel side, VB, is basically considered vapor because the data so indicates from ROSA facility, and therefore, we used the Henry Fauske there.

The break on the DVI side is very complex. If you look at the data, this break goes two phase initially. Then it becomes fully liquid because the accumulator is dominant, and then becomes fully vapor because then the accumulator stops injecting.

So throughout the transient it goes all over the place so that we don't have any idea what that might be, and so we will see that that particular term will use it as a tuning parameter in achieving our result.

The DF is the DVI flow on the impact side, and that is basically gotten from the specification of the test. Essentially we know the flow rates, and we input that as boundary condition to our single node. Decay heat similarly is known. PRHR is modeled as a function of time from the data. Then there is the system volume that we are going to use that's going to be different we're going to do for ROSA for AP 600 and for AP 1000.

According to the size, initial pressure also is gotten from the test, and initial inventor is gotten from the test and from the other facility according to older plant and facility according to the size.

These are the references where we got the information from. Yes?

MEMBER SCHROCK: You've got a quality of one. You have single phase steam. I don't understand choosing Henry Fauske to calculate the critical flow of single phase.

MR. DI MARZO: Yeah, that's no problem. Basically it's critical flow, steam critical flow. I can give you the --

MEMBER SCHROCK: I don't think I'd go to Henry Fauske to do that for --

MR. DI MARZO: Well, you can use --

MEMBER SCHROCK: -- saturated steam.

MR. DI MARZO: Well, you can use a number of type of situations there, and you will see that you could also use the HEM model or other models. It doesn't really make much of a difference in the end what you get, but that's what I've been using in a number of occasions, and it worked kind of reasonably well.

You will see the variation there is in terms of using a different model for that. So I picked that as it is no problem implementing a different formulation.

CO-CHAIRMAN WALLIS: What is that si band reference?

MR. DI MARZO: That's basically the original reference of the homogeneous equilibrium model. It was a cascade of references. At some point I finally found that this is the first guy that put it down somewhere. It's on some remote things.

MEMBER SCHROCK: I don't think that you could argue that he's original.

MR. DI MARZO: I don't know if he's original, if there's someone even before him, but that's what I basically landed.

MEMBER SCHROCK: You could turn to checks on thermodynamics 20 years prior to that.

MR. DI MARZO: Before to that, right. Yeah, that's the one I landed with. That's where I stopped myself.

CO-CHAIRMAN WALLIS: -- and Prague and people like that --

MR. DI MARZO: Yeah.

CO-CHAIRMAN WALLIS: -- have homogeneous

models.

MR. DI MARZO: So this is the formulation of the model. We start with the consideration of mass, and V is the inventor in the system. Again, this is the inflow from the intact DVI side. This is the break on the vessel side of the DVI. This is the break on the DVI side, and this is the ADS flow.

CO-CHAIRMAN WALLIS: So V is the symbol of?

MR. DI MARZO: V is the symbol of the amount of liquid, the volume of the liquid in the system, not in the vessel, actually in the overall system because this is a single node.

CO-CHAIRMAN WALLIS: The volume of liquid.

MR. DI MARZO: The volume of liquid.

Conservation of energy says that basically you have core power and stored heat, and these two go into making vapor. They go into the PRHR, who is a sync, and they go into heating up the injection.

CO-CHAIRMAN WALLIS: You have been very wise in that you have no momentum equation.

MR. DI MARZO: Right, no momentum.

(Laughter.)

MR. DI MARZO: It's a single node. Nothing goes anywhere. There is not much going on there.

MEMBER SIEBER: It's a straight line.

MR. DI MARZO: So in terms of the vapor generation, you have the first three terms, which are basically from the equation of state. They just are the variation of the amount of mass that's in the vapor due to the changing pressure, the changing volume because the liquid recedes.

CO-CHAIRMAN WALLIS: It's a perfect gas.

MR. DI MARZO: It's not a perfect gas. I use R star, which should be corrected for compressibility. Okay?

And then -- which is kind of fixed at some MOD (phonetic).

And then I have the amount of --

MEMBER POWERS: In thermal hydrolysis, the chemists go to all of this effort to get you a universal gas constant, and you --

MEMBER SIEBER: And then you don't want to use it.

MEMBER POWERS: Right. Decorating it with all of these correction factors.

(Laughter.)

MR. DI MARZO: It's some sort of a -- then you have the three flows with the qualities associated with them. This is quality one, as we discussed before, the flow from the vessel side break.

We use Clausius-Clapeyron in this form, this being a constant as you will show later. So if you go to the equation of state that's like that, and as I said, I used the compressibility factor at the average temperature.

CO-CHAIRMAN WALLIS: It looks upside down.

MR. DI MARZO: It looks upside down? No. That's --

CO-CHAIRMAN WALLIS: No, the bigger the pressure, the bigger --

MR. DI MARZO: Yeah, it's upside -- well, a misprint, okay? I mean vis-a-vis and then I wrote -- you're right.

The depressurization equation is basically the energy equation. So if you take the consideration of energy, the vapor generation, Clausius-Clapeyron, and the equation of state and put everything together and solve with respect to the pressure, that's basically what you get.

CO-CHAIRMAN WALLIS: This looks like one of those things in Moody's book.

MR. DI MARZO: Right, that's correct.

The bottom part is what we -- it's

basically what we have been referring to as the compliance of the system. It has two parts, a thermal part, which is associated with stored heat, which is basically this part here, and another part which is associated with the vapor space, which is this part here.

And up here you have basically all of the energy contribution. In other words, core power, PRHR, injection, and then you have thermal dynamic group, which comes from the gas law, and then you have all of the dischargers that carry away latent heat.

Now, if you take the depressurization equation and put in the consideration of mass, you get this thing I call the trajectory equation, which is very important because it basically relates how much liquid you lose compared to how much pressure you lose, which is what Dr. Wallis was alluding before. It's essentially your problem. You want to lose pressure without losing too much mass, too much liquid, so to speak.

So this trajectory equation is key, and that's basically what we are going to then use.

So you want to have dv/dp small in terms of a safety concern. If dv/dp becomes large, you're in trouble.

So we take this equation, and we non-dimensionalize it in the following manner. We identified four nondimensional groups, and the interesting thing is that each group is directly related to a scale of the system, to a physical scale of the system.

The first group is basically related to the net in-flow. So that relates to all of the boundary conditions to the system, the flow that goes in and out, establish the boundary conditions.

The second group is the energy associated with that net in-flow.

The third group relates to power, and obviously the PRHR has been lumped in there.

And finally, the last group relates to the size of the system essentially. It relates to the total volume that's available in the system.

And then there is a last group which is the ratio of the density of the vapor and the density of the liquid which I just left out, but, I mean, that's one term that you also want to consider.

Now, if you assume that your system is independent of scale, in other words, if you assume that all these groups are small with respect to one, look at this formulation here. Basically they're compared to one are small, and you assume also that the quality of the ADS-4 is one. Actually the ADS-1, 2, 3 and 4 is one.

Therefore, you may call these terms small. You get basically a self-similar (phonetic) solution.)

CO-CHAIRMAN WALLIS: It looks like an adiabatic --

MR. DI MARZO: Yeah, it's basically popping up in adiabatic, which should be this equation here. You would get a coefficient of this kind.

So whatever the system introduces, it basically makes this part of the equation different from one, and will basically affect your transient. So now you can ask the question after you validate it. You can ask the question which term is doing this with respect to -- so how far are you from this type of situation? So who affects; which scale affects the system performance? So that's the key answer.

Incidentally, if you look at the early part here for the Clausius Clapeyron, this term is equal to nine, which basically justified the assumption of measuring the properties of a constant average temperature because a minimum variation in temp. will give you the maximum -- a tremendous variation in terms of pressure.

If, incidentally, you also take this and compare it to the date on the steam table, you basically get an excellent agreement between 7,000 kilo Pascals and 100 kilo Pascals if you use that kind of relationship. So that's good.

So now let's look at how reasonable the result might be with this. So I took ROSA, the AP-DV-01. I considered the transient between ADS-1 and IRWST injection, which is in that time frame. I analyzed what initial inventory was and the final inventory were in this particular transient.

You have to consider that on the DVI broken, DVI side, both the accumulator and the CMT will discharge through that line. So you have to put them into the inventory of the system, and basically on the other side, on the other DVI line, we consider that s an injection.

So you have to play a certain number of adjustments in order to fit the transient, and that's all reasonable and justified.

And all of the parameters are set in accordance to what we have from the test. The only parameter that remains open is the quality of the DVI, of the break side on the DVI line, DVI side, and the reason for that is that that flow is very much changing from total liquid to total vapor throughout the duration of the transient.

So I said: okay. Let me match the initial and final inventory. So the initial inventory is the initial condition. Let me adjust the quality until the amount of liquid in the system matches the one in the test. All right?

And that was found for one third. Obviously if you make the quality higher, you have more liquid. If you make the quality lower, you have less liquid. That's fairly simple.

So adjusting singly that parameter, then I calculated what would be the pressure trace, and I compared that with the pressure trace in the test. In other words, if the single node evolves, what is the pressure path that it will trace and how does that compare to the test?

So if these two traces are somewhere on the same page in some ways, I have certain confidence not as a predictive tool, but at least as a comparative tool so I can make my sensitivity studies and compare one facility to the other on the basis of those parameters, and that's basically the result that I get.

MEMBER POWERS: All this without the

momentum equation.

MR. DI MARZO: Right. Well, that's in the breaks. The answer to my question is in the breaks.

CO-CHAIRMAN WALLIS: That's why it doesn't matter what you have for a momentum equation.

MR. DI MARZO: Look. Remember this is a very fast transient. The system is basically all saturated. It's flashing all over. So it makes kind of sense that you're not too far off.

All right. So then I have two slides which I'm going to skip in the interest of time, which basically give you all of the numbers that I used. So if you want to basically do it, the code is a one-pager. So it's not a big deal. It runs on Quick Basic, which is an archaic form of computing.

But what I think more important is to first ask the question how -- let me see. How do I do this? I would need -- we are referring to this equation here. Okay? The original equation here, and we are now looking at how the different governing group affect the answer.

So remember they are all compared to one. So if they are less than one, far less than one, like .01, it doesn't matter. If they are .1, they are ten percent of the answer. If they are one or above, they are really affecting the answer significantly.

In order to do that, I plot them as a function of time, as the transient evolves, each one of them. I took the logarithm of them. I first took the absolute value. I took the logarithm, and so to give you orders of magnitudes compared to the value one. Okay?

So if the number is down here, it means that that particular group is not very important. It's the number that drifts up towards one that affects significantly. It's a scale parameter that really is important.

Now, on the first plot, this one here, I'm concentrating on the terms in the denominator of your trajectory equation. So this is the terms in the compliance. This is the density ratio, and the density ratio is really very much non-important. We knew that from the beginning. Basically it's rhov over rhol. It's a term that's very small compared to one.

The other two terms are the power, which basically goes to zero, is first negative. The shaded one that's not very well seen on the viewgraph, but better on your overhead; the shaded part is when the original function was negative. Remember I took the absolute value.

So it's negative, goes to zero, becomes positive, but during the transient remains less than ten percent. So power is not a big issue, right?

The controlling factor in the compliance is the stored heat, which basically is what you see up here.

Now, let's analyze what happens in the transient, and this is a good figure to do so. This is the activation of the accumulator. This is activation of ADS-2, ADS-3, ADS-4, and this is when the accumulators stop injecting.

CO-CHAIRMAN WALLIS: So the purpose of these ADS-1, 2, 3, 4 is to keep everything around .3.

MR. DI MARZO: Right. Yeah, but that's -- you understand the goodness of the thing. In other words, ports are scaled properly from here. You understand it. To give you a very nice, gradual depressurization. That's basically what this is telling you.

All right. Now, let's look at the top part of the trajectory equation. I left alone the density ration because that wasn't that important. So I took the other two and added them up together, and then I look at the term associated with the 19th floor, which is F sub-G, which is actually the dominant term, which is up here.

And then we looked also at the sum of the two, which is, again, doing this, and then the last one that we looked at is the actual volume of the system. Remember the AP 1000 if far larger than the AP 600, but that term doesn't make much of a difference.

CO-CHAIRMAN WALLIS: FG is an in-flow?

MR. DI MARZO: FG is the net in-flow. So it is basically -- let me show you again.

CO-CHAIRMAN WALLIS: In-flow minus out-flow.

MR. DI MARZO: Yes, but it's normalized with respect to the ADS flow.

CO-CHAIRMAN WALLIS: Okay.

MR. DI MARZO: That's what it is. So it's what comes in through a DVI line, intact one, minus what goes out of the broken two sides over what goes out of the ADS-4.

Now, the bonus that we get out of this kind of analysis is that we kind of understand what each thing does with respect to the figure of merit, and that's what this slide over here is about.

So if you have a negative term, PG, EG, PG plus EG, that decreases the trajectory slope. Remember trajectory slope is dv over dp. So a small dv over dp means that you're losing pressure without losing liquid, which is desirable.

MEMBER SCHROCK: V here means specific volume? What is V?

MR. DI MARZO: V? V where? V? V is the volume, liquid volume in the system.

CO-CHAIRMAN WALLIS: Volume of liquid.

MR. DI MARZO: Inventory, if you wish, liquid inventory.

MEMBER SCHROCK: Lower case V.

MR. DI MARZO: Lower case V. High case V is the total system volume.

CO-CHAIRMAN WALLIS: So lower case V is specific volume.

MR. DI MARZO: No, lower case V is unfortunately the volume of the liquid in the system.

CO-CHAIRMAN WALLIS: Volume of the liquid in the system. Okay.

MR. DI MARZO: Inventory. I could have written I, but then I is kind of, you know, even more cryptical (phonetic) than small V.

So now the power group EG is negative when the PRHR is removing heat. Remember the PRHR removes much more than core power in the beginning, and that later on turns positive because the PRHR degrades. So you can see that. That's why this turns positive.

And then you can analyze this thing. You can read it again. I don't know how my timing is, but basically there's a description of how each term affects the bottom line.

The key important point is that the net in-flow is the main term. It is negative. So is this term here. It is negative, and therefore, clearly it affects this in a positive fashion.

If it's negative, it basically means you're losing water, and so it affects this in a negative sense. It makes this term bigger, and so it means that you're losing more liquid than pressure.

Now, if FG --

MEMBER SCHROCK: Marino, is there something in here about conservation of liquid? I'm not quite with you yet. I mean as you have flashing during this flow-down process.

MR. DI MARZO: Yes, right.

MEMBER SCHROCK: You're generating steam, and now you've diminished the quantity of liquid in the system because of the flashing. You also diminish the volume because liquid goes out the break.

Is there any other way you diminish the liquid?

MR. DI MARZO: Let me show you. You diminish the liquid basically because the liquid goes out of the various hole and because vapor is generated. That's the only way you can lose -- ever even lose liquid.

CO-CHAIRMAN WALLIS: Marino, I think both FG and PG and EG are negative. So the VDP is positive. So as the pressure goes down, the mass of liquid also goes down

MR. DI MARZO: No, if these two are negatives --

CO-CHAIRMAN WALLIS: They are.

MR. DI MARZO: -- that's good.

CO-CHAIRMAN WALLIS: The numerator and the denominator are both negative.

MR. DI MARZO: They are both negative. These two are negative. That's a good sign.

CO-CHAIRMAN WALLIS: And the numerator is negative. So the VDP is positive.

MR. DI MARZO: So this fraction becomes smaller.

CO-CHAIRMAN WALLIS: Is positive.

MR. DI MARZO: Yeah, but it's smaller.

CO-CHAIRMAN WALLIS: Well, it's positive.

MR. DI MARZO: Now, wait a minute. If FG becomes larger than one, which it's trying to do that, you get refill.

CO-CHAIRMAN WALLIS: Yes.

MR. DI MARZO: Which in ROSA, for example, you do. Okay?

In other words, if this here --

CO-CHAIRMAN WALLIS: You've got to refill. At the end you get refill.

MR. DI MARZO: Right.

CO-CHAIRMAN WALLIS: At the beginning they're both --

MR. DI MARZO: Right. If this curve here crosses this line you get refill.

CO-CHAIRMAN WALLIS: It does, yes.

MR. DI MARZO: Now here it's all negative. So you don't get anything. Actually you get a tremendous loss of liquid.

CO-CHAIRMAN WALLIS: Yes.

MR. DI MARZO: So that's all there, but basically you cannot make sense of all that is happening in detail. So it's in the handout, and you can look at it. Obviously it's going to be right up --

MEMBER SCHROCK: I'm afraid that I'm just too slow in assimilating all of the unfamiliar notation, but I don't know how to interpret the conservation of mass equation.

MR. DI MARZO: Conservation of mass. I should have taken more time in going through this. Yeah, here, right?

CO-CHAIRMAN WALLIS: It's the conservation of liquid volume.

MEMBER SCHROCK: Conservation of liquid volume. It's got four different terms in it.

MR. DI MARZO: Right.

MEMBER SCHROCK: We talked about two things that change it. I don't understand what the four terms are here.

MR. DI MARZO: Okay.

MEMBER SCHROCK: The top equation, conservation of mass.

MR. DI MARZO: This is the amount of liquid that comes in through the DVI line.

MEMBER SCHROCK: Liquid entering?

MR. DI MARZO: Right. This is the amount of liquid that goes out from the vessel side of the break. Remember it's double ended. So from the vessel side of the break. All right?

This is the amount of liquid that goes out from the opposite side of that break, and this is the amount of liquid that goes out from the ADS-4.

Now, the amount of liquid that becomes vapor, which I think is what you're alluding to, is not considered because it's very small.

MEMBER SCHROCK: Huh?

MR. DI MARZO: It is not in this equation.

MEMBER SCHROCK: It's not in this equation. It's small during the ADS phase?

MR. DI MARZO: Because of the flashing part, yeah.

MEMBER SCHROCK: I'd buy that maybe a little earlier on, but --

MR. DI MARZO: So I could basically block in here the term associated to this term here with the density. This is what I basically neglected from that particular, but I recycled this thing into there again, into the energy equation because what I'm interested is the amount of energy associated with that rather than the actual physical amount of mass that goes. I made that approximation. Yeah, that's correct.

MEMBER SCHROCK: Okay.

CO-CHAIRMAN WALLIS: But if you were just boiling a pot of water with vapor going out the -

MR. DI MARZO: Obviously it won't work.

CO-CHAIRMAN WALLIS: It won't work.

MR. DI MARZO: It won't work, but remember that the discharges here are very, very large compared to what's happening here in terms of flash.

CO-CHAIRMAN WALLIS: Well, the amount of liquid entrained is important.

MR. DI MARZO: Right. Now, we'll get to that.

CO-CHAIRMAN WALLIS: Yeah, but it is because it's the only term you've got.

MR. DI MARZO: That's right.

(Laughter.)

MR. DI MARZO: Now, when I compare the two traces, they are basically the same. The notable is ADS-4, which is at this point here.

What happens there is that you have to realize that the ADS has been scaled with power, and power is not the dominant term. The dominant term is the discharge. So if you make the hole bigger, you lose more water, and so that's basically what's happening there and why these two are different.

However, as you lose more water, also the pressure takes a dive. So if you are in terms of trajectory scale, it doesn't really matter.

CO-CHAIRMAN WALLIS: What you're showing is you think that AP 1000 will, relatively speaking, lose more inventory than AP 600?

MR. DI MARZO: ADS-4, but it will get to RWST faster. You see, it's a race, and both terms -- in the end, if I were to plot P over view of P against V, you won't see any difference. I have to plot in this way to make you see.

CO-CHAIRMAN WALLIS: When does the IRWST come in? Pressure has to go down to a certain value.

MR. DI MARZO: Yeah, right, at that pressure, at this pressure here it comes in.

CO-CHAIRMAN WALLIS: But the pressure terms, the pressure curves look the same, don't they, or does --

MR. DI MARZO: No, no. This --

CO-CHAIRMAN WALLIS: -- the end at RW --

MR. DI MARZO: They end at slightly different positions.

CO-CHAIRMAN WALLIS: Okay, okay.

MR. DI MARZO: So basically you open a bigger port. You lose more water, but you pressurize faster. That's all.

CO-CHAIRMAN WALLIS: So you go down to the same inventory where one recovers a little earlier than the other.

MR. DI MARZO: That's exactly. ADS-4, AP 1000 results to be a little faster. That's all.

Now, so this is good in the sense of saying I can play with this in any number of ways and variations and whatever, but so far so good. I can say the top-down scaling pretty much -- am consistent with that, but here comes the punchline.

What if the quality of the ADS-4 is different? What is the impact of that on the figure of merit?

Now, this is very deceiving because of you look at the pressure trace, and you compare the pressure traces for different qualities, they basically are the same curve. They're not going to change much, and this is due to the competing effect.

It took me a while to figure it out, but basically what happens here is that if you were to decrease the quality, your pressure stays aloft more in the initial part because you lose liquid rather than vapor. But then you have lost basically all of the liquid. So basically your stored heat goes down the drain.

At that particular point the system

pressure drops because there is nothing to hold it up, and so in the end, they all loop in the same type of trace.

But if you look at inventory, meaning how much shorter you are left with for injection, that's a completely different answer. There there is a tremendous impact.

Now, again, this is not a predictive tool. It's just a comparative --

CO-CHAIRMAN WALLIS: No, you're saying it's very important. You carry over --

MR. DI MARZO: But what I'm saying it's tremendously important.

CO-CHAIRMAN WALLIS: It's so obvious. You carry over a liquid to --

MR. DI MARZO: You carry over. So that puts a tremendous importance on how well you will know what entrainment is. In other words, the uncertainty on entrainment cannot be large to draw a safety conclusion. You have to have an uncertainty on entrainment that's pretty -- that's basically all that this says.

Now, there are other considerations. I haven't taken all the facility. I could run all of the facility against this and see how effective they are in reproducing this transient for code variation. I could do a number of things with this scheme, but that was the point that we wanted to make, and so I stopped there.

CO-CHAIRMAN WALLIS: I think this also shows up in the code. You put in different amounts of entrainment in a big code. You should get something very similar.

MR. DI MARZO: That's right.

CO-CHAIRMAN KRESS: Because all he does is represent the code the center way.

CO-CHAIRMAN WALLIS: Now, are you folks able to run -- you are able, but are you in a position realistically to run a system code, like RELAP or whatever?

MR. DI MARZO: On this kind of thing?

CO-CHAIRMAN WALLIS: For AP 1000.

MR. BAJOREK: Well, as part of the review, and I think NRR will discuss that tomorrow -- we did RELAP calculations for AP 1000.

CO-CHAIRMAN WALLIS: You did. Okay.

MR. BAJOREK: Yes.

CO-CHAIRMAN WALLIS: But you have no table to run the Westinghouse code.

MR. BAJOREK: NRR, I think, send some

people up to Pittsburgh, but I don't believe we had access to the codes.

CO-CHAIRMAN WALLIS: They didn't come back with the code. So you have to run your own code. You have an independent code.

MR. WERMIEL: This is Jared Wermiel, Chief of the Reactor Systems Branch.

No, Dr. Wallis, we did not exercise the Westinghouse codes. We ran our own independent analyses. We did a code review of the documentation at Westinghouse, and we'll talk about what we actually did tomorrow.

MR. DI MARZO: So to summarize basically, it 's a very simplified approach that are obviously sweeping approximation all over the places, but it's used to give you a sense of who's playing what and what's the net impact of everything on the end result. It clearly doesn't mean to be accurate or predictive or any of that. It just has to be a variational type process that you're doing. If I change this, is it more or is it less? That's the kind of thing you want.

Now, one last thing. Again, having said that, to put in another frame, point three was the point. Point three, when 30 percent of the liquid was there, was the level where in a specific standard we had said if it gets to .3, we're going to get core results. That's just to give you a sense of what it means. And then, again, this is very cursory, but if you are down somewhere in here, you're at the position where you may experience some core results.

MEMBER SIEBER: Now, do you have an estimate of where it would be for AP 1000? The same number?

MR. DI MARZO: Well, we don't know the entrainment. We have no ways, you know. That's an area that now Steve Bajorek is going to go into in great detail.

MEMBER SIEBER: But do you know what level of inventory --

MR. DI MARZO: Right.

MEMBER SIEBER: -- would cause that?

MR. DI MARZO: Basically this says inventory is crucial, and now that's where he's going to come in and say what do we have to --

CO-CHAIRMAN WALLIS: But there are ways to predict entrainment. If you use the homogeneous model, presumably entrainment is 100 percent, and then it depends on how you define entrainment perhaps, and if it's --

MR. DI MARZO: Entrainment 100 percent, yeah. It depends on what you call entrainment. What do you mean? Call it zero

CO-CHAIRMAN WALLIS: And there's no fade separation.

MR. DI MARZO: Okay. So you take core exit policy.

