NUCLEAR REGULATORY COMMISSION

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

IN THE MATTER OF:

SUBCOMMITTEE MEETING

on

EMERGENCY CORE COOLING SYSTEMS

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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

Wednesday, 17 October 1979

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UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

SUBCOMMITTEE MEETING

on

EMERGENCY CORE COOLING SYSTEMS

Room 1046
1717 H Street, N. W.
Washington, D. C.

Wednesday, 17 October 1979

The ACRS Subcommittee on ECCS met, pursuant to notice, at 8:35 a.m., Dr. Milton Plesset, chairman of the subcommittee, presiding.

PRESENT:

DR. MILTON PLESSET, Chairman

MR. HAROLD ETHERINGTON, Member

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PROCEEDINGS

DR. PLESSET: The meeting will now come to order.

This is a meeting of the Advisory Committee of Reactor Safeguards' Subcommittee on Emergency Core Cooling Systems.

I'm Milton Plesset, Subcommittee Chairman.

Dr. Bates is the designated federal employee.

Other ACRS members are Harold Etherington, and we'll be joined shortly by Mr. Ebersole.

And we have consultants present, Dr. Yao, Dr. Catton, Dr. Michelson; and I believe that Mr. Zaloudek and Dr. Theofanous will join us, and Dr. Zudans, of course.

The focus of this meeting is to discuss recent calculations on small breaks by Westinghouse, Combustion Engineering, and Babcock & Wilcox. Portions of the meeting will be closed in order to discuss proprietary information, and we will leave it to the speaker to identify the appropriate time to close the meeting.

The meeting is being conducted in accordance with the provisions of the Federal Advisory Committee Act and the Government and the Sunshine Act. The rules for participation in today's meeting have been announced as part of the notice of this meeting previously published in the Federal Register on Tuesday, October 2, 1979.

A transcript of the meeting is being kept of the open portions of the meeting and will be available as stated in the Federal Register notice.

It is requested that each speaker first identify himself and speak with sufficient clarity and volume so that he can be readily heard.

We have received no written comments or requests for time to make oral statements from members of the public. So we'll proceed with the meeting.

But before going to the presentation from NRC Research, I'll see if there are any comments from subcommittee members or consultants.

As you know, there has been considerable activity with regard to procedures when one has the size of a small break, and the first bulletin put out by the Staff requested that the main coolant pumps be kept running. Then this was changed, I presume in large part due to the reaction of the Licensees, that they be kept running.

Now, this is a question which may be not easily resolved because it might be beyond the detailed capabilities of our ability to make the calculations that are required.

Also part of this problem is that the event in which you have a transient without a small break -- and there have been one or two such, and it's a question whether -- what procedure would be the optimum.

Well, the Staff has been very vigorously following this, and they're quite concerned, and it's a point of some concern to all of us to get procedures that don't complicate the life of the operators excessively.

Before we go to the meeting, let me ask if any of the other persons present would like to make a comment?

Harold?

MR. ETHERINGTON: I have nothing.

DR. PLESSET: Yes, Dr. Catton.

DR. CATTON: I would like to hear sometime during the two days three areas discussed.

The first is the adequacy of evaluation models of the EMI model for the small break.

The second I'd like to hear more about is the importance of the steam generator. I've heard conflicting views on this. On the one hand, nothing seems to matter; and on the other hand, some people seem to think the steam generator's heat characteristics are important.

Lastly, the break flow mode; I think if we have a small break in a slit in the side of the pipe, it's going to act as a steam separator, and this may lead to different conclusions when you're dealing with homogeneous flow.

I find those three areas kind of weak.

DR. PLESSET: Carl, do you want to say anything?

MR. MICHELSON: I have no questions.

DR. PLESSET: Zenon?

DR. ZUDANS: No.

DR. PLESSET: Your remark about the evaulation model I think is a very pertinent one, because I wonder if the evaluation model, as is used in this kind of problem, is truly conservative and is designed for a very large break.

There it's clear that it is very conservative, and that is one question that has been raised. Is that a conservative way to proceed, the way they do it with the evaluation model?

I presume there would be some discussion of this today and tomorrow.

DR. CATTON: In particular, the evaluation model has a requirement for goodness and badness, how well it's going to protect the peak clad temperature or zirc oxidation or something at the end point.

For a small break they're going to be making operating decisions based on their prediction of what transpires from the break to the end point. I think that's quite a bit different. You can be a lot sloppier with your analysis if all you're concerned about is one number.

DR. PLESSET: Any other comments before we go to the presentations?

(No response.)

DR. PLESSET: I'm very pleased to see such a good representation from, I would say, the cream of the Staff.

And who will organize the Staff presentations for us today?

DR. ROSZTGOCZY: Mr. Chairman, we have two sets of Staff presentations this morning. There are some presentations from the research side of the Staff, from RES; and tomorrow afternoon we are going to have presentations from the licensing side. Tomorrow afternoon is going to address some of the questions which were brought up here, and I think maybe Dr. Fabic's presentation will touch on some of this.

DR. PLESSET: Fine.

Tom, do you have any remarks you want to make?

DR. MURLEY: I don't have any remarks. I think we'll just lead in with Stan's presentation.

DR. PLESSET: We appreciate your being here, and Zoltan, also.

And so, Stan, I think we're very anxious to hear from you.

DR. FABIC: Good morning, gentlemen.

My name is Stan Fabic. I'm with the NRC Division of Reactor Safety Research.

I'd like to discuss with you some of the topics that were mentioned this morning.

(Slide.)

And the topics I will be covering are critical flow through small breaks, showing the effects of geometry, modeling issues, and influence of phase separation; flow and heat transfer in steam generators, covering some test data base, existing base, for U-tube steam generators and also for pass-through steam generators; and discussing certain stability issues during two-phase natural circulation.

DR. CATTON: Stan, could you comment on the EM model adequacy at some point.

DR. FABIC: I really wasn't prepared, but maybe we'll come to it thnrough natural circulation.

DR. CATTON: Okay.

(Slide.)

DR. FABIC: What I wanted to do is go through certain observations that come from looking at test data and comparisons that were done and calculations and then see what we have learned as far as the validity of our calculations.

I apologize if some of this sounds tutorial.

We first touch upon very short tubes -- not pipes, very short tubes. What is observed is there is a region just upstream which gives very fast-rising pressure in space, and you reach a location where pressure goes below saturation. There is therefore a region of super-heated liquid between those locations and the exit. That's the region in which vapor nucleation and growth occurs that causes choking. The larger the diameter of the opening, the longer that region, the longer tthe flowpath for that particle, for the bubble to grow and cause choking.

For very short diameter, same length tubes, there's a very short path for growth and therefore a very small chance of choking.

The same length tube, but large diameter, gives a different picture. There's a better possibility for choking there.

We also find that a very sharp entrance to the short tube will cause contracting and a smaller area of flow, while a rounder tube will give less contraction.

So the point of this part is that the diameter and length -- in this case, the short length -- and the tube entrance all play a very significant role, and thermal equilibrium is governing in this case -- thermal nonequilibrium is governing.

So here I'm stating that thermal nonequilibrium is important, that one-dimensional mechanistic analyses need to employ empirical flow coefficients to account for multi-dimensional phenomena, which are strong here.

And in lumped parameter analyses, which are used in licensing procedures, we find that Henry-Fouske and Burnell models can be used in conjunction with discharge coefficients. When tank fluid that's just upstream is subcooled or saturated liquid, we find these two models to be reasonably good.

However, an empirical discharge coefficient still has to be used for best estimate analysis, which has to be a function of diameter as well as the type of entrance. When tank fluid is two-phased mixture or vapor, Henry-Fouske and HEM models apply, although the discharge coefficients are not the same ones as in the subcooled region.

DR. PLESSET: Stan, you mentioned that these are observations. How small did they go in these experiments.

DR. FABIC: I will show some of that.

DR. PLESSET: Fine.

(Slide.)

DR. FABIC: We go next to short pipes with a length to diameter ratio between 2 and 10. Here we now see that the entrance effect and the diameter effect becomes less important, because any entrance jet reattaches to the wall, and the entrance effects are lost by the time you reach the choking point, except for very short pipes; so that L over D is on the order of 2, and L is short.

1-D mechanistic analyses give acceptable results. When I say "1-D mechanistic," I mean the type of an analysis where you're either steady state or transient, where you're solving as complete a set of conservations equations as we know today.

Okay, they give acceptable results.

Lumped parameter analyses can give acceptable results with Henry-Fouske or Burnell models for subcooled upstream conditions, and with HEM for very low subcooling of saturated upstream conditions.

However, these upstream conditions are often not adequately calculated by codes that result in a variety of discharge coefficients chosen to obtain agreement with test data. I think this is -- one of our biggest problems is -- one thing is to know how to calculate the break flow, but the other more important thing is what is the fluid condition reaching the break in the first place?

MR. ETHERINGTON: What is HEM?

DR. FABIC: Homogeneous equilibrium model; a smooth transition is needed in analysis when you switch models from subcooled.

Finally, long pipes -- by that I mean L over D, greater than 40. We find that we can do fairly well if we discretize the pipe. We also have to check for internal choke. If there is a local restriction, an orifice, or whatever in the pipe, we've got to check that we do no exceed velocities with these restrictions.

If the whole pipe is not discretized at all, but looked at as part of the break, then the pipe length has to be accounted for in the critical break flow model, like Maury did a long time ago, accounting for L over D in his model.

(Slide.)

Let me now mention a few words about orifices. These are all observations. Orifices without downstream confinement -- we are making an important distinction, whether you have an orifice at the end of a pipe or a tank or you have an orifice inside a pipe. So without downstream confinement, if you have subcooled or saturated flow, you find that a sharp edged orifice does not choke.

And a Bernoulli equation, combined with a flow contraction coefficient, adeueqatelv predicts the break flow.

Now, if the upstream fluid is nominally saturated or subcooled, again, there is the upstream region of superheat. Okay, and if that regions of superheat is long enough, you can start choking. And it becomes large enough when you have a large orifice, so the size of the orifice is as important as the size diameter of a very short tube that I first mentioned this morning.

So a small orifice, subcooled, saturated, it does not choke; a large orifice, it may choke.

DR. YAO: May I ask as question? You're talking about this upstream; is that type-dependent?