MEMBER SIEBER: But that changes with time, the amount of entrainment.

MR. DI MARZO: Yeah, that's the point that Dr. Schrock did at the beginning. All of this quality changes with time. This is just a sweeping approximation to take them constant, and you go with that.

MEMBER SIEBER: Well, that could give you some conservative answer.

MR. DI MARZO: That gives you a sense, but that's all it gives you.

MEMBER SIEBER: Right.

MR. DI MARZO: Okay?

MEMBER SCHROCK: Have you got this written up?

MR. DI MARZO: I'm five hours a week.

(Laughter.)

MR. DI MARZO: I am five hours a week.

MEMBER SCHROCK: I think I could buy all of your arguments better if I could sit down in front of the fire and --

MR. DI MARZO: And look at it, and then go page by page through everything.

MEMBER SCHROCK: I know.

(Laughter.)

MEMBER SIEBER: There's no place to sit.

MEMBER SCHROCK: I know where to put it. Discouraged.

MR. DI MARZO: It seems front of the fire is a kind of a consequential.

CO-CHAIRMAN WALLIS: Core exit quality is pretty low, isn't it?

MR. DI MARZO: What?

CO-CHAIRMAN WALLIS: I mean, if you use a homogenous model, core exit quality is pretty darn low. Every bubble carries up a lot of liquid.

MR. DI MARZO: See, in the INEL study, the core exit, what they use was .3. I don't know why they use .3, but that's what they basically use.

MR. BAJOREK: Around it. It varied from .1 to --

CO-CHAIRMAN WALLIS: If you use a homogeneous model for the core though, you carried out liquid out at no time at all.

MR. DI MARZO: Yeah, that is what the big differences are. I would like Steve to go into it, and you will see what the big differences are.

CO-CHAIRMAN WALLIS: When you try opening a champaign bottle when you've shaken it up.

MR. DI MARZO: Yeah, but this is a much narrower champaign bottle than the one before.

MEMBER SCHROCK: I guess you didn't comment at all about the point that I made earlier, that what you saw in the experiments at Oregon State so far is pulsating.

MR. DI MARZO: He's going to do that.

CO-CHAIRMAN WALLIS: He's going to come back.

MEMBER SCHROCK: You're going to do it later. You're not going to take it into consideration here.

MR. DI MARZO: Me? Impossible. Setting this, this is one pot.

MEMBER SCHROCK: thank you.

MR. BAJOREK: No, what we've been trying to do is basically build a case that as we look for top down scaling, we see concerns in what our exit quality is in the ADS. What Marino, we think, has shown is that when we do simple calculations, yes, we verify to ourselves that getting this ADS-4 quality correct is going to be crucial in determining if we have uncovery (phonetic) or heat-up in the AP 1000.

That leads now into the bottom-up scaling. Now, I'm going to spend most of the time looking at entrainment, but I just want to let you know that as part of the bottom-up scaling exercise, we looked at hot leg regimes, cold leg regimes. We looked at flooding in the serge line, used the Yei correlation to look at core exit void fractions.

As we go through that, we apply our .5 to 2.0 criteria. They fit within that. When we looked at the hot leg flow regimes, we still stay within the same two phase regime, although we're closer to a boundary now. We'll see that in a few minutes.

But the big concerns now are hot leg entrainment, how it was scaled, what the data says about that process, and upper plenum pool entrainment -- and we'll get to that in a second.

Okay. The first thing I want to talk about is entrainment in the hot leg, and as Dr. Schrock pointed out, sine there is a couple of ways we need to examine this flow regime or intended flow regime in the hot leg, most of our thinking on this, at least in AP 600 was that this was a smooth, stratified level that was fairly low in the pipe, and we could use horizontal stratified correlations to try to predict the entrainment and the onset of entrainment.

We have seen work at APEX and in another separate effects facility, supposedly well scaled for the AP 1000 and the AP 600, which would suggest that that level may be higher. It may be in an intermittent or another one of the flow regimes, and that this correlation and this process that we have assumed may not be appropriate.

CO-CHAIRMAN WALLIS: What matters is whether or not that liquid gets back into the vessel, spills over from the hot leg. If it gets in there and it can't get back into the vessel, then no matter what it's gone out as far -- eventually. So whether or not it can get back in is what matters.

MEMBER SIEBER: There's nothing to draw out of there.

CO-CHAIRMAN WALLIS: It just builds up and eventually it goes out the ADS-4 if it can't run back into the vessel.

MR. BAJOREK: Hot leg scaling or scaling for the onset of entrainment in the hot leg.

Westinghouse used an approach that was used in the AP 600. It essentially takes a modified froude number and uses the correlations that have been developed to say the modified froude number should be equal to some constant times a ratio of the free space in pipe, the region where vapor is fee to flow, H sub B, ratioed with small D, which is the branch line diameter, and that should be a small B in the froude number as well.

Now, Westinghouse used this correlation, scaled the process for entrainment in the hot leg, found that it was acceptable. We looked at it, and we see two problems with it.

CO-CHAIRMAN WALLIS: Excuse me. How do you get h_b?

MR. BAJOREK: Well, what Westinghouse did is they just said h_b was equal to capital D, as a link scale, put that into this expression.

CO-CHAIRMAN WALLIS: Oh, so h_b is D.

MR. BAJOREK: Capital D, and when you take the ratios in that context, I think it basically says that you're okay as long as you don't double your branch line superficial velocity.

Well, since the power only went up by 75, 76 percent, yeah, it has to be well scaled then.

Now, we don't have --

CO-CHAIRMAN WALLIS: I'm sorry. Jg-3 is what?

MR. BAJOREK: That's getting the velocity in the branch line.

CO-CHAIRMAN WALLIS: But that can't be h_b over D to a power M. I Mean, that doesn't make any physical sense. That's not an entrainment. That's the onset. Now, that's the onset.

MR. BAJOREK: This is the onset.

CO-CHAIRMAN WALLIS: That's just the onset. You've still got to say once it onsets, once it sets on, whatever the word is, what happens then?

MEMBER SCHROCK: Well, that requires a separate correlation.

MR. BAJOREK: Right. You need a --

MEMBER SCHROCK: The point I made originally sort of makes this discussion meaningless, it seems to me, and that is that this is not a configuration that exists at the time of concern, and therefore, what relevance has it in determining the flow of liquid out the break?

MR. BAJOREK: Let me show you how we tried to look at this from the scaling. I'll agree with you that this physical situation is probably not relevant for what we see in the hot leg. We don't have a lot of other models and correlations to go on at this point.

So I want to take a look at it. Let's assume that we do have a horizontal stratified flow, but then --

CO-CHAIRMAN WALLIS: But again, I get back to the question: how do you k now h_b? It isn't going anywhere. So how can you calculate horizontal stratified flow? It's just sitting in this hot leg sloshing around, waiting to be entrained. There's no stratified flow. It's just a pool of liquids.

MR. BAJOREK: It's a pool of liquids. This correlation --

CO-CHAIRMAN WALLIS: And what flows back is what matters.

MR. BAJOREK: What this correlation would say is that gas velocity is sufficient to entrain if you have --

CO-CHAIRMAN WALLIS: I'm saying you don't know that. Once your vessel level goes below the hot leg, there's nothing to hold that liquid in the whole leg, is there? Doesn't it just drain back into the vessel?

MEMBER SIEBER: Or go out

MR. BAJOREK: It would depending on

horizontal CCFL at the nozzle.

CO-CHAIRMAN WALLIS: Well, if it doesn't draw back into the vessel, is held up there, it doesn't really matter whether it's gone out the --

MEMBER SIEBER: If it goes out ABS.

MR. BAJOREK: At that point, for that situation, I don't think we would care about this. We would be more interested in upper plenum pool entrainment at that point.

CO-CHAIRMAN WALLIS: Yes,

MR. BAJOREK: Okay.

CO-CHAIRMAN WALLIS: That's what matters. Once you get a little hot leg.

MR. BAJOREK: Right, but the only consideration that we've seen for entrainment process is in the hot leg, was Westinghouse used this correlation.

CO-CHAIRMAN WALLIS: Well, I think what they predict though is that it's okay, and as soon as it gets below the hot leg, it shuts off. Isn't that what you predict? As soon as the level gets below the hot leg, the mechanism shuts off.

MR. BAJOREK: This would shut off, and --

CO-CHAIRMAN WALLIS: Right. So that the level hops just around the hot leg.

MR. BAJOREK: Or some low level.

CO-CHAIRMAN WALLIS: That's not serious.

MR. BAJOREK: If we had a high enough level and it were stratified the way we would say that you should apply a correlation like that is to take a look at the gas velocity that you do have and what would be the h_b or, better yet, the h_b over D value at which you would expect entrainment in the AP 1000 or in the test facilities?

Then h_b varies around depending on the gas velocity. Now, as I think it's been pointed out, that type of a correlation in the regime that we do have up there needs to be taken with a lot of distrust. Okay?

We're not sure what that regime is. That's why I want to look at it. Let's pretend it's horizontal stratified, but I'm going to look at a different regime, a few overheads from now, to take a look at it from a different point of view.

Even if it is horizontal stratified, we see some problems in trying to scale the data using this correlation. Principally this was developed from existing flow type solutions. It ignores roll wave entrainment, viscous effects, entrainment, the shearing of droplets from the top of this level.

In addition, it's almost universally based on data where the small D, the branch line to main line diameter was very small, a soda straw off of a one or two inch pipe, as opposed to the ratios that we would see for AP 1000, which is a little bit larger than .5.

So from a geometric scaling, we're out of founds from where this correlation had been developed.

Now, if we let h_b float, and we try to calculate what is that dimensionless ratio at which we would expect entrainment, if this correlation were correct, and if we had a horizontal stratified pool in this hot leg, we find that for the AP 1000, that ratio, h_b over D is larger for the AP 1000 than the applicable test facilities, which would be SPES for the high pressure periods of the transient and APEX for the low pressure periods.

It really doesn't tell us if it's scaled well or not, but we see it as an indication that the AP 1000 will see entrainment for a wider range of depths in the hot leg than we would in the AP 600 or in any of the integral tests.

So onset is more likely in the AP 1000. We can't make a judgment on if it's distorted at this point, one, because we find it a little bit difficult to apply a .5 to two on a number that can only range between zero and one. It basically says if you have a level in the middle anything between .25 and 1.0 is fine.

CO-CHAIRMAN WALLIS: Now, they're doing experiments at APEX. So one could see if this .232 whatever it is is actually happening or not. I'm not sure that there's any confirmation of that number from the APEX facility, but at least you can check it.

MR. BAJOREK: Okay. It gives us something to go on, but --

CO-CHAIRMAN WALLIS: Again, we visited APEX, and our impression was that the flow regime was not nicely horizontally stratified.

MR. BAJOREK: it was well from it.

When we looked at the hot leg froude number, one of the things that we found is that depending on the regime and the qualities that we were assuming in the hot leg, going through the hot leg to the ADS, we were in the wavy flow regime, but we're finding ourselves fairly close to the boundary between wavy and annular flow.

Now, in this particular figure, I've picked a condition at low pressure where the quality coming out of the core was fairly low, and that jams it over here very close to the transition point on the

Taitel Duckler map. Other cases tend to be further over to the left, but in the wavy regime.

But this transition boundary is not a very sharp transition, but it's a more gradual transition from what Taitel and Duckler described as annular flow in an annular wavy regime around this line.

So our interpretation is that, well, if it's wavy or stratified, it's starting to look very much like annular flow or interfacial shear and viscous effects are going to be important in the droplet entrainment.

For annular flows --

CO-CHAIRMAN WALLIS: Excuse me. Don't you have a co-current (phonetic) flow? I mean, going back to this, you can't have a co-current flow because there's nowhere for the liquid to go into the steam generator. But do you have a counter --

MEMBER SCHROCK: Well, it won't be a flow.

CO-CHAIRMAN WALLIS: Well, I know, but then this map is for --

MR. BAJOREK: Right.

CO-CHAIRMAN WALLIS: So I don't quite understand what you're doing.

MR. BAJOREK: What I'm doing is I'm trying to show that this really can't be interpreted as a stratified type regime, and that for whatever reason, even if it were co-current, I'd expect a lot of waves, and I expect this to have viscous effects so that mechanisms for entrainment similar to annular flow should be looked at.

CO-CHAIRMAN WALLIS: This flow regime map doesn't really apply. You have a short L over D. You have a steam generator 1M, which is blocking the flow so that you cannot have a co-current flow there. You have this inlet at the end, which is giving you a non-fully developed flow. There's flow around the bend. Everything is very different.

So it really has to be looked at as a new problem.

MR. BAJOREK: Okay.

CO-CHAIRMAN WALLIS: You can't just borrow something from the literature like this that doesn't apply. That's a no-no. And that is not acceptable.

MEMBER SCHROCK: Well, it won't lead to success.

CO-CHAIRMAN WALLIS: It's not acceptable. It's not professional engineering practice when you know something else is happening to apply something like this just to sort of invoke the names of Taitel Duckler. That's religion rather than engineering.

MR. BAJOREK: We agree. It's not --

CO-CHAIRMAN WALLIS: I'm sorry. I'm beginning to sound like Novak Zuber, but I mean, just --

(Laughter.)

CO-CHAIRMAN WALLIS: Someone has to do it.

MEMBER POWERS: Well, do we have a map that's appropriate to this?

CO-CHAIRMAN WALLIS: I don't think so.

MR. BAJOREK: No.l

CO-CHAIRMAN KRESS: We have an APEX text that would be appropriate for it.

CO-CHAIRMAN WALLIS: A test.

CO-CHAIRMAN KRESS: If you could interpret it.

MR. BAJOREK: We have an APEX test that show that there's a lot of oscillations.

MEMBER POWERS: Well, I'm trying to understand the criticism a little bit here. I mean, as I understood what you're doing here is you were saying would I think that there's different physics applied here than what was assumed when this correlation was derived.

MR. BAJOREK: Yes.

MEMBER POWERS: And you said for this

particular flow regime, yeah, there's -- just on the map you say you're close to the boundary, but in fact, when you looked at the particular paper, you found out that boundary was funky.

Okay. You don't have a map that's particularly appropriate to this.

MR. BAJOREK: No.

MEMBER POWERS: This is the best map you can possibly look at.

MR. BAJOREK: This is the only one that I can come up with.

MEMBER POWERS: And that led you to say, well, it's entirely possible that there's different physics here, and that's the only conclusion you drew.

MR. BAJOREK: That's correct.

MEMBER POWERS: And I guess I'm trying to understand. How do you fault him for that?

CO-CHAIRMAN WALLIS: Well, I'm trying to think of something that you would understand, Dana.

(Laughter.)

CO-CHAIRMAN WALLIS: It's like saying --

MEMBER POWERS: We don't have that long.

(Laughter.)

CO-CHAIRMAN WALLIS: We have some chemical reactions with sulfuric acid, and we have this correlation or this understanding of that. So we'll just assume that this applies to nitric acid or --

MEMBER POWERS: We do it all the time.

CO-CHAIRMAN WALLIS: -- or something else.

It's not without any scaling at all. You're simply taking something that applies to one thing and apply it to something else that doesn't apply.

MEMBER POWERS: Well, as I see what the question is he's posed is not whether he can come up and use this for some --

CO-CHAIRMAN WALLIS: You can use this. It says it doesn't apply, I guess.

MEMBER POWERS: I mean, he's not using this to say, "Ah-ha, here's the answer." He's using this to say, "Ah-ha, I'd better go get the answer."

CO-CHAIRMAN WALLIS: But it's like applying, say, a lamina flow method to a Togalin (phonetic) flow regime. It's a different situation. It's not appropriate.

MEMBER POWERS: But what are you telling him, to throw up his hands and say, "I can't tell what we need to do"?

CO-CHAIRMAN WALLIS: Well, he's saying we've got to get some more information. That's essentially what he's saying.

MR. BAJOREK: I'm going to conclude that.

(Laughter.)

MR. BAJOREK: I take it the thing that we did see of ATWS is that this is a very chaotic new flow regime. I want to use what I've got rather than trying to invent a new regime at one of these meetings. We may need to do that to resolve the problem.

MEMBER POWERS: And we'll have no trouble with your reasoning. Sulfuric acid can tell you something about how nitric acid behaves.

MEMBER SCHROCK: Dana, Graham mentioned something that should have been highlighted more when this was first reviewed at OSU, and that is that what was seen occurring in that apparatus was neither stratified -- and that's what I seized on and spoke very strongly about -- nor is it co-current flow, and both of those things are needed for these correlations of the form that Steve is showing to have any relevance whatsoever.

It's the lack of the possibility of co-current flow --

MEMBER POWERS: But I guess what I'm asking --

MEMBER SCHROCK: -- in the system at that time.

MEMBER POWERS: I'm not looking to use the correlations for anything quantitative. I'm asking are there transitions in physics that occur in this flow map, and he says, well, the only flow map he has is the one he puts up.

He didn't have one for the particular situation, and he says, "Yeah, they occur there."

It doesn't seem to me a terrible leap of bad judgment to say I bet there are transitions in the flow regime if I had the original map.

You're never going to use those numbers. You aren't going to use those numbers for anything, as far as I can understand.

CO-CHAIRMAN WALLIS: Well, I don't know.

MR. BAJOREK: The point I want to make is that we have a very chaotic regime. We think there was a lot of waves. We saw a lot of waves. We saw a lot of chaos in this flow. I only have a few correlations that I could pull out of the literature that are applicable to known things that I can apply. I don't have them yet for this physical situation.

If I use the closest I think I can get at this point at least --

CO-CHAIRMAN WALLIS: There's still a problem.

MR. BAJOREK: -- there's still a problem. If I look at entrainment for a co-current annular flow, okay, which says that, hey, I'm shearing off droplets from waves --

CO-CHAIRMAN WALLIS: You don't have a co-current flow.

MR. BAJOREK: -- you don't have a co-current flow. But we're shearing droplets from waves. That's as close as --

CO-CHAIRMAN WALLIS: I don't understand how you get an entree in to the figure because there's an X, which is the ratio of flow rates, and if you don't have a co-current flow, you can't even go into the figure.

MR. BAJOREK: Well, I did that the same way as the top-down scaling does. It assumes that you have a co-current flow up and out the ADS-4.

CO-CHAIRMAN WALLIS: Well, let's not dwell too much on this because there may be other things like this going on with some of these codes.

MR. BAJOREK: Okay.

CO-CHAIRMAN WALLIS: Of a similar nature.

MR. BAJOREK: Now, as I look at the onset of entrainment, assuming that I have a sump split in the system, two thirds, one third based on a single failure assumption in the ADS and I look at that gas velocity where you would get entrainment for a co-current annular flow, I see something kind of interesting drop out.

It tells me that I would expect entrainment for that type of a flow in an AP 1000 situation. I would not get it for any of the test facilities or the AP 600.

Now, it says for AP 600, not getting too excited on entrainment may have been the right thing, but it's not anymore for the AP 1000. Not knowing the flow regime and now seeing from newer tests that we have a flow regime that's different from horizontal stratified or co-current annular only gives us more evidence to say that we don't understand entrainment in the hot leg for the AP 1000.

CO-CHAIRMAN KRESS: Or the AP 600.

CO-CHAIRMAN WALLIS: Or for any of these.

MR. BAJOREK: Or for the AP 600.

CO-CHAIRMAN WALLIS: Any of these tests or for any of these geometries like this.

MR. BAJOREK: So our conclusion at this point is we can't say that hot leg entrainment is well scaled in these tests relative to the AP 1000 for several reasons.

Our conclusion at this point is that Westinghouse has not demonstrated that those processes were adequately present in the test facilities for the range of conditions that would apply to the AP 1000. So we're saying for Phase 3 this is something that we have to investigate in more detail.

MEMBER SCHROCK: See, a part of your problem is that the inappropriateness of this was just as great for AP 600, which is already approved using a code that imagines the physics as you were trying to describe them here.

MR. BAJOREK: That's what those numbers say. AP 600, if you look at it --

MEMBER SCHROCK: And now you've got to deal with AP 100, where this tradition of not challenging previously approved concepts comes home to haunt.

MR. BAJOREK: We think a more critical entrainment process, however, is this upper plenum pool entrainment. If we're entraining and we have these high levels and these intermitting sloshing regimes in the hot leg, well, that's also a clue there's still an awful lot of water left in the system, and we're a long way from core uncovery (phonetic).

When that liquid is gone and there's not much of a level in the hot leg and the mixture level has gone into the upper plenum, we're now looking at the situation where gas, steam being bubbled through the core plate, through a diminishing pool, picks up the droplets, sends them out the ADS. There's a trace of liquid in the --

CO-CHAIRMAN WALLIS: And your previously work suggested that if it gets into the hot leg it's gone.

MR. BAJOREK: Yes, yes. So some might be entrained, but our assumption is if it's entrained here, it's gone.

Now, this also comes about from tests that were run in the APEX facility following most of the AP 600 work. These are what we would term the no reserve tests. They were beyond design basis tests that they basically shut off the accumulators, the injection flows to the system, drained it down to the bottom of the hot leg, opened up the ADS-4 starting from 100 and 200 psi initial pressures for a range of pressures.

What they found -- and this is power down here at the bottom versus pressure on this figure --

in some cases it was sufficient to blow out all of that mass in the upper plenum.

All of the tests as you look at them in the hole suggest that upper plenum entrainment is real. There's a large amount of it, and Westinghouse's reranking of that process and the PIRT from the medium to a high was correct.

I think what Dr. Schrock had noted maybe in AP 600 that should have been a high and should have been looked at in greater detail.

CO-CHAIRMAN KRESS: Let me understand. You had this whole system closed up at temperature and at pressure and with a certain water level, and then you opened up the ADS-4. So you get a flashing process going on.

Now, that's not exactly what happens in the AP 600 when you get down to that level. You've flashed a long time ago, and now you're boiling, aren't you?

MR. BAJOREK: These tests are not indicative of whether you should get core uncovery or not, but they're showing that when you are having some flashing, power generating steam in the bottom of the core, that you are generating the type of gas velocities in the upper plenum that's sufficient to entrain a lot of fluid.

It doesn't necessarily mean you're going to get core uncovery because purposely in those tests, they've shut off IRWST, cumulators and other things that would help replenish that mass.

CO-CHAIRMAN KRESS: Sure, I understand, but my point was that you'll never get to that stage in the AP 600 because once you open ADS-4, you will finish your flashing process long before the water level gets down to where you worry about this process, and then the steam that's entraining is steam coming from the decay heat, and I just don't think --

CO-CHAIRMAN WALLIS: But as long as the pressure is dropping, you've got flashing.

CO-CHAIRMAN KRESS: Yeah, but not --

MEMBER SCHROCK: The most important flashing is in the flow path from the low mach number regions into the critical flow zone, and there there's a considerable amount of flashing.

CO-CHAIRMAN WALLIS: But that's not in the core. It's not in the upper plenum, is it?

CO-CHAIRMAN KRESS: No, that's outside.

MR. BAJOREK: Here, again, I'm going to look at this in terms of a steady state process. I'm not going to worry about the flashing, but I'm going to look at the gas velocities through the upper plenum that is due to the steam that is being generated in the core.

So we're going to throw away the flashing component. Even though there were tests in that APEX no reserve that started at fairly low pressures that I would say were indicative of the end of the ADS-4 --

CO-CHAIRMAN KRESS: That might be more indicative. I'll go along with that.

MR. BAJOREK: Okay. Here, again, we find ourselves in looking for correlations that may not be applicable to this situation. I've listed several of them up here, and I'll talk about why in just a second.

But what I want you to note is the way we would look at entrainment in a non-dimensional fashion is this Efg parameter, which is the ratio of the entrained flux to the gas flux that enters a certain region.

Now, several works have been done on this. They have looked at bubbling gas through relatively large diameter pools, not complicated with guide tubes and upper plenum structure. Okay? So there are atypicalities of them.

Several of them had been proposed, an

earlier one by Rozen, some Russian workers. I can't pronounce this guy's name.

Most recently, and perhaps the best work in this country, by Kataoka and Ishii, who did some studies in the mid-'80s where they took data from previous investigators and developed some non-dimensional, more mechanistic type of correlations based on what they had.

One of the things that you want to note from the equations is that they depend primarily on the gas exponent or the gas velocity to some power, three to four depending on how you define your regime, and these people did it in different ways, and how far you actually have to carry the droplet before you're up and out of the system.

So H or distance enters into there in some format, either in the exponential or in a dimensionless form the way Ishii treated it.

The important thing to note right now is that the sensitivity between the entrainment and the gas velocity, third to the fourth power. Okay. Well, let's assume everything was scaled fine for the AP 600, that we're down at about the same pressure. So we don't have to worry about the H or the H star. We don't worry about geometry. We can throw away the delta rho over rhos.

It tells me that entrainment should scale something like J sub g to some power, which ranges between three and four.

Well, that's a direct relation to power. Throw the power in there, and without a whole lot of work, it tell us that entrainment in the AP 1000 is going to be five, maybe ten times what we see in the AP 600, and presumably the tests, if they were as well scaled for that.

Now, in looking at this, we can look back at AP 600 and look at the AP 1000 documentation. No one had ever scaled that before. This is something that went through the cracks.

CO-CHAIRMAN WALLIS: No one had ever scaled one of these very important phenomena?

MR. BAJOREK: This I couldn't find it. I asked Westinghouse, and they told me no. It hadn't been looked at.

So we took a look at the test facilities, APEX, SPES, ROSA, and of the correlations which are available, I think that the Kataoka and Ishii is the most complete set of work that's available. So I said, "Let me look at that."

What they do, and this isn't in your

package, is they break entrainment up into several regimes. If you have a level up near the hot leg, you're in what they would call a near surface regime, which means any kind of a gas flux entrains virtually everything. It doesn't exist for very long.

As you entrain more and more from a pot or a pool or an upper plenum, you go into what he refers to as a momentum controlled regime, and that depends on the gas flux. Okay?

The exponent increases. Okay? It's three for this intermediate flux regime, which I just showed you. It's up to seven in his report or 20 when you get to a high gas flux regime.

And then eventually as you drain this level to a low enough, you enter the deposition controlled regime, which I really interpret as being a no man's land. It says you can't analyze it because deposition has a bigger effect.

Now, as I looked at the facilities, the AP 600 and the AP 1000, I find that we're in the momentum controlled regime. We don't get down to the deposition controlled regime, and we remain in this intermediate gas flux regime in all of the facilities and the AP 1000.

So that Jg to the three correlation that

I showed you on the last page I think would be the most typical one to use. So I'd define a scaling parameter, this pi sub up, entr as being this upper plenum pool entrainment parameter, and I'd say, well, let me define this as the package of terms from Ishii's correlation Jg over H to the cubed times the hydraulic diameter, one and a half, ratioed that from the test to the AP 1000.

And I said, well, let's assume that we had the same pressures. That lets them get rid of the star terms on there. It leaves me with this expression at the bottom of the page that I leave in terms of the core power area available for flow in the upper plenum.

Delta Z, the distance between the bottom of the hot let and the top of the active fuel. And when I scale, when I pull out numbers from INEL, numbers today obtained from Westinghouse for areas, lengths and so forth, and the power factors, I wind up with this table.

Now, the scaling ratio that I defined is on the next to the last one, but I think an easier way to look at this is the one over pi up, entr, which gives me the relative entrainment in AP 1000 to what I saw in the test facilities.

AP 1000 should have about 18 times the entrainment that we see in ROSA, 156 times in SPES, only six times APEX. There's a saving grace here. APEX was a one quarter height scale.

So where it doesn't have the correct J sub g, it makes up for that because there's less height you have to carry fluid out of the upper plenum. We might call this a compensating error if we look at how much time it would take to train the facility. It is saying that Apex may not be unusable.

CO-CHAIRMAN WALLIS: Excuse me. This H is the height from the hot leg down to the core?

MR. BAJOREK: Top of the core, yes.

CO-CHAIRMAN WALLIS: When you're above that, you're entraining much more rapidly.

MR. BAJOREK: Oh, yeah. Now, if I just defined the scaling parameter, I would use this to demonstrate the problem and our concern.

Now, since I put these numbers together, I have taken a step back and used this initial form of this scaling parameter with the dimensionless terms in there. That allows me to look at different pressures and play games with heights.

Even when I do some of those sensitivities, I still get these entrained -- I still get this parameter out of range. It improves a little bit. This .16 might go to .2, maybe a .25.

CO-CHAIRMAN KRESS: When you take your equation or the Efg which you think is most appropriate -- I guess it's this bottom one -- and plug in some numbers or say AP 1000, what do you get for an absolute value rather than these ratios?

MR. BAJOREK: We took that out of the overhead yesterday. I'm sorry.

CO-CHAIRMAN KRESS: Because that's going to tell you the importance. It's an importance measure if you know the absolute value. You know, if you're not --

MR. BAJOREK: Well, not now because I'm not comparing it to anything else like I was in the top-down scaling.

CO-CHAIRMAN KRESS: Well, yeah, I mean if you assumed this model is correct and you plug in the things for AP 1000, it's going to give you an idea of how much liquid is entrained to go out with the gas, and you know or you've got an idea of the gas flow. So it's an importance measure in my mind if you had that absolute number.

MR. BAJOREK: Well, the way I've tried to look at this, and I don't have those results and could spend half a day looking at this, is in terms of how long it would take to drain the upper plenum in an AP 1000 and an APEX facility, and how does that time compare to the transition time from ADS-4 to IRWST.

So far I've been able to convince myself that APEX drains at about the same time, but preliminarily, it still tells me that I could potentially deplete the mass in the upper plenum before I've completed that transition.

I'm not far enough along on that to say whether we've got an uncovery or whether there's plenty of water. I'm very comfortable, however, looking at these numbers and concluding that upper plenum entrainment is something that we definitely need to look at in more detail in Phase 3 of this review.

Keep in mind that this is a dominant process in the most critical small break that we would see for an AP 1000, the double ended guillotine break for a DVI line where you would expect the two phase level to be somewhere in that upper plenum. So entrainment, okay, is going to be higher in the plant than in the test, and our question is: if we're off in however this is modeled in the core -- in the code -- excuse me -- are we potentially claiming there's no cover uncovery in heat-up when, because of test data not being in the right regime, we may actually see some type of a heat up?

Now, in looking at the analysis, the RELAP, looking at the type of entrainment on here, I think we can say at this point if we do get a core uncovery, it's probably not a very deep one, and it's probably not a very prolonged one. It still gives us the appearance that there's a lot of water in the system that has to be swept out in addition --

CO-CHAIRMAN WALLIS: Well, once you begin to uncover the core, you don't have a pool anymore in which you've got entrainment. You've got little channels in which you've got entrainment.

MR. BAJOREK: Right.

CO-CHAIRMAN WALLIS: And the stuff is being pushed along the channel wall. One might wonder if it's actually worse entrainment because it's in a little tube, and it's got a launcher for its droplets instead of being in a pool.

But I'm not sure.

MR. BAJOREK: That's one of our questions. At what point when that level drops in the upper plenum can you really consider it a pool anymore and you have to start looking at localized effects and jets in various regions of the upper plenum?

CO-CHAIRMAN KRESS: Will given my past experience with rod bundles and the opening in there, with other things that are similar to this, you can treat it as a pool. Just forget the rods, but you know, that may not be true, but that's my experience.

MR. BAJOREK: So our conclusion with regards to upper plenum pool entrainment is that we think that this represents a distortion between AP 1000 and the test data. We see a nonconservative distortion in that we would be losing more mass out of the AP 1000 than any of the test facilities.

At this point we haven't seen a scaling rationale from Westinghouse, and we don't see evidence that this test data or other test data that you might want to consider for an entrainment effect is appropriate for the AP 1000.

So we think that in Phase 3 this is another area that we would need to look at, and I guess I would have to say I would consider this one a more critical than the hot leg entrainment.

CO-CHAIRMAN WALLIS: Do you know what equations Westinghouse uses to predict entrainment?

MR. BAJOREK: In COBRA TRAC, but not NOTRUMP.

CO-CHAIRMAN WALLIS: You could make that comparison between Ishii's -- use an Ishii's model. They use something else. They must use something, and presumably you can find out what they do use and make that comparison.

CO-CHAIRMAN KRESS: I thought I remembered that they use test data from the 2D3D program, but I may be thinking about another code.

MR. BAJOREK: Well, in the core model I know we used or Westinghouse used a model that was benchmarked or had a very close relation to one of the Ishii correlations. It's something different than the upper plenum. They used the upper plenum test facility to try to look at that for a large break.

We're looking at small break, and we'd have to look at NOTRUMP for that.

To wrap up and to give some conclusions, I don't think we want to lose slight that a lot of the test data, a lot of this integral effects data is still pretty good for the AP 1000. It still has a lot of use.

We see a couple of exceptions. Hot leg entrainment, we're not sure how we should treat it. We don't know what the flow regime is. We think that we're probably at a situation where we would expect to see that onset in the AP 1000, but not in the test.

For the upper plenum pool, we think there's going to be a lot more entrainment in the AP 1000 than was observed in any of these three integral test facilities.

CO-CHAIRMAN KRESS: Do you know how much entrainment was observed in the integral test building? Have you gone back and extracted that information?

MR. BAJOREK: We haven't yet, but that's one of the missions right now, yes.

CO-CHAIRMAN KRESS: Because it was a small value in the first place, and even though AP 1000 may be considerably more of a small thing, it can still be a small amount.

CO-CHAIRMAN WALLIS: It may be zero. One hundred times zero is still zero.

(Laughter.)

CO-CHAIRMAN KRESS: Good point.

MR. BAJOREK: Anyway, that's where I'd like to conclude and wrap up, with the idea that it's entrainment processes that we need to look at in a lot more detail.

CO-CHAIRMAN KRESS: At this point we have on the agenda to hear from Westinghouse or the other alternative is to have break and then hear from Westinghouse. But I'd ask how long Westinghouse might be.

MR. BROWN: We're going to be here tomorrow. So --

CO-CHAIRMAN KRESS: Okay. Well, it would be a good time to comment on what you've already heard now rather than to wait.

MEMBER POWERS: Rather than to let you sit on it.

CO-CHAIRMAN KRESS: Rather than to let you sit on it. So the question is about how long would that do you think take you.

MR. BROWN: Well, do you want to take a break and come back? Is that what you're thinking?

CO-CHAIRMAN KRESS: Well, that's what I'm trying to decide. If you're going to take -- if it's not going to take you long, well, we'll go ahead and hear you.

MR. BROWN: He has quite a bit presentation.

CO-CHAIRMAN KRESS: Well, let's take a ten minute break.

CO-CHAIRMAN WALLIS: Could I say I really appreciate this sort of discussion from the staff?

And it's a real breath of fresh air compared to --

CO-CHAIRMAN KRESS: Oh, yeah.

CO-CHAIRMAN WALLIS: -- literally that they've met the requirements and everything is okay. In thinking about what really happens, it's a breath of fresh air.

CO-CHAIRMAN KRESS: Yeah, we appreciate that.

(Whereupon, the foregoing matter went off the record at 5:11 p.m. and went back on the record at 5:23 p.m.)

CO-CHAIRMAN KRESS: We can start again.

MEMBER SIEBER: Sort of.

CO-CHAIRMAN KRESS: Scaling.

MR. BROWN: Some of this, most of this is repeat. So I'll try to go over this pretty quick.

As you all know, we're talking about no new phenomena. We found that entrainment certainly ranked higher for AP 1000.

We submitted a WCAP, AP 1000 curb scaling assessment, and we also answered quite a significant number of RAIs associated with that. The one thing we did add, you know, additional work, was we also scaled the ROSA facility. Originally we scaled SPES and APEX, and we also added ROSA on top of there.

We also had some additional work here trying to address some of the ACRS comments, specifically yours, Dr. Wallis, from before.

CO-CHAIRMAN WALLIS: You did a cylindrical, symmetrical CFD model or something instead of a slab?

MR. BROWN: We did a pie shape.

CO-CHAIRMAN WALLIS: Okay, pie.

MEMBER POWERS: Oh, it's truly 3D.

MR. BROWN: Well, you could say that.

We had two areas of importance which we just went over. Of course, we're talking about upper plenum and hot leg. The main area I wanted to focus on here was obviously back in the upper plenum, and we had done some work. Obviously Steve has discussed that already before about some of the stuff from the hot leg, but I had a little bit of maybe a little different way of slightly looking at it as far as the upper plenum. So I wanted to go into some of that.

MR. BOEHNERT: Did you use the same correlation?

MR. BROWN: Yes, I did. Yes, I did, but I guess I don't need to get into it too much, but one of the things I did want to mention a little bit is that when you look at the Kataoka-Ishii work and he talks about the near surface region and momentum and he talks about the near surface region and momentum control region, the near surface region was found at least in their work to be independent of Jg and H, and it essentially correlated with density ratio.

So it seemed to me that for events in which we had a level in the hot leg where we didn't really have to lift the droplet very far, whenever the facility would get into pressure similitude with the plant, then from that standpoint it would seem like there was not really a serious scaling issue there.

It really is whenever you get levels where you drop below the hot leg is where you really get interested because that's really where the Jg and the height and so on really come into play.

So I think for the majority of events in which we get these smaller breaks and so on as far as the upper plenum is concerned, entrainment, I don't think there's a serious scaling issue there. I think the issue is with, for example, the DVI break where we actually start to drop below.

Now, I think Steve would agree with that.

MR. BAJOREK: I agree with that.

MR. BROWN: Okay. I could skip on a little bit there. I guess it was good to see at least

Steve and I must have made the same error or got to the same place here as far as scaling is concerned, but going back to looking at this regime where you're below the hot leg and so you have the height and Jg dependency to the third power, it essentially just shows that you got to the same places trying to scale the entrainment ratio.

And when I went through the exercise, I struggled a little bit with trying to come up with a reference value for velocity, quite honestly, because you're going through the upper core plate for the upper core plate holes, and then you are going to move into the main part of the upper plenum where you have all of these guide tubes there.

And so trying to pick, you know, a characteristic velocity is, I think, pretty tough. So what I did was essentially try to look to sort of try to see if I could hit the extremes, and one was where you went into looking at the flow area through the core plate itself, and then finally when you went through all of that and then get to where you've just got the guide tubes to contend with as sort of a bound on that.

CO-CHAIRMAN WALLIS: Don't the guide tubes de-entrain some of these things, the droplets, too?

MR. BROWN: Yeah, they sure do. I think that's probably even less well understood than entrainment unfortunately unless you really want to go there.

CO-CHAIRMAN KRESS: The core plate is how thick compared to the length of the guide tubes?

MR. BROWN: Thick? It's not very thick at all. I mean, compared to the length? You said compared to the length of the guide tubes? Yeah, it's pretty small.

CO-CHAIRMAN KRESS: You know, that would to me say it's more appropriate to use the guide tube velocity

MR. BROWN: Yeah, but the only thing I was thinking is that depending on perhaps where the level was, if you were talking about a level that was maybe you would -- if you were to think that there might be an event where there was a level that was approaching the guide tubes, you might be -- I mean approaching the core plate, then maybe you'd be closer to the core plate and vice versa.

CO-CHAIRMAN KRESS: The percentage of time it's there is going to be small.

MR. BROWN: Let's hope we don't get there, but anyway, when I did that --

CO-CHAIRMAN WALLIS: Well, excuse me. These facilities like APEX, do they have simulated guide tubes in them?

MR. BROWN: Yes, they do.

CO-CHAIRMAN WALLIS: They do?

MR. BROWN: Yes, they do.

CO-CHAIRMAN WALLIS: Does SPES have that?

MR. BROWN: I don't know.

CO-CHAIRMAN WALLIS: I think APEX does, but I'm not sure the other facilities do.

MR. BROWN: Well, the one I think that concerns me the most is the ATWS facility that you've been discussing here a bit earlier before, looking at some of the entrainment in the hot leg, is the fact that you know, I don't know enough about it so you guys certainly know more than I, but when I hear about, you know, a wave bouncing around back and forth and I've at least seen some papers on that and talked to Dr. Reyas out there, it doesn't sound like there's any upper internals, and I begin to wonder about the boundary conditions on this thing even being applicable to an AP 1000.

But, yes, the APEX facility itself does have upper guide tubes in it, yes.

MEMBER SCHROCK: Yeah, I think you're

right. There are a lot of reasons that's not a very similar.

MR. BROWN: Yeah, it's hard to say what its relationship is.

MEMBER SCHROCK: Only we're initially pulling the gas through the pool that's air-water, and they're blowing the air through the pool, and Graham suggested they try putting it in the upper plenum to see what happens. I guess they did try that, didn't they?

MR. BAJOREK: They did try that.

This is Steve Bajorek from Research.

The oscillations that were seen injecting from the porous injectors from below were also apparent changing that.

MR. BROWN: Were you suggesting to blow it horizontally, vertically downward or --

MR. BAJOREK: Well, this would go through the top of the vessel.

MR. BROWN: The top of the vessel?

MR. BAJOREK: But those tests are -- were intended to take a look at entrainment and flows in the hot leg.

MR. BROWN: Right.

MR. BAJOREK: They were never really

intended to take a look at the pool entrainment.

MR. BROWN: Yeah. It just did look like there was quite a bit of an influence potentially there, but to answer your question, APEX is probably as prototypic, I guess, as you can probably attempt to do in an integral effects test facility in that regard.

But anyway, as you can see, certainly you would expect from this here that we're going to get a significant amount of entrainment in AP 1000 relative to OSU, and I certainly would agree that there's distortion here, and I don't think that we can claim that this is necessarily from looking at this type of analysis that this is, you know, well scaled, but this is how I came at it. So --

CO-CHAIRMAN WALLIS: So you're substantially in agreement with --

MR. BROWN: yes. I think though that I guess the question is, which goes back to what Dr. Kress has asked, and I don't think anyone has given a good answer, and I think even early on when APEX -- I think Dr. Reyas was asked this -- is, you know, well what do you do when something like this is a factor of two, is a factor of three?

Because Dr. Wolfgang Wolfe from

Brookhaven, when he was doing scaling in AP 600, he used a factor of three. Westinghouse used a factor of two. Looking in the FSER, the NRC never really came out and said what the criteria is. They sort of just reiterated Westinghouse's criteria.

So I don't think anyone has given a satisfactory answer.

CO-CHAIRMAN WALLIS: What's in your code? I would think what matters is what's in your code. Do you use this Ishii-Kataoka?

MR. BROWN: I don't believe we use it explicitly, no.

CO-CHAIRMAN WALLIS: So what is --

MR. BROWN: Probably if you want to know with COBRA TRAC, Dr. Katsu Ohkawa of Westinghouse here could answer your question with respect to COBRA TRAC.

MR. OHKAWA: Katsu Ohkawa of Westinghouse.

I can speak for COBRA TRAC, and Steve mentioned earlier, and he was correct, that we use the form very similar to Kataoka-Ishii in the core. In the upper plenum we only looked at EPTF 3D, the sterility type (phonetic).

CO-CHAIRMAN WALLIS: Kataoka-Ishii in the core is for an annual flow regime. Do you have another correlation for annual?

MR. OHKAWA: No. The core behave much more open than the annual.

CO-CHAIRMAN WALLIS: So you use a pool correlation for the core?

MR. OHKAWA: As a starting point, and then we modified it, and then checked against FLECHT.

MEMBER SCHROCK: And what does that code use for the ADS break flow, ADS-4?

MR. BROWN: The hot leg ADS-4, we use the froude number type at inception.

MR. OHKAWA: Currently we use the froude number correlation. Okay?

CO-CHAIRMAN WALLIS: So what's your conclusion?

MR. BROWN: Well, we're going to get lots of entrainment in AP 1000, and we certainly see more in that than we expect in --

CO-CHAIRMAN WALLIS: Well, it's not clear that you get lost. You get more than an APEX, but does it matter?

CO-CHAIRMAN KRESS: That was my other question.

CO-CHAIRMAN WALLIS: Maybe it doesn't matter.

MR. BROWN: Well, I think as long as we

have levels in the hot leg, I think we don't care too much. I think we're concerned about if it goes too low.

The next thing I wanted to move into, looking at this thing with this liquid entrainment, may be, you know, a lot of salt here needed, but it may be a little bit to address your question, Dr. Kress. I had the same interest of, well, okay, everybody has been scaling this entrainment ration, and you know, we're getting back into, well, is it a factor of two, a factor of three, but how big is it? How important is it? What does it look like?

Well, I made a crude attempt in the short time I had to try to do that, and I'm not going to claim here that this is an extremely rigorous model, but I made an attempt here.

I said, well, what if I have a level here that's dropping at the hot leg or below and I looked at the region from the core plate up to the bottom of the hot leg and said, well, what if I had some situation where I have a two phase mixture in this region.

I looked at the time approximately when ADS-4 would initiate and said, okay, what if I were to take this entrainment upper plenum correlation where we were in this momentum controlled regime here, and I just applied enough liquid to satisfy core decay heat. What would happen as a function of time with this level? And just kind of see where this would fall out for AP 1000.

So I started off with just, you know, a very simple conservation, a mass equation where I had a two phased mixture in the upper plenum region from the core plate up to the hot leg initially, and I've got the core flow in and I've got the steam passing through this, and I've got an entrained liquid at the surface from this Kataoka-Ishii correlation here. And I reference my two-phased mixture level to the top of the upper core support plate.

So I used the simplified Yei correlation to estimate what the void fraction would be in this region. Then I, of course, was using the entrainment model using Kataoka-Ishii and this regime which has this form which Steve showed you before, and I applied, even though this certainly is still a transient, but I applied just to see what would happen.

At the peak period of decay power when ADS-4 would go off, what was, you know, the mass flow through the core? And, again, I neglected things that might help like subcooling and so on to try to maximize the amount of steaming I might get in there.

So I took those with the initial condition of starting from at the top of the upper plenum near the hot leg, that is. What I found was this thing really immediately grabbed liquid and took it out of there quite fast, very, very rapidly and dropped it to -- this is roughly, I think, -- is roughly a meter in AP 1000 from the upper course of the core support plate to the bottom of the hot leg, and as you can see, within a few seconds it seemed to settle out to kind of a steady state of --

CO-CHAIRMAN WALLIS: That's because it goes down to H cubed.

MR. BROWN: Right, H cubed. So you can see while Jg is killing you, H is helping you. If you can get away from that it can also stabilize. So I think, again, probably from our perspective it's --

CO-CHAIRMAN WALLIS: Well, I've thought about that. There must be a certain Jg which is big enough that H no longer matters, and once you entrain everything and carry it up, you're going to carry it over. If the droplets can't fall down, it doesn't really matter what H is. They just keep on going.

You need a moisture separator or something to get them back.

MR. BROWN: Yeah, although I guess if you look at the Kataoka-Ishii work, you know, and I think Steve put up the curve before, yeah, I mean, you see though that basically with H you're dropping.

CO-CHAIRMAN WALLIS: There must be some range though with this correlation. You can't go up to J cubed forever because, again, you know, you predict for that amount huge amounts of entrainment for that.

MR. BROWN: Well, you do get the large amounts as you go back up to the near surface region.

CO-CHAIRMAN WALLIS: But I mean eventually if you took the correlation too far with a big Jg, you're going to get entrainment which is bigger than homogeneous flow, and it's physically impossible.

MR. BAJOREK: This is Steve Bajorek.

I think what you're referring to is it comes up in this type of a gas regime. There are some criteria on how you switch from the correlation that you see there to other ones, and I think what you're referring to is the situation that when you do get a gas velocity that's so high, it just sweeps everything out.

CO-CHAIRMAN WALLIS: That's right. The

gas loss is bigger than the terminal speed of the biggest drop you could have. t hen everything is gone.

MR. BAJOREK: So even if you have a large H, it still sweeps it out.

CO-CHAIRMAN WALLIS: That just be a Jg star because that's what Jg star is. If Jg star is bigger than a certain amount, everything goes.

MR. OHKAWA: This is Kat Ohkawa from Westinghouse.

Yes, there's a flooding limit, and it should go back all the way to that new surface, according to the paper, and that's probably appropriate.

MR. BAJOREK: Right.

CO-CHAIRMAN KRESS: So your basic conclusion is that this is more or less self-limiting.

MR. BROWN: Yes. I think that's what I thought was interesting to me to share with you, that, you know, you can look at Jg and at first you can get pretty startled by it, but as you, you know, begin to look at it a bit further, you realize that it's a big limiting, and again, looking at AP 600, many of the tests tended to have an oscillatory level up and down, almost sort of the self-correcting type of behavior where as you get a level up into the hot leg, of course, you get a hellacious amount of entrainment, which, you know, knocks it back down, but then as you get away from the hot leg, it tends to reduce significantly, and then you can catch up with the injection again and fill it back up, and it would go back and forth.

MEMBER SIEBER: At the same time you're moving an awful lot of heat, which should tend to bring the entrainment down.

MR. BROWN: Down. That's right. In fact, you think about the other end of this is we look at imagining, well, if I get a pretty good slug out there, then shouldn't I also be slowing down in my entrainment because I've essentially plugged or temporarily blocked my outlets?

So you can't just look at these things from a separate effect, and we all get spun off on this here, as I see us in this conversation, but you know, I look at it as, you know, you can't really get too carried away with that because you recognize what's -- you have the H in here, which we're restoring you. Plus you also have the effect that you have on the -- I agree that the entrainment is important, but also it's going to effectively increase the resistance significantly on the outlets and now you can't entrain as much. So the whole thing slows down again until you catch up.