DR. FABIC: It's dependent on what the fluid condition is coming to it. If I have an infinite tank with the same tank condition for a long time, and it's not, but if the tank condition changes, then the equation changes.

DR. YAO: For a very large tank, if your orifice is very small, even the pressure, the tank pressure is very high. You never observe any choking.

DR. FABIC: I'll show you one of the graphs that shows no choking at all if it's small — if it's smaller.

DR. YAO: Thank you.

DR. FABIC: Again, if you have a larger orifice, and that upstream region is long enough so you can start growing vapor even before you get to the orifice, then there is choking, and you have to use empirical discharge coefficients.

Now, confined orifice is a strange situation that we find mainly in test facilities. In test facilities oftentimes you put an orifice in the pipe in order to model small break or whatever.

Now, what was observed, that if the fluid immediately upstream of the orifice is subcooled or saturated liquid, and the orifice is small, choking does not occur at the orifice; but downstream of the orifice, where the expanding jet coming out of the orifice reattaches to the wall, where it meets the wall, at that location observations are everything becomes homogeneous, you imagine a picture of a solid jet coming out of the orifice and expanding because of flashing. And where it reattaches to the wall at that location, if you use the HEM model, the fluid properties at that location, that predicts choking quite well.

MR. ETHERINGTON: For the interpretation of item 4 and 5, is the downstream pipe behind the relieve valve considered a confinement or not?

DR. FABIC: That would be a confinement.

DR. FABIC:

MR. ETHERINGTON: If sufficiently small to be a confinement.

DR. FABIC: That's right.

DR. ZUDANS: Where would a crack in a pipe wall fit?

DR. FABIC: Okay. I'm coming to that.

So that's as much as I wish to say about confined orifices.

Obviously, if the upstream fluid is two-phased, then whether it's confined or not, you have usual two-phased flow through an orifice. That hasn't been studied experimentally for a long time.

DR. PLESSET: Stan, let me go back to my previous question about of the range of size in connection with the orifice. Suppose you were to go from a hole of the order of a millimeter to one on the order of many centimeters, does your information cover this?

MR. ETHERINGTON:

DR. FABIC: Yes.

DR. PLESSET: And what differences do you find? You're going to give that later?

DR. FABIC: Yes.

DR. PLESSET: Okay. All right.

DR. FABIC: I will try. Let's see if I answer it.

Relief valves test data base is lacking for choke filter relief valves. Mechanistic multi-D analysis, one could use to calibrate one-D or lumped parameter models, acknowledging that there is uncertainty in that whole analysis. But theoretically, you can do that analysis. We've done it in the past, and compared it with some flow geometries that are sort of multidimensional. We have never in the past looked at flow geometries. We have a horizontal pipe with a small opening on the top of the pipe.

The effects of noncondensible gas, current mechanistic analyses adequately predict two-phased, two-component critical flow through a pipe. We have done that, and we're doing it well.

We're also predicting fairly well one-phased critical flow.

The question is: how are we going to do, when you have -- I mean, we're doing well on one component; how are we going to do when we have a one-phased two-component? Well, we haven't done that yet, although the tests are coming from the Rebecca facility. We have a steam-water mixtures of different concentrations there. We are going to receive the data. I will see how well we do.

(Slide.)

DR. PLESSET: What major pressures do they cover?

DR. FABIC: They're not high pressures. They're the kind of pressures that are encountered in containments.

DR. ZUDANS: Stan, the impacts on noncondensibles -- this is a general observation, and you can relate it to all the previous discussions?

DR. FABIC: Yes. It's a general observation, but minding the fact about the uncertainties that are covered. For geometry effects, they, of course, hold as well.

Critical flow through cracks. In order to preserve flow area and the wetted perimeter, because we are now concerned about wall friction and heat transfer, the crack can be represented by a parallel array of thick-walled tubes. You can think of it as a parallel array of thick-wall tubes. Tube length is equal to depth or thickness of the wall in which you have a crack. All right? So, for a crack of length A and an average width of the crack B, an equivalent array consist of N tubes of diameter D, and this is what you get for N and D in terms of crack sizes when you preserve the flow area and the wetted perimeter.

All right. And length of each tube equals the pipe wall thickness, L. And I give an example: if you have a crack of six inches long and the width of the crack is chosen in such a way that the total area is equal to a flow area of one-inch diameter pipe. So, you see, .13 inches width of the crack, and pipe wall thickness of 2-1/2 inches.

We find that we need something like 14 or 15 tubes of .26 inches in diameter to represent the flow that goes through that crack. And it should be noted that L over D, the length over diameter ratio for such tubes is larger; it's like 10. They're not very short tubes.

So, we feel, although we have not really had a chance to see how this theory holds together, we feel that we should have a fairly reasonable handle if you use this procedure to calculate the flow through a crack.

DR. ZUDANS: But one question immediately comes up: if it's a progressing crack, its width will vary from the edge to the middle quite significantly. And you have a variable diameter pipes stacked to each other?

DR. FABIC: I made it simple for illustration purposes. I imagine a uniform equivalent width crack. All right? So, we know it's not going to be uniform width; it's going to go from very low to some larger value, a lip shape. And I want to postulate all kinds of shapes and see what the effects are through sensitivity analysis. But just for illustration purposes of the approach that one can take.

Okay. We're not saying, "Look, we don't know what to do; we have no test data. We're open to all kinds of speculations." I don't think we are that bad.

I am saying a reasonable simulation approach could be obtained with this method.

DR. ZUDANS: Now, how can you get the same wetted perimeter with this? It works out that way?

DR. FABIC: That's right. You conserve the wetted perimeter; you conserve the flow area. You get the number of equivalent tubes and their diameter.

MR. ETHERINGTON: I would like to be clear on the meaning of something. A "parallel array of thick-walled tubes," does that mean a parallel array of tubes whose length is equal to the wall thickness?

DR. FABIC: That's correct. And when I say "thick," it's because the pipe wall is thick. So there is a lot of stored energy in there, and if your concern is some short-range effect, heat transfer effect, therefore it has to be a thick-walled tube.

But the point is that if we know, if we have some confidence, that we can calculate the critical flow through one short tube -- okay? -- of that kind of a character, then we think we know what the flow is through the crack. We've multiplied that flow rate by the number of tubes you would have to have to represent the crack and the linear flow rate.

DR. CATTON: Stan, isn't there another facet to this? The flow is parallel to the axis of the pipe, and the crack is at the surface. So, any flow through the crack —

DR. FABIC: I am sorry, no. I am talking about a crack through wall. Okay? So, that crack through wall, the access of flow is the same access as the access of flow through a pipe.

DR. CATTON: That's correct.

DR. ZUDANS: But it transfers to the flow in the pipe?

DR. CATTON: It transfers to the flow in the pipe, and some of the results from Leahy's experiments show significant separation.

DR. FABIC: Well, I will talk about separation in a minute.

I am saying, assuming you know the upstream fluid conditions, would you be able to calculate the flow through that crack? I am saying "Yes," if I can calculate the flow through the pipe.

DR. PLESSET: Ivan, when you're worrying about separation questions, are you also including boundary layer effects?

DR. CATTON: No.

DR. PLESSET: These very small-size holes, it might be important, too.

DR. CATTON: Well, that is true.

DR. FABIC: Well, that remains to be seen. But then we do have a lot of test data on very small pipes.

DR. ZUDANS: But do you have any test data on cracks?

DR. FABIC: No. What we do have is indirect information. A long time ago, Battelle Institute conducted some crack propagation tests in full-sized pipes, so they had 2-1/2 inch walled thickness, large-diameter, 2-1/2 feet or so diameter, with dumbell arrangements. There were tanks on both ends of that pipe, initial full-sized pressure and temperature. And a crack was made officially — okay? — and with a thin membrane soldered underneath, and you increase the pressure until you break the membrane, and then the flow goes on. And depending on where the initial crack length is critical or not, the consequence will be propagation of a crack or arrest of a crack.

Well, I recall following the program while I was at Westinghouse a few years ago. We tried, in fact, to model the fluid flow through that crack and tried to match the pressure-time history to see if our model of fluid flow through that crack is reasonable. And, in fact, it was modeled with the blowdown to code as a series of orifices which were opening sequentially in time to model this opening area.

I am not prepared to describe this in detail now, but this is the only data that I know of that shows pressure-time history for an opening crack; therefore, if you match the pressure-time history --

DR. ZUDANS: The pressure-time history in the vessel, did they also measure mass flow?

DR. FABIC: No. It wasn't the purpose of the experiment.

DR. ZUDANS: It's unfortunate that important things are lost because the purpose doesn't call for them. I guess it wasn't easy to measure flow rate.

DR. FABIC: It was very hard to measure the crack propagation, let alone the flow rate.

DR. ZUDANS: I heard about the Germans setting up extensive testing of large vessels, maybe a meter in diameter, with their idea to follow the crack propagation.

DR. FABIC: The same way it was done at Battelle.

DR. ZUDANS: I know that Battellle was doing the analysis, and they had protective behavior. And the Germans are testing it.

DR. FABIC: This falls into the materials problems. Crack propagation, this is the structural dynamics.

DR. ZUDANS: And that's where the crack discharge is the most significant parameter.

DR. FABIC: It determines the pressure-time history, which then determines whether you h arrest pressure or not. Okay.

(Slide.)

In summary, I really just wanted to point out that even if you don't have the data on cracks, I don't think we have nothing. We have a method, which is not completely unreasonable, to calculate the flow through cracks.

DR. ZUDANS. One more question, Stan. Hasn't anybody ever attempted to model it two-dimensionally?

DR. FABIC: Not yet. We are thinking about it.

DR. ZUDANS: It's like a thin layer, a sheet, you know.

DR. FABIC: As a matter of fact, I will tell you in a minute what we are trying to attempt two-dimensionally through the resulting question of phased separation effect -- okay? -- and maybe at that time we may do something about the crack.

DR. ZUDANS: All right.

DR. FABIC: Just brief illustrations of the effect of orifice diameter, that was raised by Dr. Plesset. Here is the mass flux. This is orifice diameter for different pressures. These were quasi-static tests. A vessel was depressurizing. As the pressure dropped from 68 to 63 atmospheres, the red curve shows how the break flow varied with orifice diamater, as I stated.