CO-CHAIRMAN WALLIS: Well, there's something very strange. I can understand Jg star. Jg star is the ratio of the gas flux to the terminal speed of the biggest drop you can have.

MR. BROWN: Yeah.

CO-CHAIRMAN WALLIS: That's what it is, and H star is the ratio of the height to the size of the biggest drop you can have.

Now, the biggest drop you can have is going to be on the order of millimeters. So I'm rather bothered about giving a height of, let's say, a meter by a millimeter size droplet. It doesn't seem to make sense to me.

So the scaling of H is weird. The scaling of J makes a lot of sense. Physically the way H is designed is H star. The characteristic dimension of the droplet scaling the size of the vessel doesn't seem to me quite right.

Well, Jg star is what you get in a thunder storm. If you get a big enough up draft, you carry the raindrops up instead of down.

CO-CHAIRMAN KRESS: Well, you have to think about that Graham because what I envision is you impart -- the gas flow determines some sort of spectrum or sizes for your droplets that you're entraining, and they have a certain momentum that they get started with.

Now, that momentum may or may not be enough to carry that droplet up far enough to get it out of there, and so the H related to the droplet size, which is somehow related to the momentum through the velocity might be an appropriate scale, although it's --

CO-CHAIRMAN WALLIS: That is true. If you look at firing particles into a gas --

CO-CHAIRMAN KRESS: Yeah.

CO-CHAIRMAN WALLIS: -- or the rain -- the distance they go is scaled and total flow linearly with the size of the particle.

CO-CHAIRMAN KRESS: Yes. So it might make some sense.

CO-CHAIRMAN WALLIS: It's a transient like that.

CO-CHAIRMAN KRESS: Yes.

CO-CHAIRMAN WALLIS: They get thrown out, and then they go up in the trajectory and fall back down, and you're right. But if they're carried out completely --

CO-CHAIRMAN KRESS: Then it wouldn't matter.

CO-CHAIRMAN WALLIS: -- because they're just lifted up --

CO-CHAIRMAN KRESS: That's right.

CO-CHAIRMAN WALLIS: -- then it doesn't matter anymore. So this has got to be a regime where it just doesn't matter anymore, but I don't think you're -- do you know how much -- how big is your Jg star? What's the number? That would be very revealing.

MR. BROWN: Offhand I don't know.

CO-CHAIRMAN WALLIS: That would be the first thing I'd calculate, would be the ratio of the velocity of the vapor to the terminal speed of the biggest drop I could put in there, and if it's above that, then it's all gone no matter what you do.

MR. BROWN: and I thought this was kind of instructive to --

CO-CHAIRMAN WALLIS: Did you know, Steve, how big the Jg star is?

MR. BAJOREK: I can get those numbers for you tomorrow.

CO-CHAIRMAN WALLIS: That would be good.

MR. BAJOREK: I'm thinking that they're on the order of one and a half to two, but I'm -- this scaling, you look at a lot of numbers, and I'd have to check, but I'll get those for you tomorrow.

CO-CHAIRMAN WALLIS: If it's one and a half to two, then I would think you're in real trouble.

CO-CHAIRMAN KRESS: Yeah. That's what --

CO-CHAIRMAN WALLIS: But still maybe it's two times ten to the minus two or something. That's more like what you mean. You'll get that tomorrow anyway. That would be very good.

MR. BROWN: Anything else on that one?

CO-CHAIRMAN WALLIS: Well, again, I'm very suspicious of a correlation which has a coefficient of E to the sixth.

(Laughter.)

MR. BROWN: We can change it if you like.

CO-CHAIRMAN WALLIS: It indicates to me that some of the physics is wrong.

MR. BROWN: We can --

MEMBER POWERS: You must have real troubles with homogeneous nucleation then.

MEMBER SIEBER: Just need another offsetting.

MEMBER POWERS: It has surface tension

cubed in the exponent.

CO-CHAIRMAN WALLIS: Yes.

MEMBER POWERS: Well, I mean, that's even more than your sixth.

CO-CHAIRMAN WALLIS: No, these are the sixth -- the number, the dimensionless number represented by this correlation is 5.417 E to the sixth. That's very suspicious.

CO-CHAIRMAN KRESS: Yeah, yeah.

CO-CHAIRMAN WALLIS: Unless there's some kind of units. No, there isn't a units problem here, is there?

CO-CHAIRMAN KRESS: No, those are all dimensions.

CO-CHAIRMAN WALLIS: Anyway, this is the best correlation we've got.

MR. BROWN: This is the best I'm aware of. I was told you did some work earlier in your days, but --

CO-CHAIRMAN WALLIS: Yes, but that was --

MR. BROWN: One of the reasons for thinking this is the best we've got, yes.

(Laughter.)

MR. BROWN: Dr. Powers paid me for that one.

(Laughter.)

CO-CHAIRMAN WALLIS: That was when I was as student, you mean?

MEMBER POWERS: Well, maybe it's better than we thought.

CO-CHAIRMAN KRESS: Well, this at least suggests what I wanted to see, is how important is it.

MR. BROWN: Yes, yes.

CO-CHAIRMAN KRESS: It's a way to address it.

MR. BROWN: It is not quite a top-down scaling, but it was sort of an attempt to do that and sort of put it in perspective a little bit, and I think as I said before that you can't lose sight of the fact that as you begin to entrain such a huge slug where everybody is concerned about this, then you have to look at, well, this meant this probably temporarily sort of degraded the vent path a bit so that your entrainment is going to slow down.

CO-CHAIRMAN WALLIS: I'll tell you the problem is probably that MUG, depending on viscosity of the gas, is a small number, which is why you need this huge number to multiply it by, and I'm wondering if it should be there. Because even if the gas had no viscosity, you still would be entraining droplets. So it's something weird.

Again, I'd have to look at the paper. Could we have this paper? Could you folks get Kataoka-Ishii and send us a copy?

MEMBER POWERS: It's two topical reports. They're relatively thick topical reports.

MR. BROWN: I have a bad copy of the paper that they submitted if you want.

CO-CHAIRMAN WALLIS: Do you have it, Steve?

MR. BAJOREK: Yeah, I have the NUREG upstairs. It's less than an inch thick.

CO-CHAIRMAN WALLIS: An inch thick?

MR. BAJOREK: It's less than that.

MEMBER POWERS: It's substantial.

MR. BROWN: Yes, it is.

MEMBER POWERS: And I don't know. There are about what, 38 operational pages in it? But it's a substantial document.

There is a paper, but I don't know that the paper is -- I mean, I prefer the topical.

CO-CHAIRMAN WALLIS: But there isn't a published paper in a journal or something?

MR. BROWN: Yeah, there is.

MEMBER POWERS: There is.

CO-CHAIRMAN WALLIS: Well, that can't be an inch thick.

MR. BROWN: No, no, it's not.

MEMBER POWERS: But the topical is more useful. What you guys publish in journals is too terse for me.

MR. BAJOREK: I have a copy I could probably give you.

CO-CHAIRMAN WALLIS: Topical. You mean Kataoka-Ishii is a contract?

MEMBER POWERS: They were contracted by the NRC.

PARTICIPANTS: It's a NUREG.

MEMBER SCHROCK: Steve has got a copy.

CO-CHAIRMAN WALLIS: Okay. I guess if you want to give it to me, I could carry it.

MR. BROWN: Okay. Moving on, I guess there was some issues before in a previous meeting that we had in which Dr. Wallis had a number of questions, again, similar to the question you brought up, Professor Schrock, on the use of homogeneous, which we all seem to do in the AP 600 as well as probably AP 1000 scaling.

And specifically, you asked with respect to its impact on two phase natural circulation of the pressure, and you specifically directed me, even though you may criticize it in a moment, for actually trying to actually put some of this down on a flow regime map, and this was during long-term cooling, closer more towards sump injection as opposed to IRWST injection.

And I also went back and just used more of a slip model in the equations and just to check the core exit quality scaling.

Again, at the risk of revoking my license or something like that I'll put up these --

(Laughter.)

MR. BROWN: -- flow regime maps here. You can have my PE stamp at the end of the talk.

But one of the reasons, I guess, for showing this, I was interested in a bit, is we had been doing some COBRA TRAC calculations, and during the sump injection phase, and COBRA TRAC seems to so far show two situations in the hot legs and the ADS-4, and it seems to sort of bounce back and forth between a counter current flow and the hot leg, for example. Any other time it's showing that it's in some kind of a stratified regime intermittently between the two.

It spends the majority of the time so far in this -- it predicts it's using a horizontal flow regime map, and it's predicting that it's stratified most of the time, and the other times it's going through a counter current flow back to the core.

Looking in the --

CO-CHAIRMAN WALLIS: So presumably if it's a co-current flow, it's all going out the ADS-4, is it?

MR. BROWN: I would think so, yes.

The other, I looked at the ADS-4 pipe, and again, similar to COBRA TRAC, the vertical and then also next, the horizontal sections appear to be an annular flow.

CO-CHAIRMAN WALLIS: This is in the flow regime map for the hot leg?

MR. BROWN: No, this next is the ADS-4 pipe, the vertical section.

CO-CHAIRMAN WALLIS: Oh, the vertical pipe, okay.

MR. BROWN: Yes, and then also for the horizontal section for the ADS-4 pipe, and both of them show that they're in --

CO-CHAIRMAN WALLIS: And UGS at 100 meters a second at these pressures is pretty high velocity.

MR. BROWN: Yes, it is.

CO-CHAIRMAN WALLIS: It carries everything out.

MR. BROWN: Well, the interesting thing to note, too, is that, again, in situations like the hot leg in which we didn't -- we didn't change the size from AP 600 to AP 1000, you know, you can see that AP 1000 has a bit, you know, drifted off a little bit relative to AP 600, but in situations where we did change the size of the ADS-4 piping, you can see that we, in fact, were maybe a little bit closer toward OSU with respect to that with the piping that we did modify for the AD 1000.

And then the last thing that I got involved in to move into was the core exit quality scaling during this same low pressure phase here. Dr. Wallis asked me to look at it again, and I just used the slip model. I just simply went back to using a quality and density ratio based slip model for the pressure drop and so on.

And I did find that the results that I got for the core exit quality did change significantly because of that. I mean, they really did, but, again, as far as ratioing between the plant versus the test, the same conclusion, not exactly the same ratios, but they hovered around one as you can see.

So it did have a significant effect on the actual answer, but again, as far as scaling them, it sort of came to the same conclusion.

And that's about all I had.

CO-CHAIRMAN KRESS: Good.

CO-CHAIRMAN WALLIS: Good. Thank you.

CO-CHAIRMAN KRESS: Thank you.

Well, I guess we will -- is there anything else we need to do today? We're going to continue this tomorrow.

CO-CHAIRMAN WALLIS: I think we all have a homework assignment to figure out the importance of what we learned today.

CO-CHAIRMAN KRESS: Yeah. So we'll go home and ruminate on it. So at this point I'm going to recess until tomorrow morning at 8:30. We'll see you all then.

(Whereupon, at 5:50 p.m., the Subcommittee meeting was adjourned, to reconvene at 8:30 a.m., Friday, February 15, 2002.)

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 and Future Plant
Designs Subcommittee Meeting
Docket Number: (Not Applicable)
Location: Rockville, Maryland

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.

Pippa Antonio

Pippa Antonio
Official Reporter
Neal R. Gross & Co., Inc.

3.1 Emergency Response Facilities

Design Description

The technical support center (TSC) is a facility from which management and technical support is provided to main control room (MCR) personnel during emergency conditions. The operations support center (OSC) provides an assembly area where operations support personnel report in an emergency.

1. The TSC has floor space of at least 75 ft^2 per person for a minimum of 25 persons.

2. The TSC has voice communication equipment for communication with the MCR, emergency operations facility, OSC, and the U.S. Nuclear Regulatory Commission (NRC).

3. The plant parameters listed in Table 2.5.4-1, minimum inventory table, in subsection 2.5.4, Data Display and Processing System (DDS), with a "Yes" in the "Display" column, can be retrieved in the TSC.

4. The OSC has voice communication equipment for communication with the MCR and TSC.

5. The TSC and OSC are in different locations in the annex building. The TSC is adjacent to the passage from the annex building to the nuclear island control room.

Inspections, Tests, Analyses, and Acceptance Criteria

Table 3.1-1 specifies the inspections, tests, analyses, and associated acceptance criteria for the emergency response facilities.

OPEN

3.2 Human Factors Engineering

Design Description

The AP600 human-system interface (HSI) will be developed and implemented based upon a human factors engineering (HFE) program. Figure 3.2-1 illustrates the HFE program elements. The HSI scope includes the design of the operation and control centers system (OCS) and each of the HSI resources. For the purposes of the HFE program, the OCS includes the main control room (MCR), the remote shutdown room (RSR), the local control stations, and the associated workstations for each of these centers. The HSI resources include the wall panel information system, alarm system, plant information system (nonsafety-related displays), qualified data processing system (safety-related displays), and soft and dedicated controls. Minimum inventories of controls, displays, and visual alerts are specified as part of the HSI for the MCR and the remote shutdown workstation (RSW).

The MCR provides a facility and resources for the safe control and operation of the plant. The MCR includes a minimum inventory of displays, visual alerts and fixed-position controls. Refer to item 8.a and Table 2.5.2-5 of subsection 2.5.2 for this minimum inventory.

The RSR provides a facility and resources to establish and maintain safe shutdown conditions for the plant from a location outside of the MCR. The RSW includes a minimum inventory of displays, controls, and visual alerts. Refer to item 2 and Table 2.5.4-1 of subsection 2.5.4 for this minimum inventory. As stated in item 8.b of subsection 2.5.2, the protection and safety monitoring system (PMS) provides for the transfer of control capability from the MCR to the RSW.

The mission of local control stations is to provide the resources, outside of the MCR, for operations personnel to perform monitoring and control activities.

Implementation of the HFE program includes activities 1 through 5 listed below. The MCR includes design features specified by items 6 through 8 below. The RSW includes the design features specified by items 9 through 12 below. Local control stations include the design feature of item 13.

1. The integration of human reliability analysis with HFE design is performed in accordance with the implementation plan. Critical human actions (if any) and risk-important tasks are identified and used as an input to the task analysis activities.

2. Task analysis is performed in accordance with the task analysis implementation plan. Task analysis identifies the information and control requirements for the operators to execute the tasks allocated to them.

3. The HSI design is performed for the OCS in accordance with the HSI design implementation plan. The HSI design includes the functional design of the operation and control centers and the HSI resources, the specification of design guidelines, the HSI resource design specifications, and the man-in-the-loop concept testing.

Table 3.2-1
Inspections, Tests, Analyses, and Acceptance Criteria

Design Commitment	Inspections, Tests, Analyses	Acceptance Criteria
1. The integration of human reliability analysis with HFE design is performed in accordance with the implementation plan.	An evaluation of the implementation for the integration of human reliability analysis with HFE design will be performed.	A report exists and concludes that critical human actions (if any) and risk important tasks were identified and examined by task analysis, and used as input to the HSI design, procedure development, staffing, and training.
2. Task analysis is performed in accordance with the task analysis implementation plan.	An evaluation of the implementation of the task analysis will be performed.	A report exists and concludes that function-based task analyses were conducted in conformance with the task analysis implementation plan and include the following functions: – Control reactivity – Control reactor coolant system (RCS) boron concentration – Control fuel and cladding temperature – Control RCS coolant temperature, pressure, and inventory – Provide RCS flow – Control main steam pressure – Control steam generator inventory – Control containment pressure and temperature – Provide control of main turbine

Table 3.2-1 (cont.)
Inspections, Tests, Analyses, and Acceptance Criteria

Design Commitment	Inspections, Tests, Analyses	Acceptance Criteria
3. The HSI design is performed for the OCS in accordance with the HSI design implementation plan.	An evaluation of the implementation of the HSI design will be performed.	A report exists and concludes that the HSI design for the OCS was conducted in conformance with the implementation plan and includes the following documents: – Operation and Control Centers System Specification Document – Functional requirements and design basis documents for the alarm system, plant information system, wall panel information system, controls (soft and dedicated), and the qualified data processing system – Design guideline documents (based on accepted HFE guidelines, standards, and principles) for the alarm system, displays, controls, and anthropometrics – Design specifications for the alarm system, plant information system, wall panel information system, controls (soft and dedicated), and the qualified data processing system. – Man-in-the-loop concept test reports

Table 3.2-1 (cont.)
Inspections, Tests, Analyses, and Acceptance Criteria

Design Commitment	Inspections, Tests, Analyses	Acceptance Criteria
5. The HFE verification and validation program is performed in accordance with the HFE verification and validation implementation plan and includes the following activities: a) HSI Task support verification b) HFE design verification c) Integrated system validation d) Issue resolution verification e) Plant HFE/HSI (as designed at the time of plant startup) verification		A report exists and concludes that:
	a) An evaluation of the implementation of the HSI task support verification will be performed.	a) Task support verification was conducted in conformance with the implementation plan and includes verification that the information and controls provided by the HSI match the display and control requirements generated by the function-based task analyses and the operational sequence analyses.
	b) An evaluation of the implementation of the HFE design verification will be performed.	b) HFE design verification was conducted in conformance with the implementation plan and includes verification that the HSI design is consistent with the AP600 specific design guidelines (compiled as specified in the third acceptance criteria of design commitment 3) developed for each HSI resource.
	c) (i) An evaluation of the implementation of the integrated system validation will be performed.	c) (i) The test scenarios listed in the implementation plan for integrated system validation were executed in conformance with the plan and noted human deficiencies were addressed.

Table 3.2-1 (cont.)
Inspections, Tests, Analyses, and Acceptance Criteria

Design Commitment	Inspections, Tests, Analyses	Acceptance Criteria
6. The MCR includes reactor operator workstations, supervisor workstation(s), safety-related displays, and safety-related controls.	An inspection of the MCR workstations and control panels will be performed.	The MCR includes reactor operator workstations, supervisor workstation(s), safety-related displays, and safety-related controls.
7. The MCR provides a suitable workspace environment for use by the MCR operators.	i) See Tier 1 Material, subsection 2.7.1, Nuclear Island Nonradioactive Ventilation System.	i) See Tier 1 Material, subsection 2.7.1, Nuclear Island Nonradioactive Ventilation System.
	ii) See Tier 1 Material, subsection 2.2.5, MCR Emergency Habitability System.	ii) See Tier 1 Material, subsection 2.2.5, MCR Emergency Habitability System.
	iii) See Tier 1 Material, subsection 2.6.3, Class 1E dc and UPS System.	iii) See Tier 1 Material, subsection 2.6.3, Class 1E dc and UPS system.
	iv) See Tier 1 Material, subsection 2.6.5, Lighting System.	iv) See Tier 1 Material, subsection 2.6.5, Lighting System.
	v) See Tier 1 Material, subsection 2.3.19, Communication System.	v) See Tier 1 Material, subsection 2.3.19, Communication System.
8. The HSI resources available to the MCR operators include the alarm system, plant information system (nonsafety-related displays), wall panel information system, and nonsafety-related controls (soft and dedicated).	An inspection of the HSI resources available in the MCR for the MCR operators will be performed.	The HSI (at the time of plant startup) includes an alarm system, plant information system (nonsafety-related displays), wall panel information system, and nonsafety-related controls (soft and dedicated).
9. The RSW includes reactor operator workstation(s) from which licensed operators perform remote shutdown operations.	An inspection of the RSW will be performed.	The RSW includes reactor operator workstation(s).

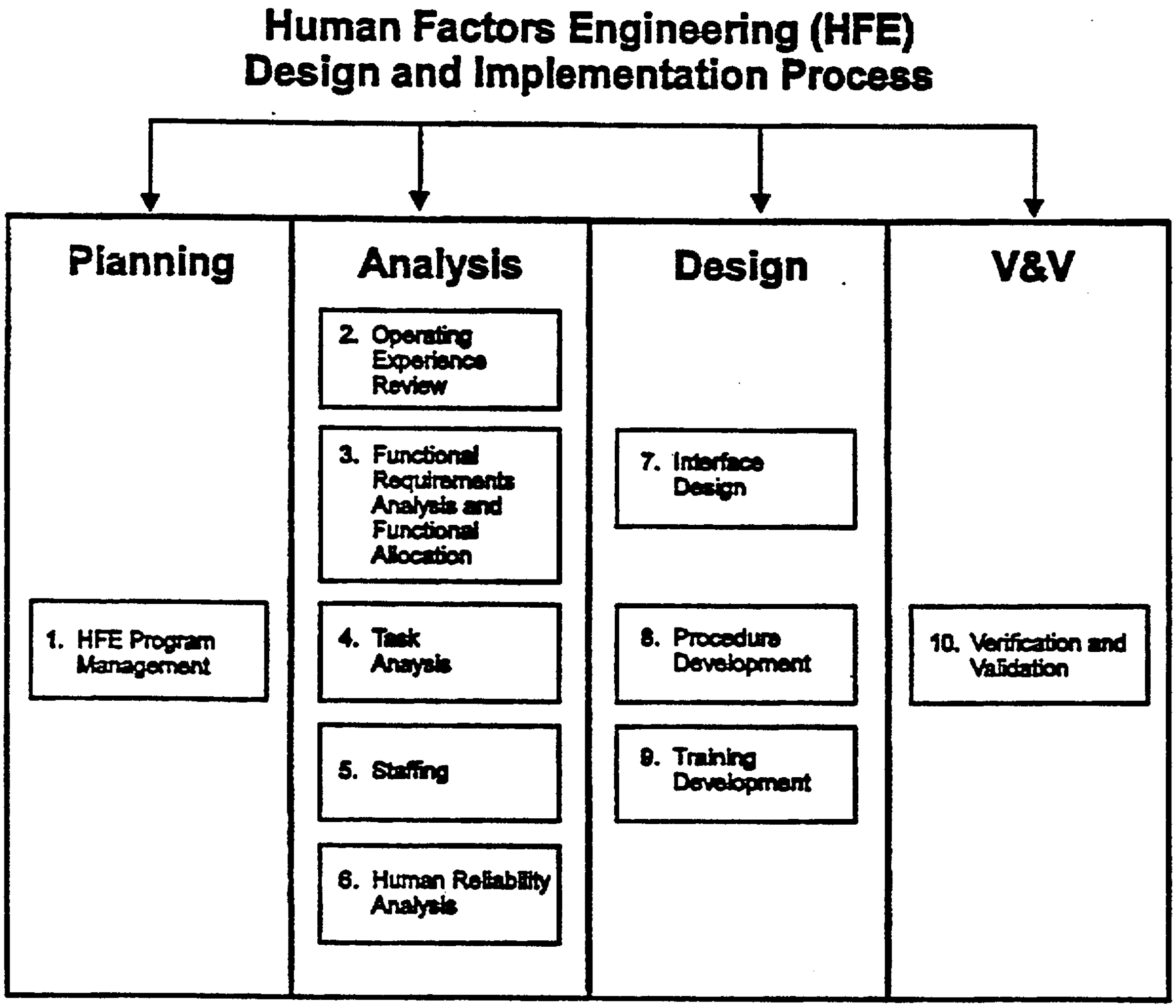


Figure 3.2-1
Human Factors Engineering (HFE)
Design and Implementation Process

EVALUATION OF THE ADS TRANSIENT IN THE AP1000 DESIGN WITH A ONE NODE DEPRESSURIZATION ANALYSIS (ONDA)

Marino di Marzo
SMSAB DSARE RES
February 14-15, 2002

OPEN

OUTLINE

- Formulation of the ONDA
- Model validation with ROSA-AP600
- AP600 and AP1000 comparison
- Relevance of the governing groups
- Sensitivity analysis on ADS quality
- Conclusions

ASSUMPTIONS

- quality is fixed at a given port for the duration of the transient
- the reference enthalpy is liquid at the transient average temperature
- the specific heat of the liquid is doubled to include the heat stored in the metal masses adjacent to the liquid
- the accumulator subcooling is a heat sink ($DF\,\Delta h$)
- the PRHR heat removal is a function of time
- all parameters are taken as constant at their respective transient average value unless otherwise specified

SUB-MODELS

AF	ADS flow: for $x=1$ [1]; for $x<1$ [2]
VB	DVI break vessel side [1]
DB	DVI break DVI side [2] with x_{DB} TBD
DF	intact DVI flow [3],[4],[5]
Q_C	Decay heat [3],[4],[5]
Q_P	PRHR heat removal [3]
V	system volume [3],[4],[5]
p_0	initial pressure [3]
v_0	initial inventory [3],[4],[5]

REFERENCES

[1] R.E. Henry, H.R. Fauske *J. Heat Transfer* **93** (1971) 179-187

[2] M. Sajben *J. Basic Eng.* **83** (1961) 619-631

[3] R.A. Shaw,T. Yonomoto, Y. Kukita *JAERI-memo* **07-189** (1995)