It shows that as you start increasing diameter in this range, there is a sharp drop in the flow rate. Now, I would like to point out, however, Dr. Plesset, that these orifices were confined, they were not at the end of the vessel or pipe. So, there could be some of that effect, as well.

DR. PLESSET: These results are interesting. I was interested particularly in going down to the very small ones.

DR. FABIC: I am coming to that.

DR. PLESSET: Okay.

MR. ETHERINGTON: I am not clear as to what is meant by "pressure change," there.

DR. FABIC: Okay. They have a vessel. In this particular case, there were two vessels: one full of liquid, saturated liquid, at high pressure; another one empty; and a large pipe connecting them. Okay? And there was, I think, a rupture of a valvee -- all right? -- and there was an orifice in the middle of that pipe.

Now, when you open the valve to discharge that vessel into the empty vessel -- okay? -- there was a region where -- pressure was dropping, obviously, in the first vessel -- all right? -- while you're discharging it. And in the region where the pressure was changing from the first number to the second number, they were measuring the flow rate. Okay?

That's why these two numbers are different pressures. It was a slow depressurization. So, it's a quasi-steady state.

DR. ZUDANS: The discharge was also in a closed tank for the pipe?

DR. FABIC: But large diameter. Unless the orifice size becomes close to, let's say, 70 percent or 80 percent of the pipe size, then I think confinement plays a very -- when it's that large, confinement plays a very significant role; but when it's small, confinement does not change.

DR. PLESSET: These curves have to turn over.

DR. FABIC: Excuse me?

DR. PLESSET: These curves, if I understand, have to turn over, because when the orifice is zero size, there will be no flow; so that this implies that there is a kind of peak.

DR. FABIC: I am showing what was reported by Tagami as test data. I am showing test data. I have not attempted to interpret.

DR. PLESSET: I realize it's specific flow.

DR. FABIC: Zero to zero it's indeterminate.

DR. PLESSET: It is not indeterminate if I don't have a hole. I have no flow out of it.

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DR. FABIC: This is why it doesn't go to zero diameter, either. The plot does not.

DR. PLESSET: I will tell you why I am getting at this millimeter size, two-millimeter size hole. Because there is a series of small-break tests projected at semi-scale which are going to be like two-millimeter size holes. The question in my mind is: how does this relate to anything?

DR. FABIC: I understand. Yes.

DR. PLESSET: I don't want to be mysterious.

DR. FABIC: No, you have a perfectly good question, because we will be making lots of tests and drawig important conclusions. The question is: what do we know about the flow through that orifice?

(Slide.)

Now, we have a four-millimeter; it's double the size that you were mentioning. But it's a four-millimeter hole. All right? And in all of these configurations, the size of the diameter is the same: four millimeters.

What is different is: the length of the passage; the entrance, whether it's rounded or sharp; and some downstream effect, like the 2-D situation here.

Now, you see here that 2-1/2 has a large L over D. And indeed, you look now at the test data for those situations, saturated liquid upstream condition in all

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cases. 2-F, which is this one, the plot of flow rate versus delta-P -- delta-P is the upstream minus downstream pressure -- if you are increasing delta-P and you get a plateau in the flow rate, it means you are choking.

DR. YAO: Stan, when you say the difference between upstream and downstream pressure, could you be more specific?

DR. FABIC: Yes, I will. If you know the pressure in the tank, in this case, now you can vary the downstream pressure — okay? — from as high as tank pressure, in which case you have no discharge.

DR. YAO: You're talking about ambient pressure?

DR. FABIC: Ambient or the vessel into which you are discharging. And if you start lowering it, you soon enough get to a situation where you get plateau in the flow rate. That means you're choking.

You notice that the geometry with the long passage chokes most because it gives the lowest flow rate — okay? -- and it chokes, obviously.

Now, 2-A, in red, is the sharp-edged orifice, and here you see there is no choking at all, at least in this pressure region, and there are large pressure changes and no choking.

So, I think this shows that for sharp-edged orifice, this diameter for saturated liquid entrance

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condition, no choking was observed. And you can also see the effect of roundness.

I found that particular representation very informative, and it's very informative for small breaks.

DR. ZUDANS: Here, the upstream pressure was maintained the same?

DR. FABIC: Yes, steady state upstream.

MR. ETHERINGTON: Is 1-A a convergence orifice?

DR. FABIC: No. This is a rounded corner. Okay? It has a rounded corner, rather than sharp as in 1-B.

DR. CATTON: Was the high pressure side saturated, subcooled, or what?

DR. FABIC: No, saturated. Obviously if it's subcooled, you'll have lower flow.

(Slide.)

Now, I just wish at this stage to mention briefly to you that in our matrix for verification of our existing codes, especially TRAC, we have decided to look at the tests coming from these test facilities here: Moby Dick, Super Moby Dick, BNL nozzle, IRB nozzle, and Marviken.

Thay all have different sizes and different shapes. Here some conditions are shown here in the matrix that shows there is a variation in pressures, whether you have gas or steam or mixture. We already have done calculations with Moby Dick, long pipe followed by diffuser with air boiling and steam boiling. We coupled it quite well in both cases. This was calculated not by a code developed, but by another laboratory that picked the code and did the calculation.

So the last column shows number of tests that we will consider in validation of a code from each test facility.

So I must admit that we do plan to do a thorough job in verifying our ability to calculate the break flow. I also wish to point out, however, as I previously mentioned, that there are many situations that require empiricism, and those calculations are done with one-dimensional codes that we'll have to use for a small break. We cannot afford multi-dimensional analysis, and so multi-dimensional true phenomenological effects have to be somehow accounted for empirically. If you don't, then you have to know what is the uncertainty band in your answer caused by the core choke flow alone, so we can account for that uncertainty band when we do the peak clad temperature calculations.

(Slide.)

Now just a few words about phase separation. I was really hoping that I would have the chance to show you the results of some calculations, of the dimensional calculations. But we asked the laboratory on a moment's notice. I got a notice fairly late about my presentation. So when I told them, I need some calculations, they really weren't able to finish them in time. So I don't have more than hand-waving and words to present to you.

However, I'd like to point out one thing. Tests were done at RPI and at Harvard in which you have a T, okay, a right-angle T, and the entrance condition is a homogeneous flui, air-water, homogeneous. It is found that in every case, nearly all of the vapor leaves the first leg. It reaches the off-branch, okay, and the other vapor continues on. So vapor has a propensity to turn corners very fast, given a sufficient pressure gradient.

Now, I would like to therefore suggest that if we have a case of natural circulation, pumps are off, so the flows are fairly low, one foot per second, something like that, and you're generating vapor in the core. If you have a break in the hot leg, I think there should be sufficient pressure gradient to sweep most of that vapor into that hot leg, which implies that if you're doing a homogeneous -- if you are considering that as one lump parameter, control volume, and smearing everything inside and saying that the void fraction that's there is also in the pipe, I think you'll be wrong, because there'll be a higher void fraction entering this pipe than the mean void fraction up there.

DR. CATTON: But in the core under these circumstances there is no flow, and with the experiments there's flow in the pipe.

DR. FABIC: I'm saying that, consider natural circulation, pumps are off, and look at the loops. If you just say, I have no two-phased flow, just single-phased flow, natural circulation ought to give you velocities in this leg, single-phase liquid of a foot per second, something like that, low flow.

Now, superimpose on that a break in a pipe. All I'm trying to say is that break is going to sweep the vapor from the core into that pipe, so that the void fraction into that pipe feeding the break is going to be much higher than if you did not sweep the vapor, in your calculation, into the pipe, but just homogenized everything in here and said that the void fraction entering the pipe is the same as what's in the upper plenum.

DR. YAO: Do you think that the location of the break either on the upper or lower --

DR. FABIC: Good point, yes, thank you. We think it doesn't matter.

I first wanted to make a point that there should be much higher void fraction coming into the pipe than the average. I think that's the important point.

Now, what is really going out the break is the second point, okay?

DR. CATTON: Stan, I think I would agree with your picture of the pipe, but not of the vessel. It seems to me that in th vessel velocities are very low, and that the gravity is going to cause --

DR. FABIC: No, but the point, you see, this mean average up-flow velocity, okay, of the vapor itself is going to be low, one foot per second. Okay, it's bubble rise velocity alone, if you're not providing any suction at this pipe. But if you're providing suction at this pipe, it's going to sweep the vapor right out that pipe.

DR. CATTON: But I think there's a difference. I think in the experiments there was actually a delta P that acts across the fluid.

DR. FABIC: A large delta P here.

DR. CATTON: And that sweeps the vapor. Here you don't have that.

DR. PLESSET: I think I understand Stan's point and I'm inclined to agree with it. What he is implying is that the pressure gradients that are induced by the flow, the gross flow, are really quite small compared with the very strong pressure gradient across that whole.

DR. CATTON: I agree with that.

DR. PLESSET: This is felt downstream, and I think that's kind of the idea.

DR. FABIC: That's the idea.

DR. PLESSET: And that the bubbles respond to this.

I think that sounds reasonable; don't you agree?

DR. CATTON: NO.

DR. ZUDANS: I am not in disagreement. I just want to clearly understand what is the driving power for bubbles to be swept out. Is it the pressure gradient?

DR. PLESSET: Yes, it is the pressure gradient that drives it.

MR. ETHERINGTON: Centrifugal separation, in essence, isn't it?

DR. PLESSET: Gravity is the pressure gradient.

DR. ZUDANS: Induced by the liquid that surrounds the bubble.

DR. FABIC: Yes. You're pulling this liquid stronger because of the break.

DR. ZUDANS: Why do you unmix it? That's not quite clear.

DR. FABIC: Let me go now. I first wanted to say that the entrance here, okay, will be higher void. Now let's go downstream, okay. Let's march.

The question now becomes, first of all, if this diameter is of good size and your bubble rises, gravity is trying to separate the void. If the void separates, would it stay separated? It depends on relative velocities, okay? So if the relative velocity between these two is on the order of less than ten feet per second, then they can stay separated. But as you are approaching this break, I think my just gut feeling is that they will not stay separated there. There's going to be a significant amount of entrainment obliquely, so there'll probably be some kind of vapor with lots of entrained droplets type of flow, not a homoegeneous mixture, not bubbly flow.

DR. ZUDANS: Would you not imagine in your upper picture that you really would form like vapor channels preferentially?

DR. FABIC: That's correct. I don't know, I haven't done the calculations, what the mean velocity of that liquid will be. The mean velicity will still be fairly low, okay, higher than if you had no break, but still fairly low. And the relative velocity, I've done the calculations by hand, where I assume we'd have a two-inche break and I had pure vapor going out, okay, and the pressure upstream is 1200 psi and doesn't vary in time. I considered that case, all right. Then I calculate -- and this is straight out of tables -- what is the break flow for that condition. And if I assume there's a complete separation, then I ask, what should be the depth of that liquid such that I can maintain separated flow, all right?

And I calculate that if I have about 40 percent void or depth of the liquid such that the flow area of the gas is about 40 percent, that I should be able to have a separated flow and draw all the vapor up.

I also consider how much I would be generating in some reasonable time period, how much vapor generating, how much vapor sweeping this way, how much that way and this way. And the balances come out reasonably.

DR. YAO: Stan, let me get -- ask you one more question about that. I think inside this pipe we will know that there are two forces acting on the flow and the vapor. One is the axial pressure gradient; one is the buoyancy force. Do you think that the location of your break, how far from your tank, will make a difference?

DR. FABIC: Yes, it would. What I don't know at this stage is what is the picture right at the entrance. You know, I was just sweeping a lot of bubbles more or less uniformly into this opening, okay. Or is there already some kind of a channel? If you're sweeping more or less uniformly, and if the break is closing here, then it's going to be different, but I don't know how, because I still expect there will be a lot of entrainment close to the break of liquid droplets into that break.

Right now it's all hand-waving. We don't know. So what we are proposing in order to help us understand it better is to look at a situation where we have at RPI, as I previously mentioned to you, we have a transparent slab geometry, okay. We're looking at air-water flow patterns to see if we can calculate multidimensional situations, two-dimensional. Well, it's easy in that facility to look at this case, okay.

We put a gradient here, so we have air supply at the bottom, uniform more or less on the bottom. Okay, we establish a free surface up on top open to the atmosphere, and we're going to pump some mixture out of the break, and see how do these bubbles separate. I think this is one of the important features: How do we calculate the void fraction entering the broken pipe. That's a very important feature. We know we can't afford doing it multidimensionally. We don't know how to fix that type of simulation in a one-dimensional or one parameter code, and we have to learn how to do it. But that's what the first thing was to look at.

DR. ZUDANS: This would be, then, with the noncondensible gas?

DR. FABIC: Exactly. We are now concerned, and why? Because we expect that this is going to be saturated liquid, okay? The whole condition is saturation, so the phase change should not play a major role in the tank, nor even in the pipe, until you get to the causes and so on.

DR. ZUDANS: On these tests, could you simulate the upper picture?

DR. FABIC: I have not thought about it, whether we'll go further in here to simulate the break. I don't know yet. It depends on how much pressure we can put in here. If we can't apply enough pressure to get choking, then we can't do it.

DR. CATTON: Shouldn't you also close that to the atmosphere and watch the rate build up to the bubble, so that you can get the distribution of the flow?

DR. FABIC: Here, close it to the atmosphere? Yeah. Unless my discharge in here exactly matches, I'd have a hard time.

DR. CATTON: But then you're going to have that free surface is going to be moving down.

DR. FABIC: Yes, it will be moving down.

DR. CATTON: And you're going to get a split and find out how much goes where and whether you feed the bubble at the top or you feed the break with the vapor or the air. I think that's the question I have about the one above.

DR. FABIC: I think we have to examine, you know, what kinds of conditions that we think might take place in the vessel, examine and visualize what's going on into the pipe to see if we can do it.

DR. CATTON: Because there's not a hole in the top of the vessel.

DR. FABIC: I understand, but I wanted to maintain some pressure in here. That's why I opened it to the atmosphere.

DR. CATTON: If you close it, you're going to be more representative of your picture above.

DR. FABIC: But the pressure is maintained constantly in the picture above because of the flashing process, I mean, vapor generation, which is trying to keep the pressure while I'm losing the flow through the break.

DR. CATTON: It's acting like a bubble pump. The question is, where are the bubbles going? Are they just going to feed the air space above or are they going to feed the break or where? If you close the top, you'll get some of those answers, I think.

DR. FABIC: Thank you. We'll consider putting a valve there.

DR. PLESSET: I think you're ultimately interested in steam, not air.

DR. CATTON: That's true, but you want to know where it goes.

DR. PLESSET: They may be different.

DR. ZUDANS: They would be different.

DR. CATTON: That's another complication.

DR. FABIC: Actually, the difference would be -- isn't it right, Dr. Plesset -- the pressure effects can make a strong difference. If this is done at low pressure, the bubbles are a different size. At high pressure, the bubbles are a different size again.

DR. ROSZTOCZY: Mr. Chairman, I just have a brief question. Stan mentioned that some future testing -- the actual geometry of the upper plenum is not that free volume. There are many structures coming in there. In the RPI tests, are they going to get to this?

DR. FABIC: I'm glad you mentioned it. Thank you for mentioning it, because I really should have shown this first.

(Slide.)

This is our present test configuration at RPI, where we have -- for example, we can inject liquid up on top, drain it through the bottom, inject an air-liquid mixture and vent it out here. We get some multimensional flow pattern, to see if we can predict with and without rods. These rods represent internal structure in the core or in the upper plenum. So this same experiment we will do with and without rods.

Thank you.

DR. ZUDANS: But if you look at that picture, Stan, how are you going to make a representation of what you showed in the previous slide?

DR. FABIC: Oh, we have to change this. In fact, we have two vessels. This one is three by three feet. We have one already one by three feet that we are abandoning in lieu of this, and that one by three feet is really -- we can represent the geometry of the upper plenum better and modify the nozzles

I'd like to switch gears now, if I may --

(Slide.)

-- and start discussing steam generators. Now, first, what test data base do we have available? Well, the Flecht-Seaset program has completed 20 steam generator tests. In those tests the emphasis goes to the secondary to primary side heat transfer. The secondary side was all liquid, either covering the tubes or partially covering the tubes. These were the boundary conditions on the secon v side.

On the primary side, there was a two-phased mixture entering the plenum of different void fraction. That was the parameter. The test parameters are shown here. Briefly, what the temperature and pressure parameters were for the one on the secondary side and the quality variations on the primary side --

The typical result that I wish to point out --

(Slide.)

-- may look something like this. If you unwrap this U-tube and look at the temperature distribution along the tube on the outside on the secondary side, you originally have a time zero uniform temperature in this vessel. But as you start flow of two-phased mixture, then neither tube sheet is here and here, you see, cooling. So at this time, for example, in the typical test it was this kind of a temperature profile on the secondary side.

The temperature profile varied with time on the secondary side and that you can't avoid.

DR. ZUDANS: This is temperature on the secondary side. Why is it so low on the primary side inlet, then?

DR. FABIC: I didn't show primary side inlet.

DR. ZUDANS: But you showed unwrapped the whole length.

DR. FABIC: This is all on the secondary side. There are two curves, one times zero and one times 1500 seconds, all on the secondary side.

DR. ZUDANS: However, one end is at the primary side entrance; the other is at the exit, isn't that so?

DR. FABIC: Correct.

DR. ZUDANS: Why is the entrance temperature so low?

DR. FABIC: It is higher than the primary side temperature, but it's cooled by the primary.

DR. ZUDANS: Oh, it's cooled by the primary, not heated.

DR. FABIC: This is a case where the secondary side temperature is higher than the primary, as would be encountered during reflood, okay, large break reflood, steam binding problem. This was really the situation that was being examined.

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DR. ZUDANS: Okay.

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DR. YAO: Why does the temperature drop in the neighborhood of the exit?

DR. FABIC: Why does it drop? Because you see the tube sheet, it's freely communicating on both sides. So you're cooling -- the cold liquid is diffusing radially, uniformly.

And one other explanation, I think, is stability. You know, the hot liquid wants to rise and the cold liquid wants to drop.

So the cold liquid would distribute itself along the tube sheet.

(Slide.)

Now a snapshot -- here is at a given elevation what the temperature time histories look like on the secondary side of the tube itself and on the steam water vapor mixture on the primary side.

It shows how they vary at a given elevation as a function of time. I think this is extremely valuable data to verify our ability to calculate steam generator behavior, at least for that kind of condition.

(Slide.)

There have been 20 tests. The next with the once-through steam generator tests at B&W, I have shown only two facilities -- the 37 tube unit, the 19 tube unit, and a 7 tube unit. There were three.

The 37 tube unit had the full height and had all other parts of the steam generator represented, simulated properly. Okay?

So everything is linear except for, naturally, the radial extent because you have 37 tubes. But it does have an aspirator region, it does have a downcomer region in the actual apparatus.

This 19 unit is simpler and easier to measure because the downcomer is not enclosed; it's separate. The downcomer is separate and the bundle itself, 19 tube, full height, full pressure, right temperatures. That's very important.

They're all there.

Now these were proprietary tests, but we do hope that being of significance to reactor safety, that we will have access, in fact, have all the information that we need to see how well we calculated.

DR. ZUDANS: One question to the previous slide. You don't have to put it up.

You said that you had 32 tubes. Were they baffles?

DR. FABIC: Baffles, yes. I'm not showing so much detail on the original drawing, but all the grades, all the baffles are exactly as in full scale. And the important thing is when they obtain the data, for example, on where is the boiling length on the secondary side, I'll show you what they tested in a minute, that the different number of tube units gave the same results.

So the number of tubes didn't make that much difference.

DR. ZUDANS: Although, in the real steam generator, the U-tube steam generator, the cross-flow is much longer than in this model.

I'm talking about the other one.

DR. FABIC: The other one is a different story. I'll come back to that.

(Slide.)

Now a typical plot of result comes from the 19-tube unit, and that's one that we took most of the measurements from on general hydraulics.

You see that the primary fluid is entering up on top, as you recall, primary fluid entering on top, exiting on the bottom, while the feedwater is coming in on the side.

Well, primary fluid temperature, as a function of height along this tube varies like so. Okay, that's a profile -- steady state flow situation.

While the secondary fluid temperature looks like so, it shows that there is a departure, DMB occurring on the secondary side at about that elevation.