[4] S. Banerjee, M.G. Ortiz, T.K. Larson, D.L. Reeder *INEL Report* **96-0040** (1997)

[5] W AP1000 documentation

Conservation of mass

$$\frac{dv}{dt}=\frac{DF-VB-DB-AF}{\rho_L}$$

Conservation of energy

$$Q_C+\rho_L c_L v\left(-\frac{dT}{dt}\right)=\frac{dm}{dt}\Lambda+Q_P+DF\Delta h$$

Vapor generation

$$\frac{dm}{dt}=\frac{V-v}{R*T}\frac{dp}{dt}+\frac{p}{R*T}\left(-\frac{dv}{dt}\right)-\frac{(V-v)p}{R*T^2}\frac{dT}{dt}+VB+DB\,x_{DB}+AF\,x_{AF}$$

Clausius-Clapeyron

$$\frac{dp}{dT}=\frac{\Lambda}{R*T}\frac{p}{T}=CC\frac{p}{T}$$

Equation of state

$$\rho_V = \frac{R*T}{p} \qquad R* = Z\ R$$

Depressurization

$$\frac{dp}{dt} = \frac{Q_C - Q_P - DF\ \Delta h + p\ CC\frac{dv}{dt} - \Lambda\left(VB + DB\ x_{DB} + AF\ x_{AF}\right)}{\left(V - v\right)\left(CC - 1\right) + \frac{\rho_L c_L T}{CC}\frac{v}{p}}$$

Trajectory

$$\frac{dv}{dp} = \frac{\left(DF - VB - DB - AF\right)\left[\frac{CC\left(CC - 1\right)}{c_L/R*}\left(\frac{V}{v} - 1\right)\left(\frac{\rho_V}{\rho_L}\right) + 1\right]\frac{c_L/R*}{CC^2}\frac{v}{p}}{\frac{Q_C - Q_P}{\Lambda} + DF\left(\frac{\rho_V}{\rho_L} - \frac{\Delta h}{\Lambda}\right) - VB\left(\frac{\rho_V}{\rho_L} + 1\right) - DB\left(\frac{\rho_V}{\rho_L} + x_{DB}\right) - AF\left(\frac{\rho_V}{\rho_L} + x_{AF}\right)}$$

Trajectory in non-dimensional form

$$\frac{dv}{dp} = \frac{(FG-1)(VG+1)}{PG + EG - \dfrac{\rho_V}{\rho_L} - x_{AF}} \frac{c_L/R^*}{CC^2} \frac{v}{p}$$

Governing groups

$$FG = \frac{DF - VB - DB}{AF}$$

Net In-**F**low **G**roup

$$EG = \frac{DF}{AF}\left(\frac{\rho_V}{\rho_L} - \frac{\Delta h}{\Lambda}\right) - \frac{VB}{AF}\left(\frac{\rho_V}{\rho_L} + 1\right) - \frac{DB}{AF}\left(\frac{\rho_V}{\rho_L} + x_{DB}\right)$$

Net In-Flow **E**nthalpy **G**roup

$$PG = \frac{Q_C - Q_P}{AF\ \Lambda}$$

Net **P**ower Input **G**roup

$$VG = \frac{CC(CC-1)}{c_L/R^*}\left(\frac{V}{v} - 1\right)\left(\frac{\rho_V}{\rho_L}\right)$$

System **V**olume **G**roup

FRAMEWORK

$$\frac{dp}{dT} = CC\frac{p}{T} \quad \Rightarrow \quad \frac{p}{p_0} = \left(\frac{T}{T_0}\right)^{CC} \quad CC \approx 9$$

For a scale-independent solution let

$FG = 0 \Rightarrow EG = 0; \quad PG = 0; \quad VG \approx 0; \quad \rho_V / \rho_L \approx 0; \quad x_{AF} = 1$

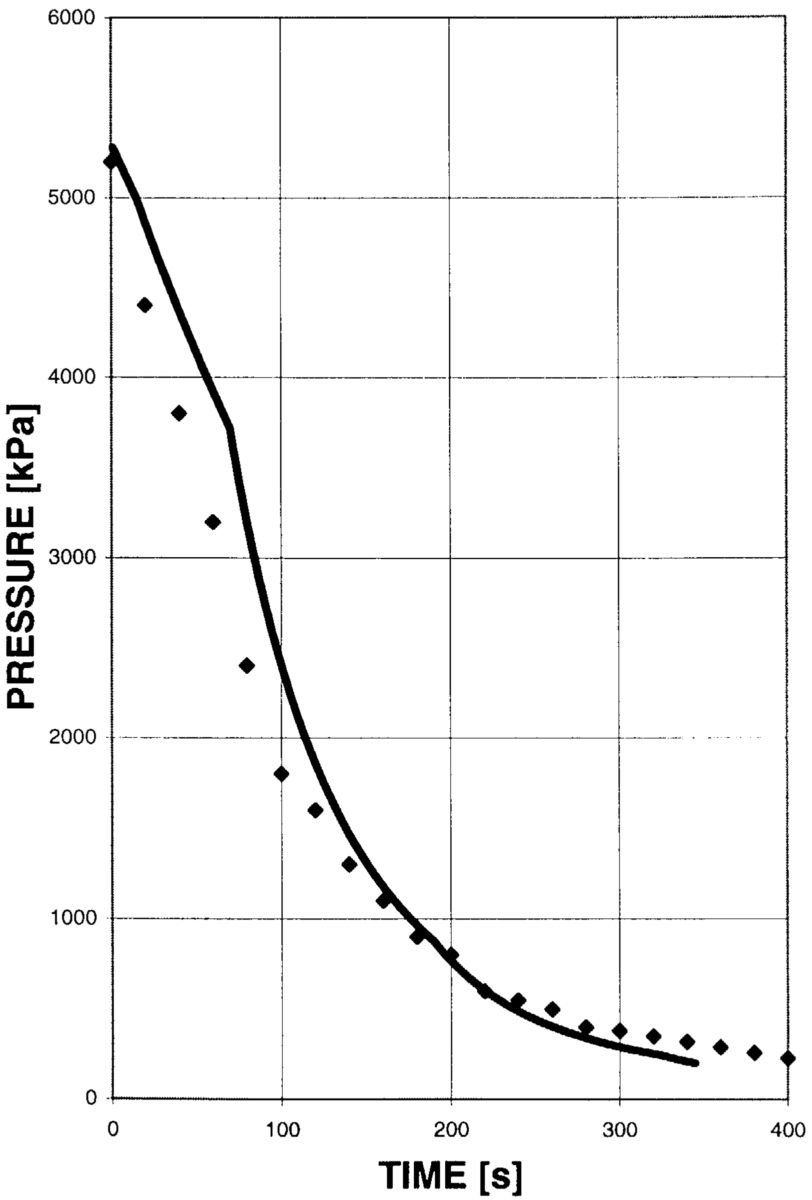
Then, the trajectory becomes

$$\frac{dv}{dp} = \frac{c_L / R^*}{CC^2}\frac{v}{p} \quad \Rightarrow \quad \frac{v}{v_0} = \left(\frac{p}{p_0}\right)^{\frac{c_L / R^*}{CC^2}} \quad \frac{c_L / R^*}{CC^2} \approx 0.3$$

VALIDATION

- Consider ROSA-AP600 test **AP-DV-01** [3] between the ADS 1 activation and the IRWST injection (180 - 600 s)
- The initial and final inventory distributions are known and the final inventory referred to the vessel volume below the legs is 61 percent
- We add the DVI broken side accumulator and CMT to the inventory and we consider the accumulator and CMT on the DVI intact side in the injection (DF)
- All the parameters are set in accordance to the ROSA-AP600 data available

The quality of the ADS as well as of the vessel-side break are set to unit and the quality of the DVI-side break is used to match the final inventory ($x_{DB} = 1/3$). Then the pressure traces, calculated and measured, are compared.



PARAMETERS & FUNCTIONS

latent heat kJ/kg	1,800	gas constant kJ/kg-K	0.46 x 0.83
temperature K	510	liquid density kg/m^3	810
subcooling kJ/kg	700	specific heat kJ/kg-K	0.45 x 2
initial pressure kPa	5,300	final pressure kPa	200

$$\dot{G}_{x=1} = 1.53p$$

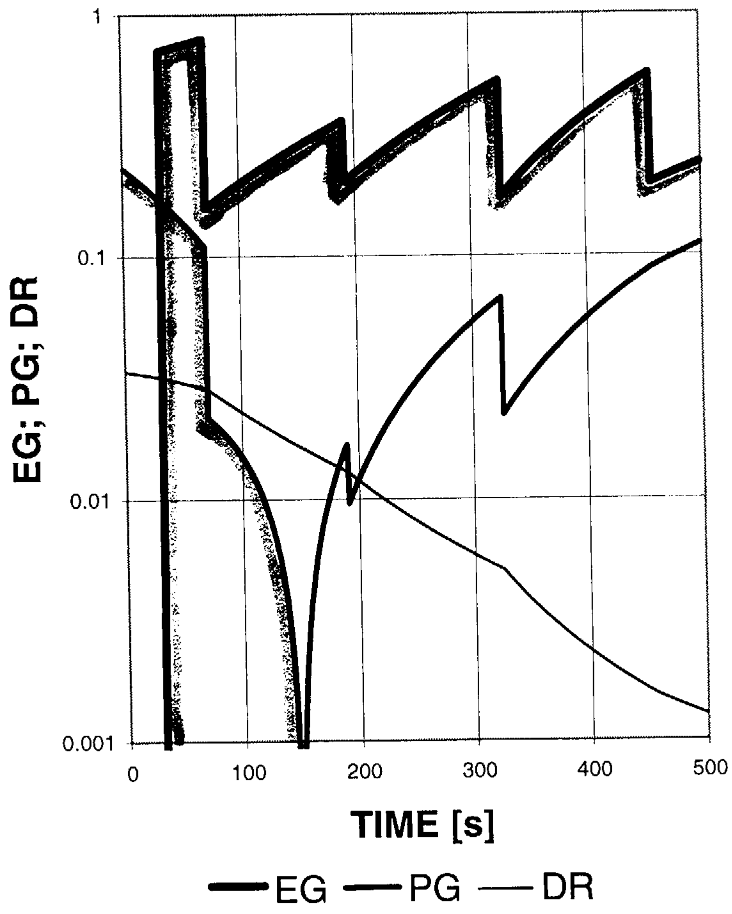
$$\dot{G}_{x<1} = \left(3.791 - 1.856x\right)p + \left(1{,}780 - 1{,}723x\right)$$

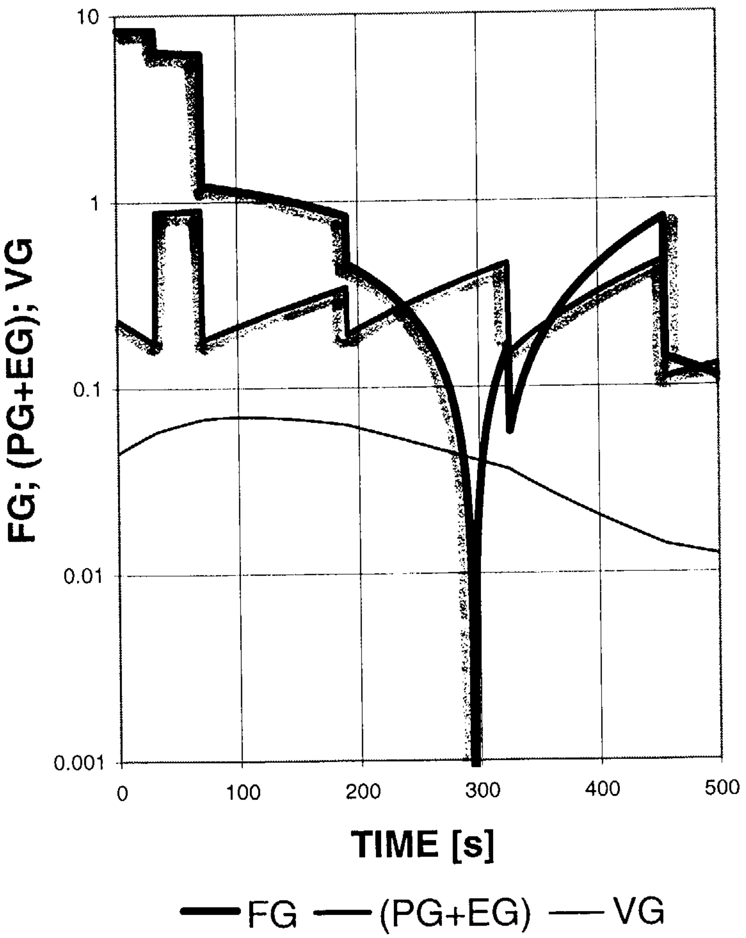
$$Q_P = Q_C\left[0.45 + 1.55e^{-0.007t}\right]$$

PLANT DEPENDENT PARAMETERS

	AP1000	AP600	ROSA
system volume m^3	305	238	8.02
liquid volume m^3	120	117	1.96
core power kW	25500	14500	1600
accumulator flow kg/s	114	114	3.4
accumulator flow duration s	424	424	459
CMT flow kg/s	40	40	1.3
vessel-side break m^2	.008105	.008105	.000259
DVI-side break m^2	.02432	.02432	.000815
ADS 1 m^2	.0075	.0075	.000247
ADS 2 m^2	.0378	.0378	.00135
ADS 3 m^2	.0680	.0680	.00239
ADS 4 m^2	.1412	.0803	.00533

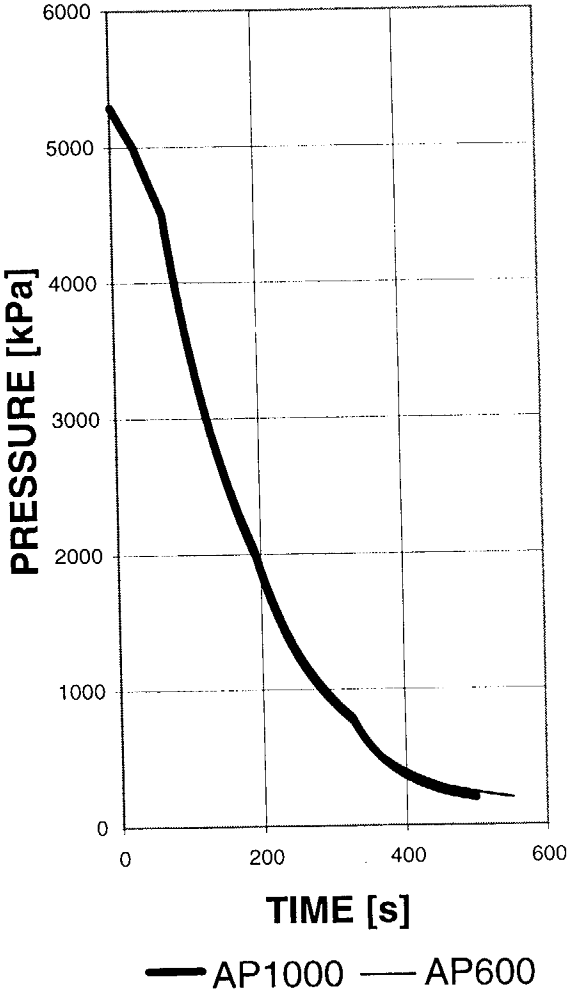
NON-DIMENSIONAL GROUPS

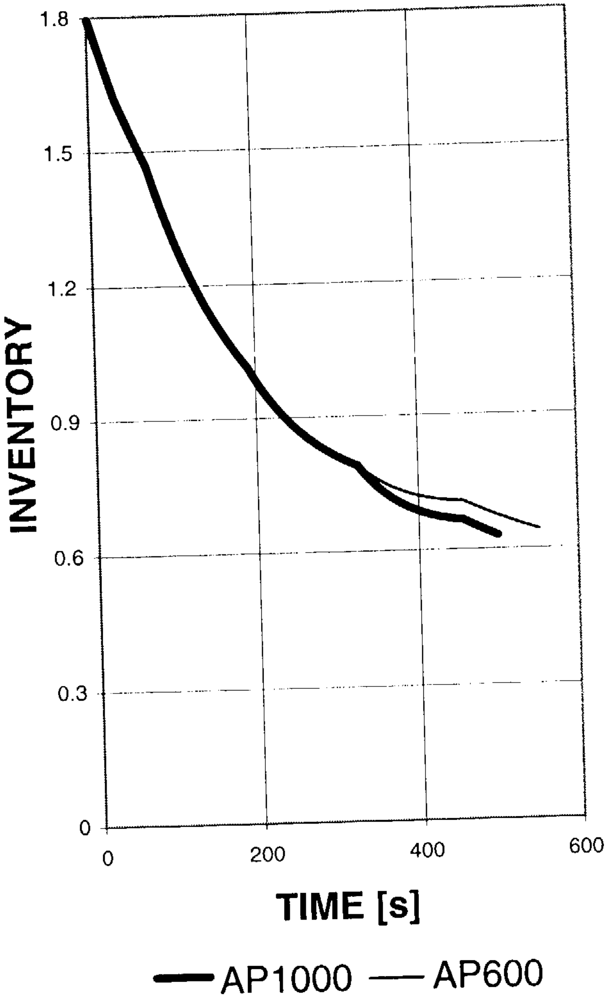




- The compliance term (PG+EG) is negative and has a significant effect decreasing the trajectory slope (dv/dp)
- The power group (PG) is negative due to the PRHR heat removal and later turns positive while the enthalpy group (EG) remains always negative.
- The Net In-Flow Group (FG) is negative and has a dominant effect early on, then turns positive with a significant impact. At the very end (as the accumulator flow subsides) it becomes negative again. Note that when FG is positive it decreases the trajectory slope
- The density ratio (DR) and the volume group (VG) play a minor role in the transient evolution

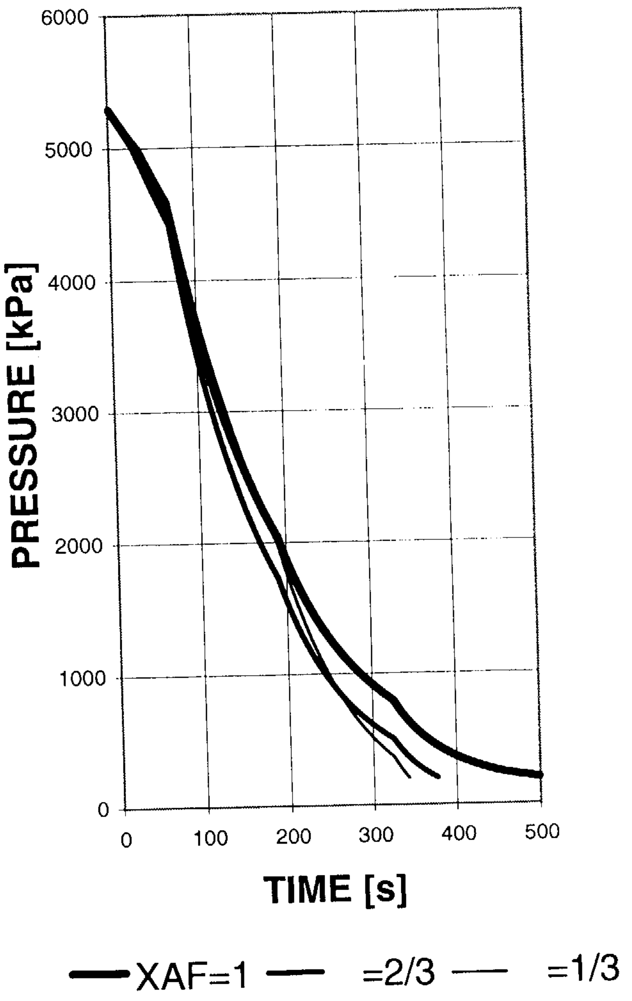
AP600 VERSUS AP1000 (for $x_{AF} = 1$)

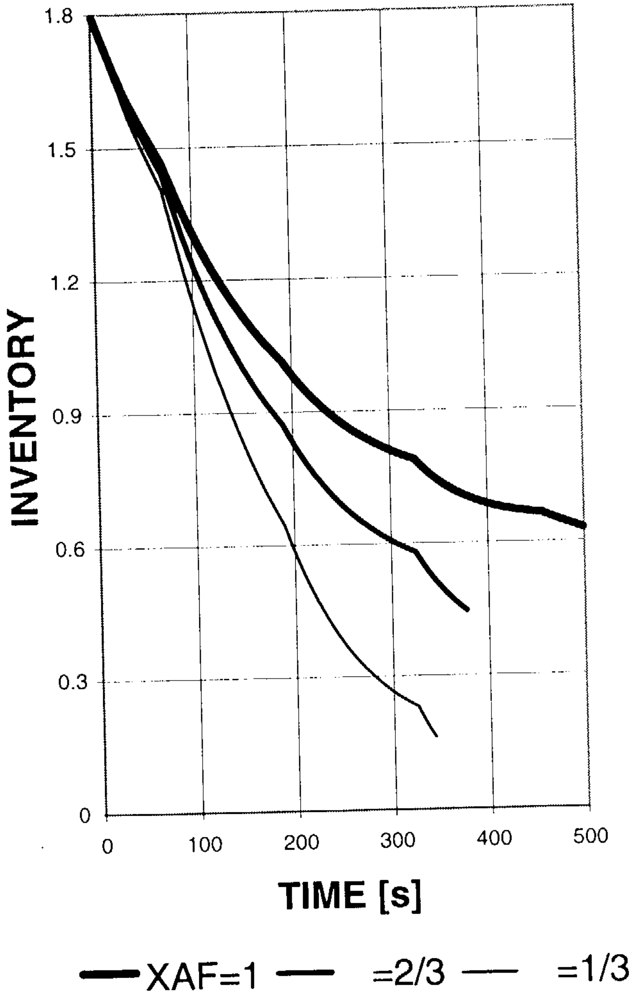




- The pressure traces of the AP600 and AP1000 are virtually indistinguishable. However, the AP600 takes a longer time to complete the depressurization
- The inventory traces of the AP600 and AP1000 are also virtually indistinguishable up to the activation of ADS4
- The size of ADS4 is scaled with core power and we know that PG is not a dominant term. The actual dominant term is the net-inflow FG. Therefore a larger ADS4 leads to a reduced FG and to a steeper dv/dt

EFFECT OF x_{AF}





- The pressure behavior of the AP1000 for decreasing quality of the ADS discharge is quite complex. There are two of phenomena that compete with each other:

1. A lower quality of the ADS discharge flow affects the heat removal and therefore decreases dp/dt early on
2. Later in the transient, the residual system compliance increases dp/dt since the residual inventory is significantly reduced for lower qualities of the ADS discharge

CONCLUSIONS

- The ONDA results compare favorably with the ROSA-AP600 data (AP-DV-01). Therefore, this analysis can be used for comparison purposes
- There are no significant differences in the performance of AP600 and AP1000 for the same ADS quality. This is consistent with the *top-down* scaling conclusions
- The uncertainty in ADS quality has a significant impact on the minimum vessel inventory
- To resolve these uncertainties, additional information is needed to better quantify the entrainment phenomena

UNITED STATES NUCLEAR REGULATORY COMMISSION

Staff Presentation to Advisory Committee on Reactor Safeguards

Joint meeting of the Sub-committees on Future Plant Designs and T/H Phenomena

February 14-15, 2002

AP1000 Pre-application Review

Phase 2

Presenter: Andrzej Drozd (rotational assignment)

AP1000 PM: Larry Burkhart
New Reactor Licensing Project Office
tel: 301-415-3053

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Outline:

Background

Status of pre-application review

Phase 2 issues:

- Regulatory exemptions
- Design Acceptance Criteria (DAC)
- Testing
- Safety analysis codes

Technical presentations by:

- Jerry Wilson
- Dave Terao / Goutam Bagchi
- Steve Bajorek
- Walt Jensen
- Ed Throm

Background for AP1000 pre-application review

NRC certified AP600 design on December 16, 1999

Westinghouse indicated an interest in applying for AP1000 standard design certification

New design based on AP600 design

April 27, 2000 meeting: staff discussed with Westinghouse three-stage approach for the AP1000 pre-application review:

Phase 1: identification of issues to be evaluate during the Phase 2

Phase 2: assessment of the applicability and/or acceptability of the AP600 testing, analysis codes, DAC and exemptions to AP1000 design

Phase 3: design certification review of AP1000

Background for AP1000 pre-application review (cnd)

May 4, 2000 letter: Westinghouse requests NRC to proceed with the Phase 1

May 31 letter: Westinghouse identified issues
June 21 letter: ACRS identified issues
July 27: NRC provided six review items and estimates

August 28, 2000 letter: Westinghouse requests to proceed with the Phase Two review of the issues:

Applicability of AP600 test program to AP1000
Applicability of AP600 analysis codes to AP1000
Acceptability of proposed AP1000 DAC
Acceptability of certain exemptions for AP1000

August 29, 2000: Staff's briefing to ACRS on AP1000

Status of pre-application review

Phase 1 completed in July 2000

Phase 2:

- technical review completed in January 2002
- SECY papers on DAC and exemptions, and testing and codes
- both papers are in concurrence (due to EDO 3/20/2002)
- discussion with ACRS subcommittees (Future Plants and T/H) 2/14-15/2002
- presentation to full ACRS 3/7-8/2002

Phase 3: possible Westinghouse application for DC in 2Q of 2002

Summary of staff position on regulatory exemptions

Requested exemptions granted for AP600 are acceptable for AP1000:

Plant Safety Parameter Display Console

AP600 basis: SPDC requirements integrated into design requirements for alarm and display systems

Auxiliary feedwater system

AP600 basis: PRHR used in lieu of an auxiliary or emergency feedwater system as safety-related method of removing decay heat

Offsite power sources

AP600 basis: passive core and containment cooling systems do not rely on AC power

Summary of staff position on Design Acceptance Criteria (DAC)

10 CFR Part 52: application for design certification must provide complete, final design information in accordance with section 52.47(a)(2).