Now there are a lot of test data there, too, that are extremely valuable.

DR. ZUDANS: What's the reason for that break point in primary? What change takes place at that point?

DR. FABIC: That's a good question. What's the reason there?

Well, the pressure is uniform. There must be a regime. I'm not sure whether that's true. Actually, I read somewhere that the water coming at the bottom tube was not sub-cooled at all, that the aspirator section insured that you had saturated feedwater conditions coming through the bottom bundle. And if so, and if the boiling starts right away somewhere, okay, then I don't understand --

DR. ZUDANS: Is that where the liquid is fed in?

DR. FABIC: No, this is along the bundle. Okay? And in fact, this geometry right here, all right, where you're feeding the feedwater, cold feedwater which is mixing with the steam coming from here on the secondary side, insuring that by the time that feedwater gets here, it's already saturated.

And now you have saturated water rising on the secondary side.

DR. ZUDANS: And some place 17 feet from the bottom some change takes place.

DR. FABIC: Something happens to the heat transfer on the primary side, which is very interesting, okay? Now B&W claims that there are fairly simple analog models that are able to get those.

DR. ZUDANS: Then they should know why.

DR. FABIC: So they should know why. I haven't seen the calculation. I don't know.

DR. CATTON: If you suddenly increase the heat transfer coefficient on your secondary side --

DR. FABIC: But why suddenly at that location is the question?

DR. PLESSET: I don't think that he'd better try to explain that now. I think we're running a little behind, anyway.

DR. FABIC: I was trying to illustrate that there is data available, right pressures, full height, that in this case pertain to heat transfer and flow on the secondary side, okay.

It was all water on the primary, bear this in mind. This is not a condition that you might see in an accident where the primary fluid is not all water. I'll come to that later.

(Slide.)

They also did a number of transient tests on the 37-tube unit that covered blackout transient, steam pipe failure, loss of station power, loss of feedwater flow, primary rupture tests with different orifice sizes.

These are all very interesting and they'll be very informative to see if we can calculate these.

I will skip the picture that shows what the transient test data looked like because you'll probably ask for a lot of explanations and I don't know the answer to it.

(Slide.)

Okay, other steam-generator related tests. There are other ongoing or in the planning stage. Her I'm not making a statement but more or less posing a question, and I'd like to see your thinking on it.

The topic is levels well and trainment and heat transfer on the secondary side.

And we know what that is in the B&W test that's measured. Except for metal swell, there's no visualization. We really don't know how far the performance extends in all temperatures.

The important thing is temperatures. But if somebody says, gee, we might be getting right temperatures but for the wrong reason. What is the level swell? The question is: Now should we conduct tests where you have transparencies on the outside so you can see what the level swell is at the expense of the right pressure?

Okay? Or should we look, see other information from which you can learn about the model in the level swell.

Here's the suggestion that for partially submerged tube bundles to verify analytical models, it may be possible to utilize results from fuel bundle boil-off tests like done at Westinghouse and other places.

Okay, the national laboratories, where we are boiling off water that is whatever the initial location is in the fuel bundle. We will then see what the level sweel is and what the entrainment is.

These are the two questions that we want to know if we are modelling these right. Of course, there's a Flecht low rate bottom flooding test also giving useful information on this aspect.

Now for a fully submerged bundle where you don't have the level to worry about, just the heat transfer from primary to secondary, the point here is that I can have an electric simulator and know what heat I'm giving without having to know what the fluid condition is inside the tube and what, therefore, heat transfer is.

This is, in effect, better because you know the boundary conditions.

So for fully submerged bundles, THTF tests should be okay. Now when you have a situation of feedwater sprayed on the bundle from the top, as in auxiliary feed in the OTSG, that is very similar to BWR Flecht tests, where you're spraying water on the bundle from the top.

We can learn from those results.

Now when we go into condensation-induced hydraulics and heat transfer within the primary side, so far I've never touched upon these. We didn't have test data to show you. However, we do plan to modify or enlarge the scope of the Flecht Seaset tests and to look on the secondary side, which will now be at the lower temperature on the primary side so that we get condensation.

We'll have tubes either fully emerged or partially immersed. These are separate effects on steam generator. All right? And on the primary side, we can have either dry steam in-flow to see how it condenses, or two-phase in-flow at low and high rates because those conditions are expected to occur.

During natural circulation, for example, small break and the effects of non-condensable gas.

So the point is that I think we ought to be reasonably well covered so far on the heat transfer and hydraulics in stable flow conditions.

MR. MICHELSON: Before you go on from that, on the last slide at the bottom you pointed out the various conditions of heat transfer.

One possible condition is also the reflux.

DR. FABIC: That is being covered. For example, let's assume on the secondary side I've got some liquid level or fully submerged.

The primary side, if I have pure steam coming in and condensing, that's the first case. Or if I have a two-phase mixture coming in and condensing, that's the second case.

MR. MICHELSON: The condensate is counter-current to the flow of the steam.

DR. FABIC: That's right.

MR. MICHELSON: Okay.

DR. FABIC: I think you're touching upon a problem that some research -- in effect, Professor Griffith feels a potential exists for this effect and how important it is for a condition when you have a very large number of tubes is open to debate.

(Slide.)

But his reasoning is along those lines. If you have two-phase natural circulation, okay, he postulates that instabilities could occur in the U-tube steam generator.

Let's look first at the time where pure steam is coming in the primary side and it's condensing along the tubes. And you start to accumulate the liquid lavel on the downflow pipe. Okay?

Now as this continues in time, take note that these tubes are not of equal height. Okay? There could be quite a significant difference in height here.

Now if you fill up the shortest one in this process and you start to spill over, you get a siphon effect and in fact, this one is going to drain out this way and pull some of the fluid of the adjacent pumps so that this flow will be enhanced in the adjacent pumps while you're siphoning a shorter pumps.

As this flow becomes large enough so that the vapor can reach all the way down into this plenum, you break the siphon and then you go back to your original position.

That is explained in this graph. You start off -- this is P1 minus P2. You have a high steam velocity going through a tube, okay? Now at some lower steam velocities you can start gathering liquid up here, right? This is the location where the water column forms.

As the water column rises, okay, less and less steam flow until you get to this siphon position.

Now you have an unstable position because you're on this unstable shape, unstable portion of the DP versus flow curve, which means that you're going to jump somewhere here into the unstable again.

That's really the phenomenological sequence that he postulates could take place, which could, if it's really important when you have a large number of tubes, it would change the results of the analysis.

I mean if we analyzed all the tubes being uniform, we may be wrong with the analysis. We don't really know how important this is. We think we'd like to understand it and we are seriously looking at this proposal where he has four tubes, okay, of different lengths all hooked to the same plenum and they're all transparent so that you can see what's happening in there.

And on the secondary side, the secondary side is a coolant, again transparent. The primary side is the fluid steam in this case. We're not sure whether we shouldn't also be doing it with freon so that we can get a pressure effect.

DR. ZUDANS: A question. The model seems fine, but what's the mechanism to get this P1 minus P2 to be negative? How does it get negative?

DR. FABIC: Okay, good. If you start -- if you increase the density in here -- I mean if you start spilling over --

DR. ZUDANS: Well, to spill over you have to have negative. So what generated that negative pressure before it spilled over?

DR. FABIC: The rise in the level here until it spilled over.

DR. ZUDANS: As long as you show that arrow on the first picture going down in that pipe, the P1 cannot be smaller than P2.

DR. FABIC: You will agree that the P2 is rising as the liquid level is rising.

DR. ZUDANS: But it still should not be more than P1 or else you would have to reverse the entire flow.

DR. FABIC: Oh, no. Condensation is sucking the vapor.

DR. ZUDANS: Ah hah, the mechanism is condensation. But the condensation would have to be on the left-hand side of this U-tube.

DR. FABIC: The question is now, you know, which one is more. These are postulations. We don't know whether this really can in reality take place.

Some knowledgeable people postulate that it could. It may be worthwhile to see if it is.

DR. ZUDANS: I don't disagree with that point. I just don't see how physically it is possible.

DR. FABIC: Condensation is going to take place everwhere along the whole path, which decreases the pressure. I think that pressure decrease is going to be felt uniformly in the tube. The pressure decrease by condensation is going to be uniformly felt in this whole gas space.

And now the liquid level is going to play a major role on the Delta P.

DR. ZUDANS: There is also another factor if you do the test -- those U-tubes are very, very long, not very short.

So instability in a short U has no relation to the full size.

DR. FABIC: Yes, yes, you're right.

MR. MICHELSON: One more question on that same slide.

P2 is at least potentially controlled by external conditions beyond the particular picture you drew since that's the return of the loop.

That may way overshadow what you're talking about and the steam generator.

DR. FABIC: For example, I think just to amplify on your statement, if there is no liquid-filled coldleg piping downstream of that, you can't fill up the tube.

So you have to say, is the situation such that you have a liquid fill? And that leads to this picture.

(Slide.)

That's, again, a proposal from MIT to hook up that steam generator unit, okay, to a very simple transparent loop in which you're generating vapor in here and see what natural circulation does.

What is the liquid in here? Can you fill this up? Can you get into this postulated flow?

Obviously, it will be at a lower pressure. But it might be possible to use freon to get a higher pressure.

These are proposals we have to obviously carefully consider because the universities usually take time to get the job done.

And we have to see whether it's a good investment and so on.

DR. CATTON: Stan, have you considered the reflux mode on the rise side of the U2, on the inlet side?

DR. FABIC: If this is all vapor-filled, right, the upper plenum is vapor-filled, at least in this region. So you're feeding the water in here. It doesn't even have to be. You can separate the water.

If the vapor is coming, when you make a statement about the reflux mode, I'd like to be clear what you have in mind.

Are you talking about a case where vapor, pure vapor is coming in here and it's condensing, okay, and providing a head of liquid to drive the natural circulation?

DR. CATTON: No. When the vapor is rising in the tube, condensing and the condensate is flowing back through the tube.

DR. FABIC: Some of it will be flowing back. Whether it will be flowing back or not depends on the vapor velocity which is driven by condensation.

DR. CATTON: That's right.

DR. FABIC: So if the velocity is high, you'll pick up the liquid and carry it with you. If the velocity is low, it can drain down into this part.

DR. CATTON: I guess that this would change the sequence of events during a transient, wouldn't it, whether it goes over?

DR. FABIC: Actually, no, I'm not sure.

We expect that a good part would go over, okay? And any water that is accumulating here, what will affect the condensation rate in there, if you have water accumulation and water film is running down, the condensation will be lower.

So, therefore, this side of the tube will get more condensation.

DR. CATTON: That's right.

DR. FABIC: So it's a complicated picture. We have test data without visualization. We'd like to see what are the flow regimes, what is the correct modeling.

I've seen some analysis done by our own lab as well as the vendors where, for example, they would use a drift flux model.

Mind you, when they say a drift flux model, I would like to make clear that it's not a drift flux model that Zuber advocated because what he, Ishi, and others mean by drift flux model means that the term is in the drift flux equation as well.

Now in the calculations that are done at several places, that's not the case. The drift term is only in the energy equation.

That means that the pressure changes do not account for the slip, and pressure changes are important to drive natural circulation.

So now let's look at the case where they find using the drift or slip, they find that, as they should, for the full current upflow, you are going to have a lesser void fraction in the tube than for full current downflow.

This is well know.

What is then done if you have one control, somehow that bubble rise model, that separates the fluid. So if you get a level of fluid here, vapor here, and a lower level of fluid here, and then based on what fraction of the tube is covered by liquid and what fraction is covered by vapor, they account for heat transfer.

That may be quite wrong, okay?

Not only that, but the head calculated, the driving head is going to be wrong. The question is is it possible that this downflow is designed, in which case it's a completely different picture. We really don't know at this stage and we'd like to do some visualization tests to learn more about it.

DR. ZUDANS: Would it be expected that you could produce instabilities in natural circulation, a model like this?

DR. FABIC: I showed one by the steam generators. You mean by the whole loop?

DR. ZUDANS: This particular one that you showed, the semi-T.

DR. FABIC: They speculate on instabilities inside the steam generator as to which tube works in what way, which affects the total heat transfer in the steam generator.

DR. ZUDANS: It wouldn't be really the heat transfer changes from place to place that would be the driving force.

DR. FABIC: That's a good question. I really don't know the answer to that because I think that we would be really wasting a lot of time and raising nitpicking questions if the overall effect is negligible and insignificant, you know, whether this tube goes this way and this tube goes that way.

And the overall heat transfer or mass transfer of the steam generator is not affected, and we just go into a long debate about the affairs, which may not be important at all.

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We'd like to understand it okay, but we also want to find out what is the significance of it.

DR. ZUDANS: Right. Now if we think in terms of actual steam generators in power plants as they are installed today, is there any information that the owners would have that would, in fact, indicate whether or not they had instabilities during the operation.

They are operated in many different regimes.

DR. PLESSET: I don't know that that would bear on the problem that's of concern here.

As I gather, you're interested in natural circulation.

DR. FABIC: Yes. And I don't think —

DR. PLESSET: That's a different regime, quite different. And I think we've got to think of what the physical driving mechanism is.

DR. ZUDANS: I understand.

DR. PLESSET: You have one reservoir which is at one temperature and has a corresponding pressure, vapor pressure. This is vapor evaporation condensation phenomenon and we have another reservoir of liquid at a lower temperature and you have a lower vapor pressure.

It's that difference which really drives the vapor flow. And I'm concerned about not modelling this liquid vapor relationship; that is, the pressure of the liquid at the two different temperatures and what is driving this vapor

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transport. And I think that one has to worry if you do experiments that get this more or less correct. And I'm not so worried -- I'm going to make a prophesy that that's dangerous. And in a U-tube steam generator with a lot of tubes, you won't have significant instability.

Now that's a cheap suggestion.

DR. FABIC: A lot of people feel that way, you know.

DR. PLESSET: That's a cheap suggestion. It's just my feeling, keeping in mind what is fundamentally the mechanism that drives them.

Now you might get some of this when you have just a couple of tubes and you get some monometer effects varying between one tube and another one and so on.

But you get a lot of them.

I think that you're not going to have significant instability. But presumably, you'll get some information about this.

DR. ZUDANS: Mr. Chairman, I do not disagree with anything you said, or whatever was said before. I tried in my simple-minded way to point out the best test facility for this experiment is the actual power plant.

It is not a dangerous test.

DR. FABIC: Two-phase natural circulation?

DR. ZUDANS: I don't know, whatever.

DR. CATTON: You don't want to drive it with the core.

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DR. ZUDANS: Why not? It's being driven now in Three Mile Island.

DR. PLESSET: They have other concerns than supplying us with some measurements.

DR. FABIC: I'd like to point out, Mr. Chairman, a similar instability not of the same type, but an instability caused by difference in tube length was also postulated and measured by MIT in their 4-pipe rig, the U-tube steam generator rig, and only 4 tubes.

DR. PLESSET: I'm not too surprised at that, Stan, but I can't guarantee it.

DR. FABIC: When the Flecht-Seaset tests were done with many more tubes, okay, we have not seen in the report an observation of fluctuation, okay.

That doesn't mean that it doesn't exist. Maybe people really haven't taken a good look at the data. We will. But at least, superficially, it wasn't observed, although it was postulated and measured in a 4-tube rig.

DR. PLESSET: Is there something — we're running a little late.

DR. CATTON: I just want to know how important is the steam generator to the small break analysis, and I haven't heard that.

DR. FABIC: It wasn't on the menu for me.

DR. CATTON: Am I going to be way off on any

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conclusions I might reach as a result of my analysis.

DR. FABIC: If you have break sizes such that you cannot remove the energy through the break and through HPR and you have to rely on the steam generator for removal of your energy, I think the answer is yes, it's important to know it and know it well.

DR. CATTON: In this particular reflux mode, I think as Professor Plesset indicated, it's really acting like a heat pipe. But an inefficient heat pipe can still be a damn good heat transfer device. And I think these instabilities are just going to maybe make it a little less efficient.

DR. FABIC: You're right, yes. But it could be still prevalently enough heat removal.

Now you might ask, what if I have two steam generators totally in a plant and one of them isn't working. Okay? For whatever reason, okay? Or I have a number of steam tube ruptures, or whatever.

Well, then you start asking the question, have I got enough and how much change in efficiency of removal have I got?

I think you can't generalize completely. There could be situations where you don't have all the steam generator units.

DR. CATTON: How accurately do I have to know the heat transfer, I guess is really what I'm getting at?

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DR. FABIC: I don't have a quantitative answer for you. All I say qualitatively is that if you have to rely on heat removal in the steam generator, then I think you have to also know what is the sensitivity of modelling there?

In other words, if I'm crude and conservative and crude and best estimate, what is the change, okay?

That answer we really don't know. If I knew that, then I could tell you, yeah, I can be sloppy or no, I can't be sloppy.

We have not done the uncertainty study of the calculations for this kind of operation of the plant, natural circulation, what is the effect.

We have not done that yet.

DR. CATTON: And shouldn't the sensitivity study be done before an extensive program is initiated?

DR. FABIC: The only problem is that we first have to have calculational tools that we think it's worthwhile making the study with.

DR. CATTON: Okay.

DR. FABIC: I think we hope to have that situation reached in March.

DR. PLESSET: There's one comment, if you'll make it a final one.

MR. ETHERINGTON: I just wanted to say that I agree with Ivan's comment that the true reflux mode is a good heat

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transfer mode. It's also a perfect mechanism for separating non-condensables.

Just a comment.

DR. FABIC: Yes. Just a very brief comment on the last viewgraph.

(Slide.)

To show that there are not only separate effects facilities, but all these integral facilities that have steam generators of the right height and the right number of tubes. And they will be running small break tests. And we will be making comparisons with the indicated number of test conditions with our codes as part of the tests.

That's all, Mr. Chairman.

DR. PLESSET: Thank you, Stan. I think your presentation was very responsive to the questions that we had, and I think that overall, the group is very pleased and impressed with your planning here.

I think, if there's no more, really, serious comment, that we'll take a 10-minute break at this time.

(Brief recess.)

DR. PLESSET: We'll reconvene and we'll have a review of the Westinghouse small break calculations. Mr. Esposito, are you going to be directing the procedure?

MR. ESPOSITO: Yes, I will, Mr. Chairman. Thank you, Mr. Chairman. My name is Vincent Esposito, manager of

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safeguards engineering for Westinghouse Electric Corporation.

This morning we'd like to present the results of a number of studies which have been performed in response to various I&E bulletins issued during about the last six months and to discuss some studies that we've also performed as the result of questions and concerns that have been raised at previous ACRS hearings.

We will present the information that we have to date on those particular items.

(Slide.)

The agenda which we have put together for today's discussion is on this slide and I have copies of it for the committee. The first discussion will be a summary of the small break study that we performed back in June of this year based upon a number of questions that were generated by the staff.

This is known as WCAP-9600. It's that three-volume tome which many of you have copies of.

We will also discuss the summary of our latest calculations regarding reactor coolant pump behavior. This was documented in WCAP-9584.

This part of the presentation we'll talk about the reactor coolant model and the effect of delaying the trip, the reactor coolant pump trip, the effect on both small breaks and non-LOCA events.

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In this particular part of the discussion, we will not discuss any of our proprietary information. If it does arise, we'll put that later in the section.

The third part of the presentation will be the summary of the procedural aspects; namely, the guidelines that have been generated by Westinghouse, along with the Westinghouse owners' group.

We'd like to discuss here the philosophy that was used in generating these guidelines, the process that evolved, how we did it, and finally, some of the criteria and operating instructions which have come out of that.

The final major discussion under item 4, we would like to be proprietary and it will be a discussion of our small break model and natural circulation studies. We will specifically look at the break flow models that we've used, UHI considerations we've come up with a number of times, some work that we have done based on concerns that have come up from various ACRS consultants on natural circulation, and some hydraulic work that we have been working on to respond to some of those concerns.

The final agenda item is the work that we presently have in progress and some idea of the completion dates for those activities.

Those are the really four major items that we wish to cover for discussing the summary of the small break study, WCAP-9600.

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Mr. Muench is going to present that for Westinghouse.

MR. MUENCH: Good morning. My name is Rick Muench. I'm the manager of safeguards analysis for Westinghouse Electric Corporation.

One of the agenda items, Mr. Chairman, which the ACRS has requested was to discuss the various results of calculations performed in response to all the various bulletins that have been issued by the staff.