Staff has experience with DAC approach used for ABWR, System 80+ and AP600

Staff's conclusions:

DAC approach may be used for the technical areas affected by rapidly evolving technologies (i.e., to I&C and human factors)

Bases for approving DAC for piping and radiation protection do not apply to AP1000

Level of design detail provided for AP1000 design certification review should be the same as provided for AP600

Summary of staff position on testing and codes

No new phenomena identified.

In general, AP600 testing and safety analysis codes applicable to AP1000 design.

Certain analytical models employed in the codes need to be improved and/or verified, e.g.,

liquid entrainment model,
"penalty" factor used with the NOTRUMP PRHRHX model,
PCT methodology used during core uncovery.

Comments regarding scaling of containment LST for AP600 (i.e., not properly scaled for transients) are also valid for AP1000

UNITED STATES NUCLEAR REGULATORY COMMISSION

ACRS Combined T/H and Future Plant Design Sub-Committees

Design Acceptance Criteria for AP1000

February 14, 2002

Goutam Bagchi (x3305), David Terao (x3317), Jerry Wilson (x3145)

OPEN

Acceptability of AP1000 DAC Approach
(Background)

- DAC is related to level-of-detail issue [§ 52.47(a)(2)]
- Commission intended that design information would constitute a complete, final design (allowing for design reconciliation)
- Also, ITAAC are not to be used to reach a final conclusion on any safety question associated with the design.
- Two areas where design information should not be completed:
  - (1) rapidly evolving technologies
  - (2) as-built/as-procured information is insufficient
- Staff issued many SECY papers addressing safety, policy, and technical issues applicable to the design certification reviews.

Level of Design Information
required by 10 CFR 52.47(a)(2)

"The application must contain a level of design information sufficient to . . . reach a final conclusion on all safety questions associated with the design before the certification is granted."

DESIGN ACCEPTANCE CRITERIA (DAC)

Level of Design Information submitted for Design Certification

Design scope	ABWR	System 80+	AP600	AP1000
Instrumentation and control	**insufficient (DAC used)**	**insufficient (DAC used)**	**insufficient (DAC used)**	**insufficient (proposed)**
Human factors (control room)	insufficient (DAC used)	insufficient (DAC used)	insufficient (DAC used)	insufficient (proposed)
Radiation protection	insufficient (DAC used)	**insufficient (DAC used)**	sufficient	sufficient (proposed)
Piping	insufficient (DAC used)	**insufficient (DAC used)**	sufficient	**insufficient (proposed)**
Structures	sufficient	sufficient	sufficient	**insufficient (proposed)**
Seismic analysis	sufficient	sufficient	sufficient	**insufficient* (proposed)**

*except for the seismic analysis for hard rock sites

Staff Review of AP1000 DAC
(Seismic Analyses, Structural, and Piping)

- Bases for Acceptability:

SECY-90-241 (Level of detail)
SECY-90-377 (Requirements for Design Certification)
SECY-92-053 (Use of DAC . . . Design Certification Process)
SECY-92-196 (DAC for ABWR)
SECY-92-299 (DAC for I&C and Control Room Design)
SECY-93-087 (Policy, licensing, and technical issues for ALWRs)

- Technical: Sequence of design process and availability of design information

- Safety: §52.47(a)(2) on level of design information required

AP1000 DAC for Seismic, Structural, and Piping Design

Reference: WCAP-15614, "AP1000 Seismic and Structural Design Activities" (2/6/01)

DAC Area	Design Certification	COL Application (Prior to Construction)	Post COL Issuance (During Construction)
Seismic Analysis	stick models for AP1000 <u>rock sites</u>: • fixed-base seismic analyses and ARS • overturning/stability <u>soil sites:</u> seismic analysis DAC	FE models for AP1000 <u>soil sites:</u> • SASSI (soil-structure analyses) and ARS • overturning/stability	
Structural Design	preliminary assessment of key structural elements for soil/rock sites structural DAC	structural design/analyses for soil/rock sites	as-built structural and seismic reconciliation
Piping Design	piping DAC	analyses for LBB-qualified piping	• piping stress reports • pipe break analyses

Seismic Analysis DAC

- First-time DAC approach (new policy issue)
- Applicable to other-than-hard-rock sites (e.g., soil sites) only
- COL applicant would be required to complete seismic analyses (inconsistent with policy issue in SECY-90-377)
- Uncertainties remaining at design certification (safety issue):
  - margins for taller and heavier AP1000
  - higher seismic amplification than hard-rock sites
  - basemat design for overturning and stability
- Approach is technically feasible with some uncertainties

Structural Design DAC

- First-time DAC approach (new policy issue)
- Applicable to all sites
- COL applicant would complete structural design:
  - Substantial amount of design would remain for COL applicant
  - Level of detail is inconsistent with policy issue in SECY-90-377 for a complete design (FSAR at time of OL)
  - Lose benefits of standardization
- Approach is technically feasible for hard-rock sites only
- Uncertainty regarding use of Structural DAC for other than hard-rock sites

Piping DAC (Policy Issues)

- Piping DAC used for ABWR and System 80+ (evolutionary plants)
- AP600 completed its piping design (passive plant)

✎ How was Westinghouse able to complete piping design for AP600?
  - fewer number of safety-related piping subsystems
  - as-procured information was not necessary because of fewer number of piping components (e.g., MOVs, pumps, Hx)

- AP1000 piping diameters have changed
- Westinghouse proposes to use DAC for AP1000 piping
- Use of DAC for AP1000 does not meet SECY-92-053 as it relates to "as-procured information is insufficient to complete design"
- Leak-before-break approach is inconsistent with SECY-93-087
- Approach is technically feasible

Piping DAC (Safety Issues)

Uncertainties Remaining at Design Certification:

- Leak-before-break piping margins (load, crack size, and leakage) are unconfirmed

- Sub-compartment pressurization and flooding issues not addressed

- Thermal-hydraulic characteristics of passive safety systems may be affected with larger piping diameters

Summary

The staff findings on the acceptability of Westinghouse approach for seismic analyses, structural and piping design DAC are as follows:

- Seismic analysis
  - Does not satisfy 10 CFR 52.47(a)(2)
  - Identifies a new policy issue
  - Inconsistent with SECY-90-377 on completeness of design
  - Technically feasible with some uncertainties

- Structural Design
  - Identifies a new policy issue
  - Inconsistent with SECY-90-377 on completeness of design
  - Technically feasible with some uncertainties

- Piping Design
  - Inconsistent with SECY-92-053 bases for DAC
  - Inconsistent with SECY-93-087 for LBB piping
  - Does not satisfy 10 CFR 52.47(a)(2) for LBB, flooding, subcompartment pressurization, and thermal-hydraulic areas
  - Technically feasible

Background Discussion

- Design Changes from AP600 to AP1000 will result in significant increase in seismic loadings for the design of both structural and piping systems
- Amplification of seismic response of structures at soil sites - potential loss of dynamic stability
- Certified design of structures may end up requiring unanticipated and site specific strengthening, when located at sites with large amplification
- Amplified response spectra and relative support displacements are necessary for piping response calculation
- Piping design feasibility at sites with high amplification in vibratory motion is uncertain
- Even for rock sites, safety of AP1000 layout needs to be demonstrated through analysis and design of critical sections
- Impact of piping design on sub-compartment pressure needs to be demonstrated to be within the limits of structural design
- NRC needs to conclude finality of design

Changes that affect the seismic responses AP600 to AP1000

- The shield building height raised by 25 feet 6 inches
- The passive cooling storage (PCS) tank capacity increased from 540,000 gallons to 800,000 gallons
- The steel containment vessel height raised by 25 feet 6 inches, and the vessel thickness increased from 1.625 inches to 1.75 inches
- The fuel pit floor elevations lowered by 18 feet 6 inches
- The polar crane elevation raised by 205 feet 3 inches to 225 feet 3 inches, and the crane capacity increased from 400 ton to 800 ton
- The size of reactor coolant loop equipment (reactor, steam generator, reactor coolant pump, and pressurizer) increased
- The location (elevation) of steam generator upper support snubbers raised

- The height of steam generator and pressurizer compartment walls increased

- According to Westinghouse's preliminary analyses, the total mass of the nuclear island structures is increased by 4 percent, the center of gravity is increased by 6 percent, and the bending moment at the base is increased by 10 percent.

- The design pressure increased from 45 psig to 59 psig

- Use of ASME Code 1999 Addenda - 14 percent increase in allowable stress

- Use of Code Case for SA738 Grade B material - 6 percent increase in allowable stress

AP1000 "Top-Down" and "Bottom-Up" Scaling Evaluations

UNITED STATES NUCLEAR REGULATORY COMMISSION

February 14-15, 2002

Stephen M. Bajorek
Safety Margins and Systems Analysis Branch
Division of Systems Analysis and Regulatory Effectiveness
Office of Nuclear Regulatory Research

OPEN

Background

◆ AP600 experimental programs were reviewed for applicability to AP1000. Westinghouse contention: AP600 programs are sufficient & no new experimental tests are necessary for code validation.

◆ Major design differences:

- 75.9% increase in core power (AP600: 1933 MWt / AP1000: 3400 MWt)
- Longer fuel assemblies (AP600: 12 ft. / AP1000: 14 ft.)
- AP1000 has larger pressurizer and larger CMTs
- AP1000 ADS-4 line resistance is 28% of AP600
- AP1000 CMT resistance is 64% of AP600
- AP1000 PRHR is 22% larger than in AP600
- AP1000 uses Delta-75 (larger) steam generators.

Background, cont'd

- RES performed independent review of Westinghouse PIRT and evaluation & scaling analysis
    - Agree with modifications of AP600 PIRT for AP1000. Most process rankings remained same. Requested that CIWH be added; otherwise no "new" processes identified.

- Independent scaling analysis consisted of:
    - "Top-down" evaluation of AP1000, AP600, ROSA, SPES and APEX to examine and compare global behavior of integral systems.
    - Single node transient calculations to examine ADS blowdown
    - "Bottom-up" evaluation of local processes.

CONCLUSIONS to be Presented:

◆ AP600 tests remain valuable and useful for AP1000 code validation.

◆ Entrainment and carry-over from vessel & hot leg to ADS-4 expected to have an important impact on vessel inventory. ADS-4 flow quality is a major uncertainty.

◆ Entrainment processes in the AP1000 hot leg and upper plenum are distorted in relation to the integral tests. Westinghouse has not demonstrated that entrainment data from integral test facilities is correct the range of conditions for AP1000.

“Top-Down” Scaling

- Top-down scaling methodolgy developed by INEL for AP600 applied.
- AP1000 transient detail:
  - Transient split into 5 distinct periods, with a total of 8 subphases
  - Two scenarios considered: 1-inch CL break, DEG of DVI line
- Acceptability defined as :

$$0.5 < \frac{\Pi_{test}}{\Pi_{AP1000}} < 2$$

  - Distortions (Π group ratios outside acceptable range), were considered acceptable if the test conditions were more conservative than those expected in AP1000, or if the parameters were of secondary importance.
  - Example using Intermediate Subphase III (ADS-1/2/3 Blowdown) follows.

Dimensionless Groups for Intermediate Subphase III

Π Group	Expression	Physical Interpretation
Ψ_1	$(C_{1,1,0}(h_{in}-e_l)_0\dot{m}_{0,ADS}t_0)/P_0$	Ratio of pressure change due to change in specific energy of the subcooled field from mass inflows to reference pressure.
Ψ_2	$(C_{1,1,0}(h_l-e_l)_0\dot{m}_{0,break}t_0)/P_0$	Ratio of pressure change due to subcooled outflow of (h-e) to reference pressure.
Ψ_3	$(C_{1,1,0}\dot{q}_{core,0}t_0)/P_0$	Ratio of pressure change due to change in specific energy of the subcooled field from heat transfer to the reference pressure
Ψ_5	$(C_{1,m,0}(h_m-e_m)_0\dot{m}_{0,ADS}t_0)/P_0$	Ratio of pressure change due to saturated outflow of (h-e) to the reference pressure.
Ψ_6	$(C_{1,m,0}\dot{q}_{core,0}t_0)/P_0$	Ratio of pressure change due to change in specific energy of the saturated field from heat transfer to the reference pressure.
Ψ_{10}	$(C_{2,0}\upsilon_{l,0}\dot{m}_{0,ADS}t_0)/P_0$	Ratio of pressure change due to change in specific volume of subcooled field to reference pressure.
Ψ_{11}	$(C_{2,0}\upsilon_{m,0}\dot{m}_{0,ADS}t_0)/P_0$	Ratio of pressure change due to change in specific volume of saturated field to reference pressure.
Ψ_{13}	$(\dot{m}_{0,ADS}t_0)/M_0$	Ratio of integrated mass flow to reference mass.
π_{ACC}	$\dot{m}_{0,ACC}/\dot{m}_{0,ADS}$	Ratio of accumulator and ADS-1/2/3 reference flows.
π_{CMT}	$\dot{m}_{0,CMT}/\dot{m}_{0,ADS}$	Ratio of CMT and ADS-1/2/3 reference flows.
π_{break}	$\dot{m}_{0,break}/\dot{m}_{0,ADS}$	Ratio of break and ADS-1/2/3 reference flows.
M^*_{ACC}	M_{ACC}/M_0	Ratio of accumulator mass to reference mass.
M^*_{CMT}	M_{CMT}/M_0	Ratio of CMT mass to reference mass.
M^*_{PCS}	M_{PCS}/M_0	Ratio of PCS mass to reference mass.

Reference Values and Dimensionless Groups for Intermediate Subphase III

Parameter	**AP1000**	**AP600**	**ROSA**	**SPES**
t_0, Reference time calculated by Eq. 6.20c (s)	3369.061	3012.085	2966.173	3031.489
t_0-hat , Initial discharge time (s)	3217.833	2853.012	2822.054	2849.815
$m_{0,ADS}$ (kg/s)	807	679	24.4	1.48
$m_{0,break}$ (kg/s)	25.9	25.9	0.85	0.065
$m_{0,ACC}$ (kg/s)	227.8	227.8	6.8	0.58
$m_{0,CMT}$ (kg/s)	98.375	78.7	2.46	0.22
M_0, mass of liquid in ACC and 80% of CMT volun	209760	187060	6076	469
$M_{0,ACC}$ Accumulator reference mass (kg)	96260	96260	3056	240
$M_{0,CMT}$ CMT reference mass (kg)	141875	113500	3762	286
$M_{0,PCS}$ Primary system reference mass (kg)	276905	216840	7303	529
q_0, Reference heat addition by core (MW)	25.5044	14.5	0.5	0.1725
P_0, System pressure (Mpa)	8.3	7	7	7
$(h_{in}-e_l)_0$, Difference between ave energy in subc	-1131	-1131	-1131	-1131
$(h_m-e_m)_0$, Difference between ave energy in sat fi	-331.1	-331.1	-421.4	-361.2
$(h_l-e_l)_0$, (h-u) for subcooled field (kJ/kg)	9.46	9.46	9.46	9.46
$(h_m-e_m)_0$, (h-u) for saturated field (kJ/kg)	50.2	50.2	60.4	52.8
$C_{1,10}$ (m^{-3})	3.80E-05	3.80E-05	1.56E-03	1.94E-02
$C_{1,m0}$ (m^{-3})	4.18E-04	4.18E-04	1.35E-02	2.00E-01
$C_{2,0}*v_{1,0}$ (J/m^3-kg)	-76.1	-76.1	-3106	-38740
$C_{2,0}*v_{m,0}$ (J/m^3-kg)	-410.1	-410.1	-20138	-219285
$[C_{1,m}*(h_l-e_m)-C_{1,1}*(h_l-e_l)]_0$	-0.124	-0.124	-5.21	-99.3

Dimensionless coefficients for Intermediate Subphase III

Ψ_1	-14.07831	**-12.56**	**-18.24**	**-14.06**
Ψ_2	3.78E-03	4.01E-03	5.32E-03	5.17E-03
Ψ_3	0.393396	0.237094	0.330516	1.449268
Ψ_5	6.873602	6.130825	8.430608	6.768363
Ψ_6	4.327351	**2.61**	**2.86**	**14.94**
Ψ_{10}	-24.92809	**-22.23**	**-32.11**	**-24.83**
Ψ_{11}	-134.3365	**-119.8198**	**-208.2114**	**-140.5493**
Ψ_{13}	12.96163	**10.93**	**11.91**	**9.57**
π_{ACC}	0.28228	**0.34**	**0.28**	**0.39**
π_{CMT}	0.121902	**0.12**	**0.10**	**0.15**
π_{break}	0.032094	**0.038**	**0.035**	**0.044**
M^*_{ACC}	0.458905	**0.51**	**0.50**	**0.51**
M^*_{CMT}	0.676368	**0.61**	**0.62**	**0.61**
$M^*_{PCS} = M_{0,PCS}/M_0$	1.320104	**1.16**	**1.20**	**1.13**
$(t_0 - t_0\text{-hat})/t_0$	0.044887	**0.053**	**0.049**	**0.060**

Reference Values and Dimensionless Groups for Intermediate Subphase III

Parameter	Π_{AP600}/Π_{AP1000}	Π_{ROSA}/Π_{AP1000}	Π_{SPES}/Π_{AP1000}
Ψ_1	0.89	1.30	1.00
Ψ_2	1.06	1.41	1.37
Ψ_3	0.60	0.84	3.68
Ψ_5	0.89	1.23	0.98
Ψ_6	0.60	0.66	3.45
Ψ_{10}	0.89	1.29	1.00
Ψ_{11}	0.89	1.55	1.05
Ψ_{13}	0.84	0.92	0.74
π_{ACC}	1.19	0.99	1.39
π_{CMT}	0.95	0.83	1.22
π_{break}	1.19	1.09	1.37
M^*_{ACC}	1.12	1.10	1.12
M^*_{CMT}	0.90	0.92	0.90
$M^*_{PCS} = M_{0,PCS}/M_i$	0.88	0.91	0.85

- **Conclusion for this subphase: AP1000 scales acceptably with ROSA; distortions in SPES are conservative, and were not associated with dominant groups. Therefore, both SPES and ROSA considered accepable for application to AP1000.**

Results of “Top-Down” Scaling

- Subcooled Blowdown - AP1000 scales acceptably with SPES
- ADS-1/2/3 Intermediate - AP1000 scales acceptably with SPES
- ADS-4 Blowdown - Non-conservative distortion in APEX while flow critical; AP1000 scales acceptably with SPES
- IRWST Injection & Draining - AP1000 scales acceptably with APEX
- IRWST / Sump Injection - AP1000 scales acceptably with APEX

Results of "Top-Down" Scaling, cont'd

- ◆ ADS-4 Blowdown -

- ♦ Dominant dimensionless group is

$$\Pi_{16-CMT} = \frac{\dot{m}_{CMT}}{\dot{m}_0} = \frac{\rho_l}{\dot{m}_0}\sqrt{\frac{g\Delta Y_{CMT,0}}{R'_{CMT,0}}}$$

which relates magnitude of the CMT flow to the ADS-4 discharge flow rate. Represents the rate at which the vessel inventory increases/decreases during the phase.

- ♦ AP1000 scales acceptably with SPES, but not APEX while flow is critical.
- ♦ APEX has a non-conservative distortion suggesting APEX results are <u>not</u> applicable for code validation (at high pressure, critical flow).
- ♦ AP1000 scales acceptably with both SPES and APEX when ADS-4 flow becomes non-critical.

Π_{16} Ratios for DEDVI Break

ADS-4 Flow	Quality	$\frac{\Pi_{16,AP600}}{\Pi_{16,AP1000}}$	$\frac{\Pi_{16,ROSA}}{\Pi_{16,AP1000}}$	$\frac{\Pi_{16,SPES}}{\Pi_{16,AP1000}}$	$\frac{\Pi_{16,APEX}}{\Pi_{16,AP1000}}$
Critical	x_{core}	1.17	1.28	0.52	2.36
Critical	1.0	1.57	1.97	0.75	2.98
Non-critical	1.0	1.41	1.67	1.56	1.33

Π_{16} Ratios for 1-Inch Cold Leg Break

ADS-4	Quality	$\frac{\Pi_{16,AP600}}{\Pi_{16,AP1000}}$	$\frac{\Pi_{16,ROSA}}{\Pi_{16,AP1000}}$	$\frac{\Pi_{16,SPES}}{\Pi_{16,AP1000}}$	$\frac{\Pi_{16,APEX}}{\Pi_{16,AP1000}}$
Critical	x_{core}	1.16	1.21	0.56	2.02
Critical	1.0	1.50	1.72	0.78	2.32
Non-critical	1.0	1.41	1.54	1.61	1.26

Results of "Top-Down" Scaling, cont'd

- Conclusions from "top-down" scaling:
  - AP600 integral tests remain valuable & very useful for AP1000.
  - Top-down scaling alone does not suggest the need for new or additional data
  - ADS-4 blowdown behavior in AP1000 tends to be more like SPES than APEX
- Concerns & observations from "top-down" scaling:
  - INEL methodology assumes same ADS-4 flow quality in AP1000/AP600 and in the IETs.
  - Scaling groups in Intermediate through IRWST Injection periods show sensitivity to ADS flow quality.

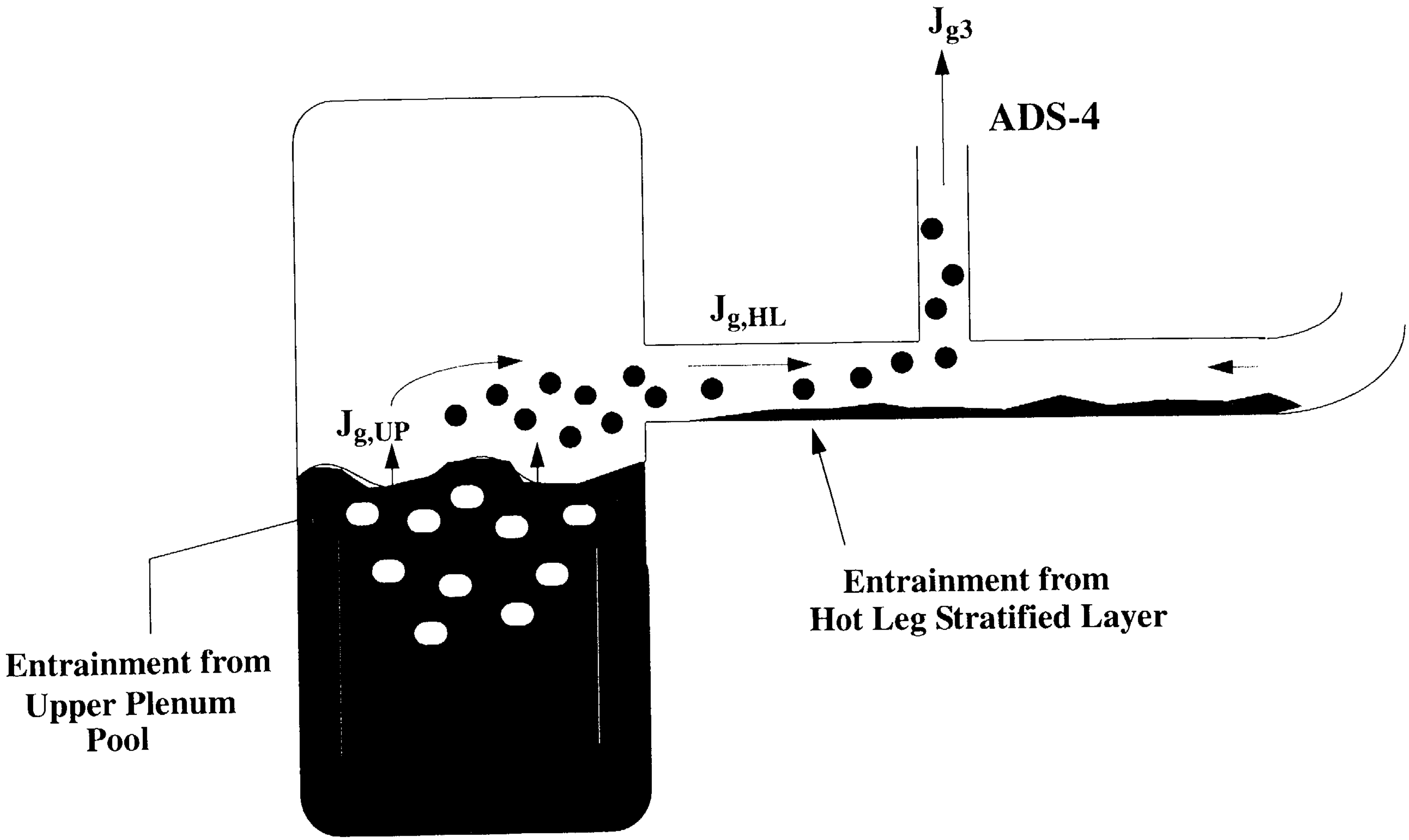
“Bottom-Up” Scaling

- “Bottom-up” considers processes that may have large local effect, or may represent bifurcations in the top-down evaluation.

- AP1000 scaling relative to integral tests considered:

Process	Scaling Parameters	Conclusion
Hot leg flow regime transition	Fr_m	Acceptable
Cold leg flow regime transition	Fr_m	Acceptable
Flooding	Ku	Acceptable
Core exit void fraction	α	Acceptable
Hot leg entrainment	(h_b/D) $J_{g,onset}$	Distorted
Upper plenum pool entrainment	E_{fg}	Distorted

Entrainment Processes



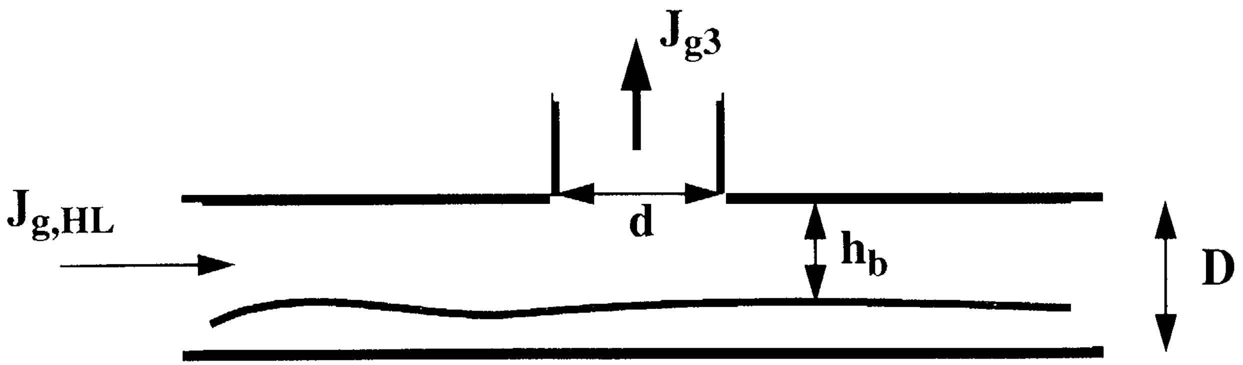
Entrainment from Upper Plenum Pool

Entrainment from Hot Leg Stratified Layer

Results from “Bottom-Up” Scaling

- **Entrainment from Hot Leg Stratified Layer**
- **Westinghouse approach used typical correlation for entrainment onset:**

$$Fr_m = \frac{J_{g3}}{\sqrt{\frac{D_h g \Delta\rho}{\rho_g}}} = C\left(\frac{h_b}{d}\right)^m$$



- Problems with horizontal-stratified onset correlation(s) of the form,

$$Fr_m = \frac{J_{g3}}{\sqrt{\frac{D_h g \Delta\rho}{\rho_g}}} = C\left(\frac{h_b}{d}\right)^m$$

- Correlations not based on data from prototypical geometry.

$$(d/D)_{AP1000} >> (d/D)_{data}$$

- Viscous effects, interfacial shear and suface tension is ignored. For high steam velocities, roll wave entrainment is expected to be an important process.

- Formulation is based on inviscid flow to a point sink. (Valid for only for small d/D ratios.)

- **If correlation is assumed valid for AP1000 geometry & horizontal -stratified flow exists in hot leg, dimensionless entrainment onset heights become:**

Period	$\left(\frac{h_b}{D}\right)_{AP1000}$	$\left(\frac{h_b}{D}\right)_{AP600}$	$\left(\frac{h_b}{D}\right)_{ROSA}$	$\left(\frac{h_b}{D}\right)_{SPES}$	$\left(\frac{h_b}{D}\right)_{APEX}$	**Branch Line**
Intermediate (ADS-1/2/3)	**0.095**	**0.065**	**0.082**	**0.063**	**0.061**	**Pzr Surge Line**
ADS-4 Blowdown	**0.298**	**0.228**	**0.245**	**0.194**	**0.232**	**ADS-4 Branch**
IRWST Injection	**0.323**	**0.247**	**0.260**	**0.206**	**0.240**	**ADS-4 Branch**
Sump Injection	**0.214**	**0.163**			**0.156**	**ADS-4 Branch**

- **In all periods, entrainment onset will occur for lower water levels in AP1000 than in integral tests.**

◆ **Consider annular flow, where roll wave entrainment expected - Typical correlation for critical entrainment velocity has form**

$$\frac{\mu_l J_{g,\,onset}}{\sigma}\sqrt{\frac{\rho_g}{\rho_l}} \geq C$$

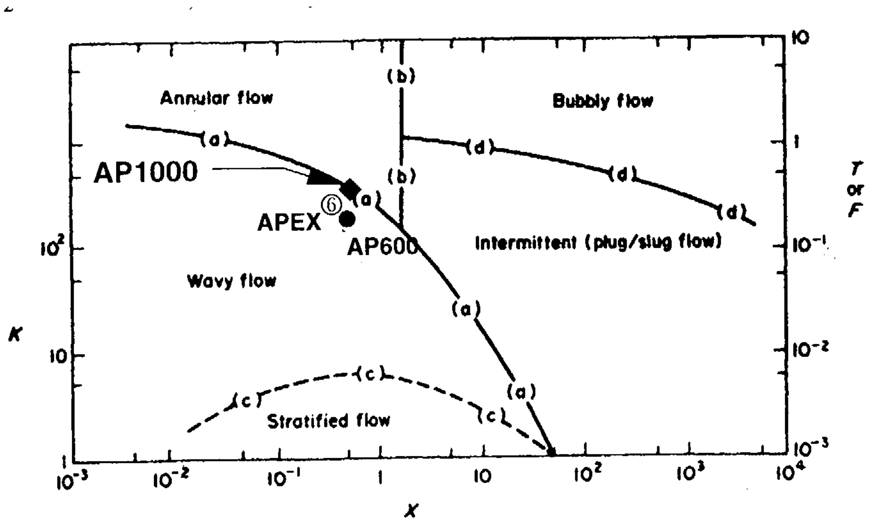


Figure A. Expected hot leg flow patterns in IRWST Injection period.

◆ J_g in hot leg compared to $J_{g,onset}$ with $C=1.5\times10^{-4}$; Entrainment assumed if $\left(\frac{2}{3}\right)J_{g,\,HL} > J_{g,\,onset}$ (assumes flow split due to single ADS-4 valve failure)

Period	AP1000	AP600	ROSA	SPES	APEX
Intermediate (ADS-1/2/3)	YES	NO	NO	NO	NO
ADS-4 Blowdown	YES	NO	NO	NO	NO
IRWST Injection	YES	NO	NO	NO	NO
Sump Injection	NO	NO	-	-	NO

◆ Hot leg entrainment expected for AP1000, but not for AP600 or IETs.

◆ Conclusions for Hot Leg Entrainment:

- Entrainment from horizontal stratified water levels in hot leg will occur at lower water levels in AP1000 than in AP600 or in test facilities.

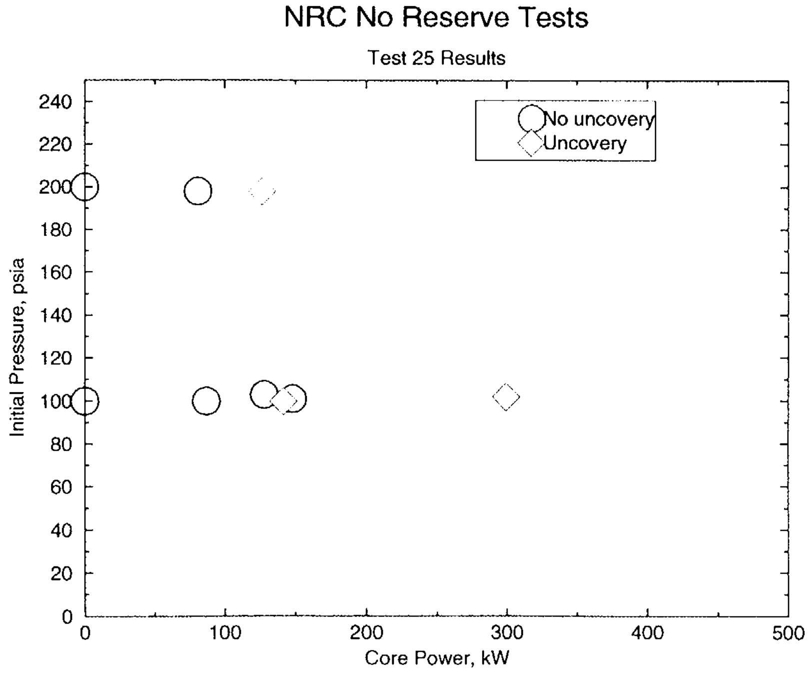
- The high J_g in AP1000 is expected to exceed entrainment onset requirement. The J_g in AP600 & IETs were below those for entrainment.

- Westinghouse has not demonstrated that hot leg entrainment processes evident in SPES or APEX sufficiently approximate conditions in AP1000.

■ Upper Plenum Pool Entrainment

◆ Entrainment & de-entrainment in upper plenum assigned a high "H" ranking for IRWST Injection period and medium "M" ranking for ADS-4 Blowdown. It has not been scaled for either AP1000 or AP600).

◆ Beyond design basis (BDB) tests in APEX facility following W and NRC AP600 test programs showed high rates of entrainment and carry-over from upper plenum pool to ADS-4 branch line.



◆ **Relatively few data or correlations for UP "pool" entrainment. Correlations suggested include:**

$$E_{fg} = \frac{\rho_f J_{fe}}{\rho_g J_g}$$

Rozen

$$E_{fg} = 0.37(J_g{*})^{4.2} N_{\mu g}^{0.7} \sqrt{\frac{\Delta\rho}{\rho_g}} \exp\left(-0.23\frac{h}{D_h}\right)$$

Kruzhilin

$$E_{fg} = C_k(J_g{*})^4 \sqrt{\frac{\Delta\rho}{\rho_g}} \sqrt{\frac{\Delta\rho}{\rho_f}}$$

Ishii & Kataoka (deposition controlled region)

$$E_{fg} = 3.18(J_g{*})^3 N_{\mu g}^{0.5}$$

Ishii & Kataoka (momentum controlled, intermediate gas flux regime)

$$E_{fg} = (5.417x10^6)(J_g{*})^3 (h{*})^{-3} N_{\mu g}^{1.5} (D_h{*})^{1.25} \left(\frac{\rho_g}{\Delta\rho}\right)^{-0.31}$$

◆ **Preserving geometry & with pressure similitude,,**

$$E_{fg} = \frac{\rho_f J_{fe}}{\rho_g J_g} \propto (J_g)^{3 \leftrightarrow 4.2}$$

so,

$$\frac{(E_{fg})_{AP1000}}{(E_{fg})_{AP600}} \sim \left(\frac{q_{core,\,AP1000}}{q_{core,\,AP600}}\right)^{3 \leftrightarrow 4.2} = (1.75)^{3 \leftrightarrow 4.2} = 5.4 \leftrightarrow 10.5$$

For AP1000, AP600, and test facilities, conditions suggest Kataoka & Ishii's "momentum controlled, intermediate gas flux regime". Then, define:

$$\Pi_{UP,\,entr} = \frac{[(J_g{*}/h{*})^3 (D_h{*})^{1.25}]_{test}}{[(J_g{*}/h{*})^3 (D_h{*})^{1.25}]_{AP1000}}$$

$$\Pi_{UP,\,entr} = \frac{[(\dot{q}_{core}/A_{UP})^3 D_h^{1.25}/\Delta z^3]_{test}}{[(\dot{q}_{core}/A_{UP})^3 D_h^{1.25}/\Delta z^3]_{AP1000}}$$

Upper Plenum Scaling Parameters

	AP1000	AP600	ROSA	SPES	APEX
Core Power Factor	1.75	1.0	1/30.5	1/395	1/96
Upper Plenum Area, m^2	5.97	5.97	0.126	0.013	0.115
Δz	1.827	1.827	1.903	1.822	0.457
D_h	2.76	2.76	0.401	0.129	0.382
$\Pi_{UP,\,entr}$		0.187	**0.055**	**0.0064**	**0.160**
$\dfrac{1}{\Pi_{UP,\,entr}}$		5.3	**18.2**	**156**	**6.3**

$$\frac{1}{\Pi_{UP,\,entr}} = \frac{\textit{Entrainment in AP1000}}{\textit{Entrainment in Test Facility}}$$

- ◆ **Upper plenum entrainment non-conservatively distorted in all three IETs, and applies to ADS-4 blowdown and IRWST Injection periods.**

- ◆ **APEX agreement is closer to AP1000 than ROSA or SPES because of 1/4 height scale in APEX vessel.**

■ Upper Plenum Pool Entrainment - Conclusions

- ◆ Upper plenum pool entrainment in intergal facilities may be significantly lower than entrainment in the AP1000. This represents a non-conservative distortion. This suggests that ADS-4 flow quality may be much lower in AP1000, than in the integral tests.

- ◆ Westinghouse has not provided an upper plenum entrainment scaling rationale, nor demonstrated that upper plenum entrainment in APEX or SPES reasonably approximates that in AP1000.

Conclusions

◆ In general, integral tests performed to validate codes and confirm behavior of AP600 remain valuable and can be used AP1000 code validation.

◆ Entrainment and carry-over from vessel & hot leg to ADS-4 expected to have an important impact on vessel inventory during the SBLOCA periods when inventory is near a minimum. ADS-4 flow quality is a concern.

◆ Entrainment & carry-over not well understood. Existing correlations are dependent on geometry & T/H range of conditions. Can not be reliably extended to complex geometry in AP1000 UP and HL-branch line. They do however, suggest significantly higher entrainment in AP1000.

◆ It has not been demonstrated that entrainment data from integral test facilities is correct the range of conditions for AP1000, as is therefore not considered appropriately scaled to validate entrainment models in thermal-hydraulic codes. Alternate data or revised approach is necessary to validate entrainment modeling for AP1000.

AP1000 Pre-Certification Review

Presentation to the

Advisory Committee on Reactor Safeguards

Combined Thermal-Hydraulic Phenomena / Future Plant Designs Subcommittee Meeting

February 14 - 15, 2002 OPEN

AP1000 Pre-Certification Review Overview

Mike Corletti

Phased Approach to AP1000 Licensing

- Phase 1
  - –Establish goals and estimate for Prelicensing Review
  - –Westinghouse prepare submittals to support goals
- Phase 2
  - –NRC perform Prelicensing Review
  - –NRC estimate Cost and Schedule for AP1000 Design Certification
  - –Westinghouse develop Safety Analysis Report
- Phase 3
  - –NRC perform Design Certification Review

Four Main Issues Addressed in Pre-Certification Review

- Applicability of AP600 Test Program to AP1000
- Applicability of AP600 Safety Analysis Codes to AP1000
- Defer Detailed Engineering using Design Acceptance Criteria
- Applicability of AP600 Exemptions to 10CFR50

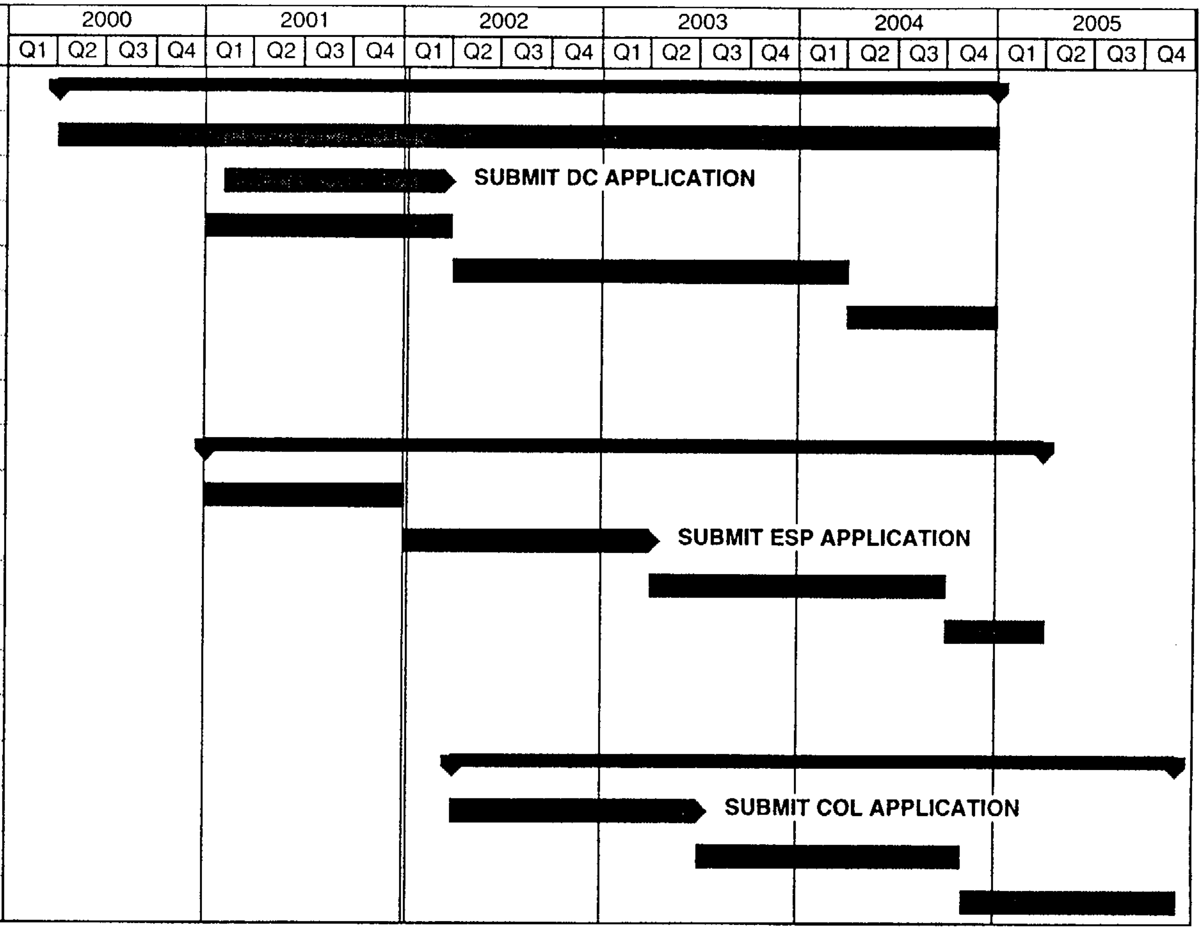
Status of Pre-Certification Review
(Phase 2)

- Westinghouse submittals complete
  - –AP1000 Plant Description and Analysis Report - 12/12/2000
  - –AP1000 Seismic and Structural Design Activities - 2/4/2001
  - –AP1000 PIRT and Scaling Assessment Report - 2/6/2001
  - –AP1000 Code Applicability Report - 5/4/2001
- Several meetings held with NRC staff and ACRS
- Staff submitted Requests for Additional Information (RAI)
  - –Westinghouse responses provided by 11/9/2001
  - –Schedule for Completion of Pre-Certification Review

–ACRS Subcommittee Meetings:	February 14-15, 2002
–ACRS Full Committee	March 7-8, 2002
–Staff Issue SECY Letters	February / March, 2002
–Commission Approval	March, 2002

Earliest New Plant Order in US - 2005

ID	Task Name
1	**AP1000 Design Certification**
2	Engineering Design
3	NRC Pre-Certification Review
4	Prepare Safety Analysis Report
5	NRC Review (Issue FDA)
6	Hearings / Rule (Issue DC)
7	
8	
9	**U.S. Utilities Early Site Permit**
10	Decide on Plan and Select Site
11	Prepare Application
12	NRC Review
13	Hearings (Issue ESP)
14	
15	
16	**U.S. Utility Combined Op License**
17	Prepare Application
18	NRC Review (Issue SER)
19	Hearings (Issue COL)



AP1000 Approach to Design Acceptance Criteria

Application of Design Acceptance Criteria to AP1000

Background

- 10 CFR Part 52 Requires an Applicant to Submit an Essentially Complete Design for Design Certification

10CFR52.47(a)(2) "*The application must contain a level of design information sufficient to enable the Commission to judge the applicant's proposed means of assuring that construction conforms to the design and to reach a final conclusion on all safety questions associated with the design before the certification is granted. The information submitted for a design certification must include performance requirements and design information sufficiently detailed to permit the preparation of acceptance and inspection requirements by the NRC, and procurement specifications and construction and installation specifications by an applicant. The Commission will require, prior to design certification, that information normally contained in certain procurement specifications and construction and installation specifications be completed and available for audit if such information is necessary for the Commission to make its safety determination.*"

Application of Design Acceptance Criteria to AP1000

Background

- Design Acceptance Criteria approach was developed by NRC and Industry to address areas where detailed design information was not needed for the staff to make a safety determination
  - Two criteria were applied:
    - Rapidly-evolving technology where it was not advisable to fix the design
      - I&C, Man-machine interface
    - As-built vendor data unavailable for final design and analysis
      - Piping design and analysis

Revised Approach to Seismic Analysis

Proposal

- Apply DAC to seismic analysis
  - –Define seismic response spectra for hard rock site only
  - –Define DAC for performing seismic analysis for soil sites

Revised Proposal

- Request Design Certification for hard rock site only
  - –Combined License applicants at a hard rock site can reference certified design directly
  - –Combined License applicants at a soil site can provide site specific seismic analyses and demonstrate acceptability of certified design including specific changes to the plant for their site if necessary

Revised Approach to Structural Design

Proposal

- Apply DAC to structural design
  - –Define design criteria, methodology and acceptance criteria for structural design approved during design certification
  - –Final structural design subject to ITAAC

Revised Proposal

- Perform structural design during design certification
  - –In accordance with seismic response for hard rock site

Application of Design Acceptance Criteria to AP1000

Background

- Evolutionary designs (ABWR / System80+) applied DAC/ITAAC approach in the area of piping design
  - –Design Acceptance Criteria (Referenced in Tier 1, Included in Design Control Document as Tier 2*)
    - –Piping Design Criteria
    - –Analytical methods to be applied for piping analysis
    - –Acceptance Criteria
  - –ITAAC portion (Included in Tier 1)
    - –Verification that final piping design and analysis conforms to the DAC

Application of Design Acceptance Criteria to AP1000

Background

- Westinghouse completed detailed piping analysis on most safety-related piping systems for AP600
  - Assumptions made on vendor data
  - Calculations were audited by NRC

However, there is little difference in the future regulatory burden on AP600 compared to other Certified Designs in the area of the review of the piping analysis

Comparison of Regulatory Burden of AP600 vs. Evolutionary Designs

	ABWR / System 80+	AP600
Piping Design Criteria	Included in Tier 2 Referenced in Tier 1/2*	Included in Tier 2 Referenced as Tier 2*
Analytical Methods	Included in Tier 2 Referenced in Tier 1/2*	Included in Tier 2 Referenced as Tier 2*
Acceptance Criteria	Included in Tier 2 Referenced in Tier 1/2*	Included in Tier 2 Referenced as Tier 2*
Audit Vendor Calculations	Small subset in Design Cert. All subject to ITAAC	Large subset in Design Cert. All subject to ITAAC

Tier 1 - ITAACS / DAC and cannot be changed without Rulemaking

Tier2* - Portion of the DCD that cannot be changed without NRC approval

Tier 2 - DCD that can be changed by the plant owner via 50.59

What Did We Gain From AP600 Piping Design and Analysis

- Confidence in line routings
- Agreement on methods

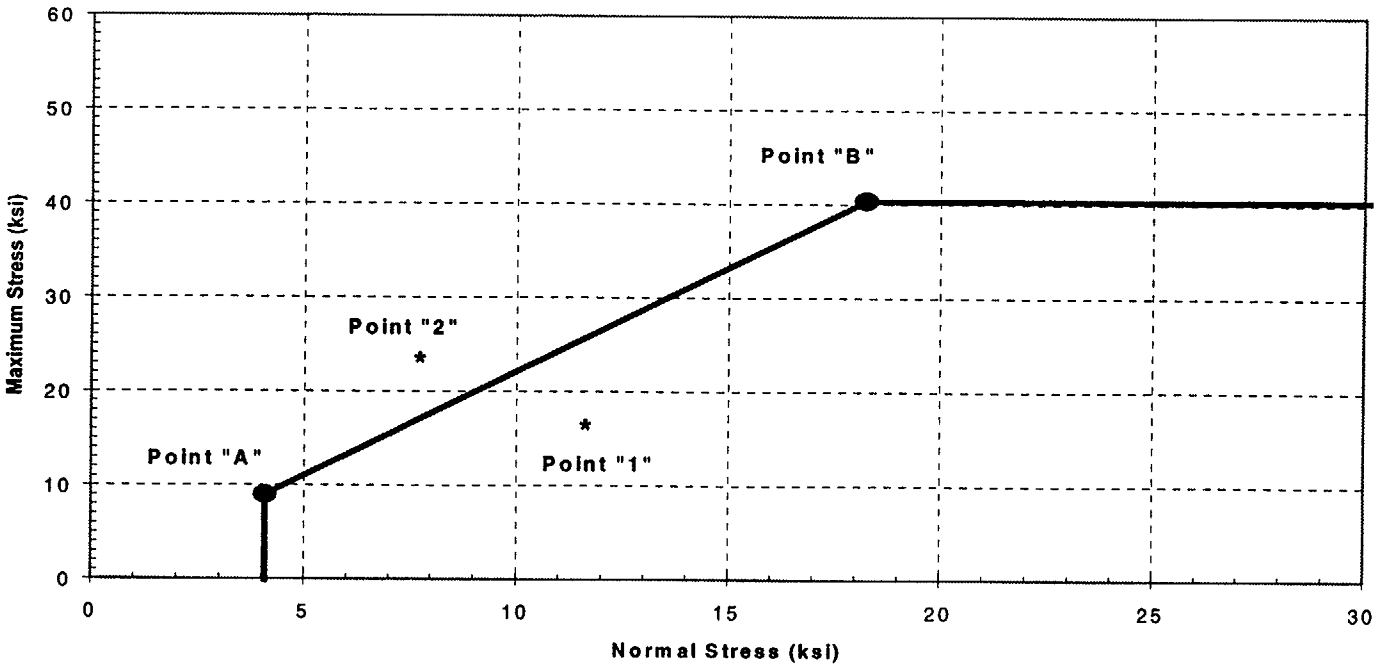
- AP1000 can achieve these same benefits from the work completed for AP600
  - –AP1000 line routings based on AP600
  - –AP1000 will use the same methods as AP600
  - –AP1000 piping design specification based on AP600

AP1000 Proposed Requirement for COL Applicant

- Leak-before-Break Evaluation of as-Designed Piping

"Combined License applicants referencing the AP1000 certified design will complete the leak-before-break evaluation by comparing the results of the as-designed piping stress analysis with the bounding analysis curves documented in Appendix 3B. The leak-before-break evaluation will be documented in a leak-before-break evaluation report."