There have been many, many calculations performed, many, many studies, many, many scenarios looked at.

So what we thought we would do is to give you a brief summary of the more early type studies and give technically more detailed presentations on some of the more recent, more pertinent studies.

So my purpose here is to give you a whirlwind tour through a lot of the early studies, including WCAP-9600.

As I go through this, I'd like to put the studies in the context of what was going on at the time in order for you to get the full flavor of why the studies were being performed. Therefore, there will be a little bit of a mix of a chronology, plus a summary of what calculations were performed and what the results of those calculations were.

(Slide.)

After the event at Three Mile Island, we spent a considerable amount of effort in the recovery, support, and analysis area, where a lot of our thermo-hydraulic transient analysis experts were devoting a lot of their time, actually to assist GPU and Met Ed in the recovery process at Three Mile Island.

However, at the same time, we had a parallel study going on to review the impact of Three Mile Island on Westinghouse NSSS.

One of the results of that study came very early and was the reminder to our customers, with coincident SI logic, to manually trip SI injection on low pressurizer pressure only.

The first couple weeks, the week that this occurred, that this thought process was going along -- by the way, there was a meeting with the customers at that time in Pittsburgh to review all the TMI-type impacts.

We were performing several type analyses to understand, number one, whether manual action, whether it was time for manual actuation of safety injection.

One of the things we did was we started to reanalyze pressure vapor space breaks. For example, one of the things we did was we looked at up to three power-operated relief valves being opened in the vapor space of the pressurizer and we assumed that the operator did not and, of course, safety injection at that time for some of the plants would not have automatically been initiated -- we assumed that we did not get any safety injection. We assumed that we got minimal aux feedwater and we assumed that the initiating event was the spurious opening, if you would, of three PORVs and showed that there were 30 minutes before the fluid level in the system -- the mixture level in the system -- would be approaching the top of the core.

The one delta we made from that was then to assume that we had minimum safeguards. We just allowed ourselves to have one high pressure injection pump. And with the assumption of one high pressure injection pump, we were able to show that there was no core uncovery, in fact, for an opening of up to three PORVs.

I point out that we thought at the time the most limiting way to do these studies was to go ahead and assume that these PORVs were open from time one, from time zero rather than a more mechanist approach of letting the steam generator dry out and having the valves pop open and sticking open.

So we were looking at limiting-type analyses at this time.

But we also did look at the sensitivity of aux feedwater, having aux feedwater for various breaks. And we also confirmed that the pressurizer level will increase my analysis. We verified that the pressurizer level would, in fact, increase with one or more PORVs being open.

At the time we were doing these studies for typical 2, 3, and 4 loop plants, and we were doing UHI calculations for some of these things.

We followed up this verbal discussion with the customers with a manual SI on the 10th of April and met with the staff on small break analyses and small break transients on Westinghouse NSSS on April 11th.

As you know, on the 11th, Bulletin 79-05 was issued, which also called for manual SI on plants with coincident logic.

On the 14th, a new bulletin was issued, 79-06-A, which talked about tripping the levels on safety injections so that you would automatically get safety injection upon reaching low pressure set points.

But in terms of analysis, what was important, I think, in 79-06-A was the discussion on reactor coolant pump operation, where it was suggested that one or more reactor coolant pumps be left on following the small LOCA.

We started doing analyses and the analyses that we did, by the time we submitted our answer to 79-06-A, indicated that there was a need for further study of reactor coolant pump operation following a small LOCA before any conclusions should be drawn.

However, and this was the conclusion that was drawn after a series of high level meetings on this issue, we knew that our safety analysis report basically covered the situation with reactor coolant pumps off, and we knew that you could not possibly make a small break worse as long as the pressure was above 1250 psia, plus instrument uncertainties which varied from plant to plant.

So our response at that time was to manually trip all reactor coolant pumps upon reactor coolant system pressure reaching 1250 psia, plus instrument uncertainties.

We also at this time started to do the analysis of the TMI type scenario on the Westinghouse NSSS, where we did, in fact, start off with a loss of all feedwater, assumed that no aux feedwater was available, let the steam generator dry out, and were able to show that we had about an hour before we would run into trouble with uncovering the top of the core.

On April 23rd and 26th, we had further meetings with the staff on our small break models. It's interesting to point out, I think, that at that time, the staff organization was such that -- I'm not sure what the correct terminology is, but there was a task force on Westinghouse plants which was made up of a cross-section of various organizations in the staff, and there were a lot of people, I think, that were not up to speed, really, and understandably so, with small breaks and small break analyses.

So we just spent a lot of time, I think, up to here talking with those people.

I think it's interesting to point out --

DR. ZUDANS: One question, if I may. Just the nomenclature.

On your Item 47, manually tripped SI, does it mean make it function or take it up?

MR. MUENCH: It means turn it on.

DR. ZUDANS: Turn it on.

MR. MUENCH: Yes. I figured when you say "trip," somehow in my mind I feel you take it off.

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It meant actuate. Okay.

(Slide.)

We also started performing another type of analysis which is similar to Three Mile Island, except for the fact that we allow the PORVs to function as designed. That is, they would open at 2350 plus or minus the various set points of those valves, and then cycle relief pressure that would close back up and cycle.

Basically, you would stay at 2350. This was at the request of the staff, who did point out, quite correctly, that even if the operator did know what was going on and started safety injection, if he were to sit there at 2350, safety injection would be very insignificant compared to what was going on in the system.

So, again, we checked out operator response time where we were headed, and actually never had a chance to finish the study, was what could it do, like eventually get aux feedwater or something like that.

We also started doing evaluation of non-condensables in a simplistic heat calculation.

DR. PLESSET: Let me understand that point. Supposing that you have a small break, or are you? This is just for the PORV?

MR. MUENCH: The initiating event would be a loss of all feedwater leading to the opening of the PORV.

DR. PLESSET: But no break.

MR. MUENCH: But no break except for the PORV. Okay? We do term that, at least when it's stuck open, as a loss of coolant accident.

On May 7th, the NRC bulletins and orders and lessons learned task forces were formed and on May 9th, we received our first formal set of questions from the staff, which we responded to by May 16th.

Also during that period of time, I'm sure that you remember that we had our first meeting with the ACRS relative to small breaks and natural circulation.

I think the interesting thing to point out at this time is that by the time that we got this first formal request from the staff, we had performed something in the neighborhood of 40 analyses, 40 scenarios, in cases including all the different plant types and scenarios.

I'm sure that most of you will remember, and are still doing this, that a lot of people have been sitting down and formulating scenarios for you to think through. And a lot of these we were running through on the computer trying to understand the conclusion of those scenarios.

So we did a lot of analyses up to this time which we used, for the most part, in our responses to the staff here on May 16th.

Also going on at that time, we were using the results of these analyses for seminars with our customers. We were running through in very general terms what small break transients looked like.

Finally, on May 30th, the Westinghouse owners' group was formed, the owners' group for customers with Westinghouse NSSS.

DR. PLESSET: These analyses that you mentioned, were they best estimate analyses or how would you characterize them?

MR. MUENCH: I would say for the most part that we made a decision to go with what we had. For the most part, they were evaluation models-type analyses.

We did have something else getting started which I'll talk about a little later where we were using our evaluation model computer code and starting to put better estimate input assumptions to it to help us a little bit in the area of operator training.

MR. MICHELSON: Before you leave these two slides, I wanted to ask a question. I guess there may not be a better time than now.

A few weeks ago, we had a few discussions with the NRC staff concerning the question of the possible levitation of water in the pressurizer for breaks in the pressurizer such that the water level never really dropped even as the core went dry.

Were your customers informed of this possible problem in some manner?

MR. MUENCH: Okay. On the first slide, I'm not sure which question you're actually asking. On the first slide, I did talk about the fact that we did confirm that for vapor space breaks. The level would in fact increase and levitate.

MR. MICHELSON: You did this on 47. Yet, the problem wasn't discussed even until long after 47.

Maybe we're not talking about the same problem, or maybe you just pre-empted the problem.

MR. MUENCH: Maybe we're not talking about the same problem.

MR. MICHELSON: The problem here is the fact that with an open relief valve, for instance, even with steam entering the surge line, there is adequate levitation effect to retain the water in the pressurizer, even though the core may go completely dry.

MR. MUENCH: That's the problem that I was talking about and we did bring that to the customer's attention again on April 7th.

MR. MICHELSON: That wasn't perhaps the way I heard, then. It was long after that before we even discussed it.

You do understand the problem I'm talking about.

MR. MUENCH: I think I do, Mr. Michelson. And we did have a meeting with the customers very, very early in the game and confirmed to them that the level would, in fact, increase.

MR. MICHELSON: The question of the level increase is not the question in hand. The fact is that the level increases and stays there forever.

MR. MUENCH: I think that's implied.

MR. MICHELSON: I don't know if it was implied. I just wonder if it's now well understood by your customers that the level for these cases, unless the break is closed off, the level will go up there and stay up there.

MR. SPEYER: I represent the owners' group, Daniel Speyer from Con Edison. And yes, we are aware of that from the interaction with Westinghouse as part of the owners' group. And in fact, well before that we were aware of that.

In fact, on an individual basis, within a few weeks of TMI, we had gone through that process.

MR. MICHELSON: Not necessarily on 47, though. On 47 you were aware of it already?

MR. SPEYER: I was. The exact date, though, with respect to most utilities, I'm not aware of.

MR. MICHELSON: Whoever's running pressurized water reactors now appreciates that problem.

MR. SPEYER: Yes.

MR. ESPOSITO: Mr. Michelson, I believe it was about that date that a letter was sent from Westinghouse to all the utilities.

MR. MICHELSON: Okay, that had been sent out?

MR. ESPOSITO: Yes, it had been sent out.

MR. MUENCH: Let me point out that if all the utilities were not present at this meeting that we had on April 7th, there was a letter to all the customers on April 10th.

DR. PLESSET: What did it say?

MR. MUENCH: It said that in the instance of a vapor space break, and I'm roughly paraphrasing it, okay, that the level in the system may not be indicative of the true level in the rest of the reactor coolant.

The level in the pressurizer may not be at the true indication of the level in the rest of the system.

Therefore, it deters the high pressure injection upon reaching the pressure over the signal.