AP1000 Typical Bounding Analysis Curve



Pipe Designator:
System:
Nominal Diameter: inch
Pipe Schedule:
Outside Diameter: inch
Pipe Material:
Minimum Weld Thickness:

Normal Operating Pressure: psig
Normal Operating Temperature: F
Critical Flaw Size = 2 x Leakage Flaw Size
Load Margin = 1.0
Leak Rate Margin = 10 (Typical for All Curves)

Notes for Typical Bounding Analysis Curve:
Point "A" - for low normal case to generate BAC.
Point "B" - for high normal case to generate BAC.
Point "A" and Point "B" are joined by a straight line.
Point "1" - analyzed critical point which meets LBB criteria.
Point "2" - analyzed critical point which fails LBB criteria.

AP1000 Proposed Approach for Piping DAC

- Follow similar path of ABWR/System 80+
  - –Piping design & analysis applicable from AP600 available in DC
  - –Complete LBB analysis during COL application review
  - –Final piping analysis subject to ITAAC verification

Conclusions

- Use of DAC is an accepted approach to allow the NRC to make a safety determination prior to all detailed design being completed
- Use of DAC for AP1000 piping should be approved
  - Intent of 10 CFR Part 52 is met, consistent with past safety determinations
    - GE ABWR; CE System 80+

Status of Design Acceptance Criteria

- AP1000 Seismic and Structural Design Activities
  - –Report submitted to NRC in January 2001
  - –Outlines our approach
    - –Includes proposed AP1000 Design Acceptance Criteria
    - –Piping design
    - –Structural design
    - –Includes preliminary seismic analysis results
- Status
  - –Staff objects to our proposal
    - –Policy Issue
  - –Westinghouse has revised our proposal
    - –Drop DAC approach for seismic / structural
    - –Continue DAC approach for piping

OPEN

AP1000 Scaling

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AP1000 Testing/Scaling Effort Overview

- PIRT reviews concluded no new phenomena expected for AP1000.
  - –Entrainment in hot leg and upper plenum upgraded to high importance.
- Westinghouse scaled AP600 test facilities to demonstrate applicability to AP1000.
  - –Results contained in "AP1000 PIRT and Scaling Assessment", WCAP-15613.
- Westinghouse answered PIRT/testing/scaling-related RAIs from NRC.
  - –ROSA-AP600 test facility scaling provided by Westinghouse.
- Westinghouse performed additional work to address ACRS comments.
  - –Separated (vs. homogeneous) flow model used to scale quality at low pressure.
  - –Flow regime maps for flow in hot leg and ADS-4 vent paths during sump injection.
  - –3-D (vs. 2-D) CFD model of containment circulation.

Liquid Entrainment Scaling

- Liquid entrainment is high ranked phenomena in SBLOCA PIRT for AP1000 during ADS-IRWST phase where minimum inventory typically occurs Two regions of interest identified.
  - Upper Plenum
  - Hot Leg/ADS-4
- Entrainment ranking upgraded for AP1000 due to increased core power coupled with retention of upper plenum and hot leg size.
- Upper Plenum entrainment scaling not addressed in WCAP-15613. --
  - Addressed via recent work using Kataoka-Ishii pool entrainment.
- Hot Leg/ADS-4 entrainment scaling has been addressed in WCAP-15613.

Liquid Entrainment Scaling

- Review of Kataoka-Ishii pool entrainment work (NUREG/CR-3304) identifies regions of entrainment
  - Near surface region
  - Momentum controlled region
- Near surface region entrainment dependent on density ratio only.
- Momentum controlled region dependent upon:
  - density ratio
  - dimensionless diameter ratio (D_H*)
  - viscosity number
  - ratio of dimensionless superficial gas velocity (j_g^*) to dimensionless height (H*) above liquid surface.

Liquid Entrainment Scaling

- Basedupon Kataoka-Ishii pool entrainment work (NUREG/CR-3304)
  - As near suface region entrainment dependent on density ratio only, SBLOCAs where mixture level is in or near hot leg(most SBLOCA events) should be well scaled in test facilities as pressure (density) approximately preserved after ADS is actuated.
  - As momentum controlled region dependent upon dimensionless superficial gas velocity (j_g^*), liquid entrainment for SBLOCAs where mixture level goes below hot leg (i.e. DE DVI) may be distorted in AP600 test facilities for AP1000 due to the higher superficial gas velocity associated with higher AP1000 core power.

Liquid Entrainment Scaling

- Liquid entrainment in momentum controlled region (mixture level below hot leg) can be expressed as follows:

$$E_{fg} \propto \left[\frac{j_g^*}{H^*}\right]^3 \cdot \left[D_H^*\right]^{1.25} \cdot \left[N_{\mu g}\right]^{1.5}$$

- E_{fg} represents dimensionless ratio of entrained liquid flux to gas flux.

$$E_{fg} = \frac{\rho_f j_{fe}}{\rho_g j_g}$$

- For pressure similitude the scaling ratio is therefore:

$$\left[E_{fg}\right]_R = \left[\frac{j_g}{H}\right]_R^3 \cdot \left[D_H\right]_R^{1.25}$$

- For saturated conditions in the vessel, this can be put in the following form:

$$\left[E_{fg}\right]_R = \left[\frac{Q_{core}}{A \cdot H}\right]_R^3 \cdot \left[D_H\right]_R^{1.25}$$

Liquid Entrainment Scaling

- Liquid entrainment scaling ratio for momentum controlled region for OSU relative to AP1000 is in following range when pressure similitude exists:

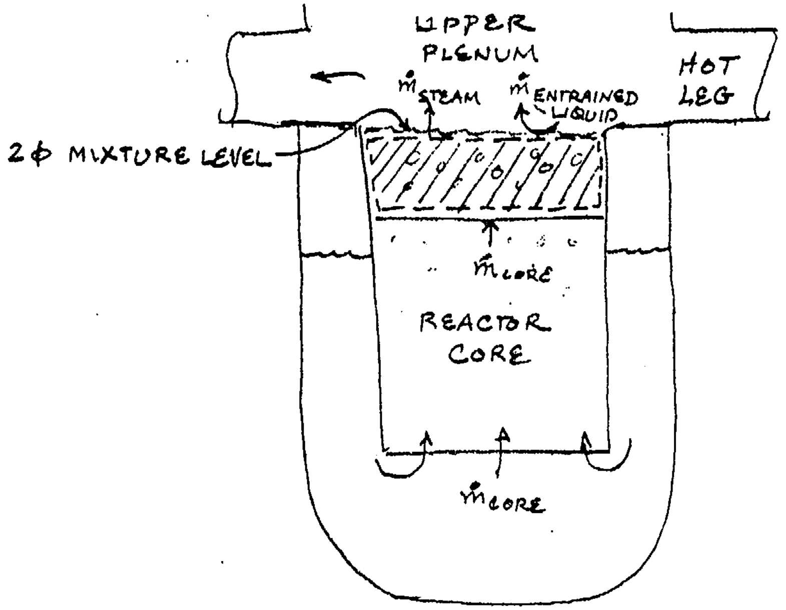
$$\left[E_{fg}\right]_R = \frac{\left[E_{fg}\right]_{OSU}}{\left[E_{fg}\right]_{AP1000}} \approx 0.25 - 0.50$$

- Scaling range represents flow area and hydraulic diameter at:
  - –upper plenum guide tube region (below hot leg).
  - –entrance to upper plenum (upper core plate)
- Scaling ratio indicates that entrainment is less in OSU test facility relative to AP1000.

Liquid Entrainment Scaling Conclusions

- Near Surface region liquid entrainment in upper plenum sufficiently scaled in AP600 test facilities for AP1000 during ADS-IRWST phases.
- Momentum controlled regime liquid entrainment distorted relative to AP1000. However, distortion in OSU test facility does not appear to be so large that data is rendered unusable for code validation purposes for AP1000.

Upper Plenum Liquid Entrainment Evaluation



MOMENTUM-CONTROLED REGION LIQUID ENTRAINMENT IN UPPER PLENUM (BELOW HOT LEG)

Upper Plenum Liquid Entrainment Evaluation

GOVERNING EQUATION SET

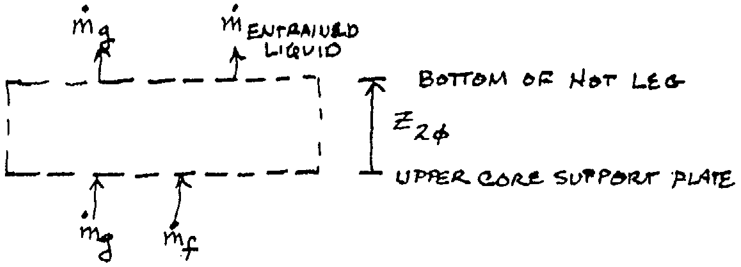
- CONSERVATION OF MASS – UPPER PLENUM

$$\frac{dM_{U.P.}}{dt} = \frac{d\left[\rho_m \cdot A \cdot Z_{2\phi}\right]_{U.P}}{dt} = \dot{m}_{CORE} - \dot{m}_{STEAM} - \dot{m}_{\substack{ENTRAINED\\LIQUID}} = \dot{m}_f - \dot{m}_{\substack{ENTRAINED\\LIQUID}}$$

AS $\dot{m}_{CORE} = \dot{m}_f + \dot{m}_g$

$\dot{m}_f$ = LIQUID COMPONENT OF CORE EXIT MASSFLOW

$\dot{m}_g$ = VAPOR COMPONENT OF CORE EXIT MASSFLOW.



- MIXTURE DENSITY DEFINED AS $\rho_m = \alpha \rho_g + (1-\alpha)\rho_f$

- VOID FRACTION MODELED USING YEH CORRELATION $\alpha = 0{,}925\left(\frac{\rho_g}{\rho_f}\right)^{0{,}24}\left(\frac{j_g}{V_{bcr}}\right)^{0{,}47}$

WHERE $V_{bcr} = 1{,}53\left[\frac{\sigma \cdot g_r \cdot \Delta\rho}{\rho_f^{2}}\right]^{0{,}25}$

Upper Plenum Liquid Entrainment Evaluation

- ENTRAINMENT MODELED USING KATAOKA-ISHII CORRELATION FOR INTERMEDIATE GAS FLUX REGIME (MOMENTUM CONTROLLED).

$$E = \frac{\rho_f j_{fe}}{\rho_g j_g} = 5.417E6 \left(\frac{j_g^*}{h^*}\right)^3 \left(\frac{\rho_g}{\Delta\rho}\right)^{-0.31} N_{\mu g}^{1.5} D_H^{*1.25}$$

WHERE $j_g^* = \dfrac{j_g}{\left(\dfrac{\sigma g \Delta\rho}{\rho_g^2}\right)^{0.25}}$ $h^* = \dfrac{h}{\left(\dfrac{\sigma}{g\Delta\rho}\right)^{0.5}}$ $N_{\mu g} = \dfrac{\mu_g}{\left(\rho_g \sigma \sqrt{\dfrac{\sigma}{g\Delta\rho}}\right)^{0.5}}$ $D_H^* = \dfrac{D_H}{\sqrt{\dfrac{\sigma}{g\Delta\rho}}}$

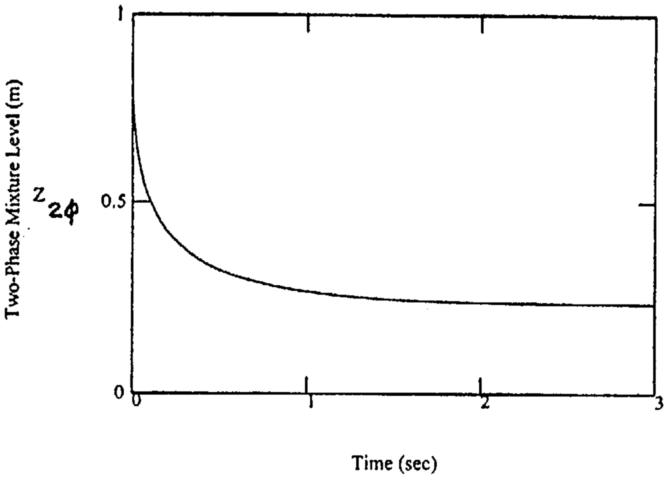
- CONSERVATION OF ENERGY - CORE

$\dot{m}_{CORE} = \dfrac{q_{CORE}}{\Delta h_{sub} + X_{exit} h_{fg}}$ W/O SUBCOOLING $\dot{m}_{CORE} = \dfrac{q_{CORE}}{X_{EXIT}\, h_{fg}}$

FOR QUASI-STEADY CONDITIONS IN CORE. ⇒ $j_g = \dfrac{q_{CORE}}{\rho_g \cdot h_{fg}\, A}$.

Upper Plenum Liquid Entrainment Evaluation

- EQUATION SET SOLVED WITH MATHCAD, RESULTS SHOWN BELOW.
- UPPER PLENUM 2ϕ MIXTURE LEVEL DROPS RAPIDLY BUT REACHES EQUILIBRUM LEVEL WITHIN A FEW SECONDS.
- ENTRAINMENT DIMINISHES RAPIDLY AS LEVEL IS REDUCED.
- TWO PHASE MIXTURE LEVEL STILL ABOVE TOP OF CORE.

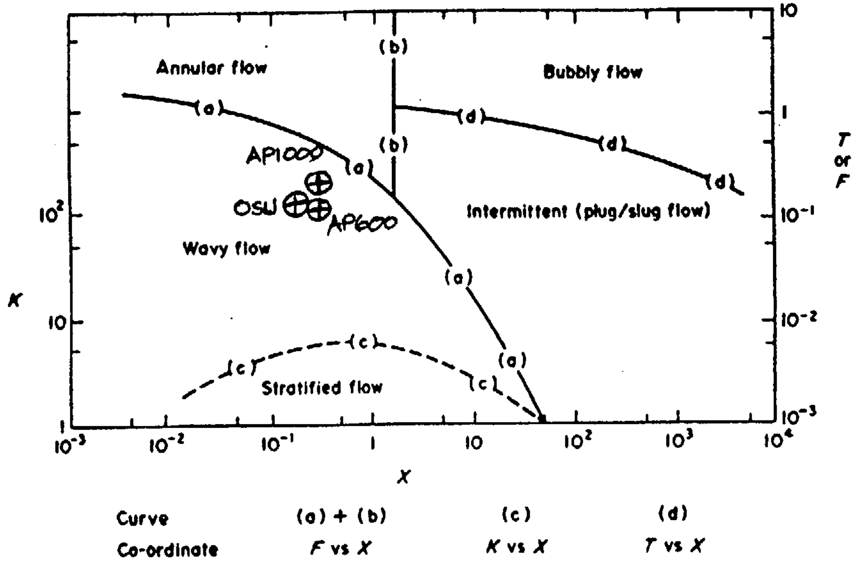


Upper Plenum Mixture Level vs. Time

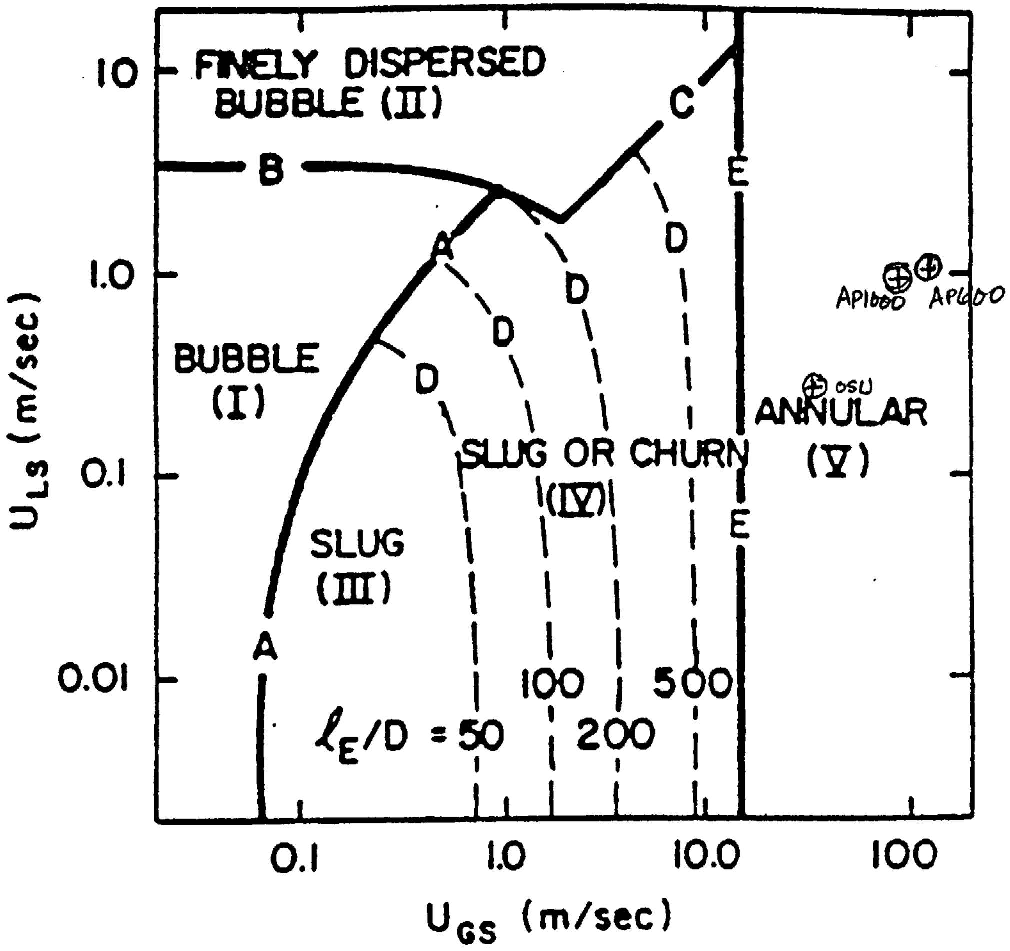
Impact of Slip on Core Exit Quality Scaling and Flow Regime during Low Pressure Two-phase Natural Circulation

- Dr. Wallis commented on flow regime in vent path and use of homogeneous model for scaling two-phase natural circulation at 3/15/01 ACRS T/H subcommittee meeting. At low pressure, such as during sump injection, slip between liquid and vapor phases is significant.
- Flow regime maps for vent path (hot leg and ADS4 piping) during sump injection phase generated.
- Separated flow model used to scale core exit quality during sump injection phase.

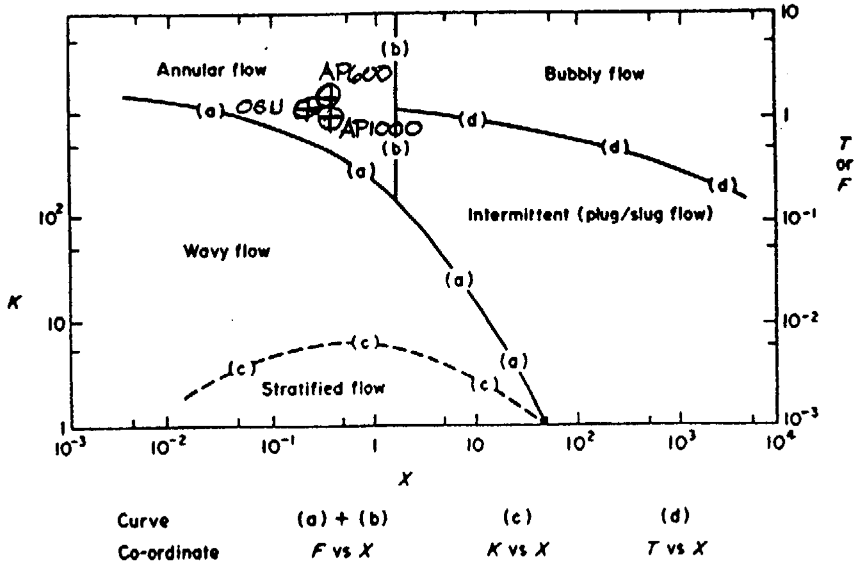
Sump Injection Phase - Hot Leg Horizontal Flow Regime Map (Taitel-Dukler)



Sump Injection Phase - ADS4 Pipe (Vertical) Vertical Flow Regime Map (Taitel-Dukler)



Sump Injection Phase - ADS4 Pipe (Horizontal) Horizontal Flow Regime Map (Taitel-Dukler)



Sump Injection Phase - Flow Regime Conclusions

- AP1000 and AP600 flow regime for hot leg and ADS4 piping well scaled in OSU test facility during Sump Injection Phase.

Sump Injection Phase Core Exit Quality Scaling

- Core exit quality scaling equation pressure drop model changed from homogeneous to separated flow model.
- Results:
  - –Core exit quality significantly higher (~50%) with separated flow pressure drop model vs. homogeneous.
  - –Scaling ratios still about the same.

Scaling Ratio	**OSU** **AP600**		**OSU** **AP1000**	
Two-phase Pressure drop model	Homogeneous	Separated	Homogeneous	Separated
$[x_{exit}]_R = (\pi_{x_e})_R$	1.19	1.15	1.08	1.11
Acceptance Criteria	$0.5 < \pi_R < 2$			

Sump Injection Phase Core Exit Quality Scaling Conclusions

- Core exit quality well scaled between OSU and AP1000. Therefore, OSU can be used for code validation during sump injection.