MR. MICHELSON: Of course the problem is far more complicated than that. If the water level stays up there indefinitely, I think that's the cause for concern.

But if Westinghouse has sent out a letter that warns people now that the water level stays up there indefinitely if there's a break in the vapor space, that's great. But if it just says, it's not indicative, that's not a very straightforward statement at all.

MR. ESPOSITO: A very straightforward statement was sent, Mr. Michelson, in the letter. Also, I believe it was four days after the TMI incident prior to the letter even going out there was a phone call made to each and every utility telling them what was in the letter.

We wanted to inform them as quickly as we could.

MR. MICHELSON: Roughly, when did the letter go out to the utilities?

MR. ESPOSITO: I believe it was the 6th or the 7th.

MR. MUENCH: The letter was the 10th, the meetings were the 6th and the 7th.

MR. MICHELSON: And in that letter, you did warn the people about the level problem and the fact that the level would stay up indefinitely if there was a break in the vapor space.

MR. ESPOSITO: We said that you would not get safety injection on a coincident level because the level would remain high in the pressurizer.

MR. MICHELSON: That part was understood. What wasn't understood as well is that even after the core went dry, the level was still in the pressurizer. They did understand that from your letter.

MR. ESPOSITO: Yes, I believe they did.

MR. MUENCH: The last thing on the previous slide was the formation of the owners' group for Westinghouse, the owners of NSSS.

(Slide.)

The first duty of that owners' group was on the very next day to have a technical meeting with the staff and discuss needs of the staff relative to small break model needs and required information for a report to be formulated for the staff.

The meeting resulted in a request to clarify and justify and so forth various methods and analyses and procedures, and this was verified in a letter from the staff to Westinghouse on June 4th.

On June 11th, our first priority, by the way, was to take care of the questions on methods. It made no sense to proceed with analyses of scenarios unless we have concurrence on the methods.

So we concentrated on the methods for the first week and met with the staff again on June 11th to resolve the methods concerns, and in general, got a consensus to proceed with the analyses.

The analyses were compelated and the report was issued on June 29th. At that June 29th date, it was a draft report. It was followed, I think, within the week by a formal report.

What I'd like to do right now is just summarize what was in that report.

DR. ZUDANS: Could I ask, I'm still a little bit bothered on the first slide, not because of what you said, but because I do not know exactly what this coincident SI logic really was doing before you instructed the operators to manually put the SI on.

Would the automatic SI actuation be dependent on the pressurizer level? Is that what the logic meant?

MR. MUENCH: The coincident logic said that you had to have a low pressurizer level and low pressurizer pressure coincident in order to get a safety injection signal for some of the plants, some of the Westinghouse plants.

DR. ZUDANS: That means that if you hadn't instructed, you might have had a scenario where the pressurizer level is high and SI wouldn't come on.

MR. MUENCH: Automatically, yes. We had done analyses before this for vapor space breaks which had been reported to the staff, which indicated a similar problem, but also indicated and has, again, verified here, that there was significant time for operator action to recognize this event.

DR. ZUDANS: And your statement in the same slide said that you had more than 30 minutes' time. Is that true?

MR. MUENCH: Let me describe the case one more time to you.

The case we talked about, the answer is yes. I want to make sure that you understand the case because everyone has the case on the table.

The case was for the opening, for the simultaneous opening of three power-operated relief valves. Some of our plants have three, by the way, very few of them, as being the initiating event times zero. Okay?

And the assumption I'm getting no safety injection, okay? With those assumptions, I guess we had minimum aux feewater in that calculation at that time.

So that we had 30 minutes before the mixture level approached the top of the core in the vessel.

DR. ZUDANS: How would the same time behave if you only had one of these PORVs open?

Would it be longer?

MR. MUENCH: If we only had one PORV open, it would be much, much longer. In fact, if we had one PORV open and we had safety injection, we would not have drained the system, to a large extent, at all.

MR. SPEYER: Let me make a statement here about the question that was raised. Again, Daniel Speyer of Con Edison.

Will a plant that, indeed, did have a situation that was mentioned, the coincident pressurizer level with actuation safety injection -- I was, in fact, aware of the potential, as mentioned in RESAR 3, which I think is something like October, '74, that there is the possibility of pressurizer level not going down and manual actuation of SI would be required.

That is stated in RESAR 3000.

DR. ZUDANS: Does it have a time limit stated as well?

MR. SPEYER: No. Well, I'm sorry, I don't recall if there was a time limit. I do recall, however, that it states that pressurizer level may not, in fact, go down. You may not get SI on the trip and it would be manually turned on.

MR. MICHELSON: Do your operating procedures reflect this fact? Are your operators aware that they'd have to start the SI manually?

MR. SPEYER: I think so, but I'm not sure what's in.

MR. MICHELSON: How about Westinghouse? Are you aware whether operating procedures reflect this requirement?

MR. JOHNSON: Bill Johnson from Westinghouse. Two distinctions need to be made, one being the plant-specific procedures are not within the scope of Westinghouse. I can only speak from the point of view of the Westinghouse reference procedures which have been in place since about 1974.

In the Westinghouse procedures that were in place in 1974, there was no specific mention of a stuck open PORV. However, there was a statement that continues to be in the current procedures. It states that manual safety injection actuation should be accomplished if the operator perceives that need, which is a move toward a safety injection set point.

a/b

DR. ZUDANS: I asked this question about 30 minutes because compared to similar situations at the Three Mile Island accident, there was no such time. Is it obvious why there is such a much longer time in your reactor as compared to Three Mile Island?

MR. MUENCH: The 30 minutes, again, was no the Three Miles Island scenario, okay?

DR. ZUDANS: But if you said the Three Mile Island scenario would be much longer in the case of Westinghouse reactors, I am just wondering what's different in Westinghouse reactors that makes this time so much longer.

MR. MUENCH: In the event of a loss of feedwater, I guess it will take a little while longer for a Westinghouse steam generator to dry out. So in the TMI type scenario, that's the answer to your question.

DR. ZUDANS: That's the only real reason for longer time available?

DR. PLESSET: I think he's not taking the strict analog of the Three Mile Island scenario.

MR. MUENCH: That first analysis is not.

DR. PLESSET: So I think that was not what he meant.

DR. ZUDANS: What I mean is very simplistic.

DR. PLESSET: Well, he did answer at one point, it makes a difference between Westinghouse and the steam generator inventory, but that's not 30 minutes.

MR. MUENCH: The 30 minutes that I talked about -- let's just put the slide back up so we understand which one we're talking about. We're talking about this 30 minutes here?

DR. ZUDANS: Yes.

MR. MUENCH: This 30 minutes was not a Three Mile Island scenario essentially. It was the initiating event -- was the opening of three power operated relief valves and pressurizer vapor space, and the assumption of no safety injection was made, and the other Appendix K assumptions as applicable were applied. And that's the analysis that we're talking about here.

MR. MICHELSON: That included pump trip, then?

MR. MUENCH: Yes, it did.

MR. MICHELSON: Which was the big difference with pump trip?

MR. SKWAREK: I think I could clear it up. Again, the 30 minute time is based on the initiating event, being the spurious opening of three PORVs. Now no safety injection came in, but you still had auxiliary feedwater. Further analyses that were performed a little bit later in time that Rick had mentioned were I wouldn't say exact TMI scenarios because I really don't know what all happened there, but it was a class of accidents that the initiating event now was a loss of feedwater and auxiliary feedwater. So it took a while for the steam generator to blow down.

After the steam generator blew down, the RCS pressure increased, opened the PORVs. Then you had a LOCA. Then we also calculated times for operator action for that transient, and it was later than 30 minutes. That was approximately 50 or 60 minutes. It was also that transient. It's two different initiating events. But the one that Rick talked there, the 30 minutes, is the earlier of the two in terms of minimum operator action.

MR. ESPOSITO: And finally in regard to a comment that Dr. Plesset made, it does take approximately 30 minutes to dry out the steam generators.

DR. PLESSET: What kind of plant is that?

MR. STEITLER: Bob Steitler, Westinghouse. That's typical of all Westinghouse designs.

DR. PLESSET: Regardless of whether it's a three or four loop?

MR. STEITLER: Regardless of whether it's a three or four tube plant. The inventory is basically proportional to the power level.

MR. MUENCH: Okay.

DR. PLESSET: Well I don't want to delay any longer. I would like to make sure that that's right. I believe you in a temporary way.

(Laughter.)

MR. MUENCH: Okay. What I want to do very quickly is run through a slide of what was aimed at WCAP-9600, give you a quick summary of the various other studies that have been performed, many of which will be discussed in detail after I have concluded.

(Slide.)

In WCAP-9600 in the "Methods" section of WWCAP-9600, we performedc a noding study of the pressurizer for the case of a break in the pressurizer vapor space and concluded that the increased noding was not causing significant change in the response of the pressurizer. We also reported the results of the surge line studies that we had done showing that flooding will indeed occur in the surge line for breaks in the vapor space larger than approximately .8 inches in diameter which includes one or more PORVs being opened.

We also did a simple steam generator noding study where we just doubled the number of nodes in the steam generator. We also went one step further and allowed for counter-current flow from the steam generator back to the vessel and showed no significant change in the core uncovery transient.

A little bit later we're going to talk about steam generator models and go a little further with more advanced studies that we performed.

We looked at the sources of noncondensibles. We took a break which was typical of a break which needs a steam generator to remove heat for a significant period of time and calculated on a perturbation type technique the various sources which may be generated during a small loss of coolant accident.

DR. CATTON: Could you amplify on that? How did you do that?

MR. MUENCH: Just very quickly, we looked at the pressurizer vapor space. We looked at the initial inventory in the reactor coolant system and assumed a concentration of noncondensible gases dissolved in it. We looked at how much safety injection was injected. We looked at flashing and dissolution type processes, and I can't think of the word --

MR. ESPOSITO: I think the word is radiolysis.

DR. CATTON: You said pertrubation analysis.

DR. PLESSET: So your total source for noncondensibles is dissolved?

MR. MUENCH: It was dissolved. That was in the reactor coolant system initially. That was injected into the reactor coolant system.

DR. PLESSET: From what sources would they be injected in?

MR. MUENCH: Safety injection.

DR. PLESSET: So it's what's dissolved in that water also?

MR. MUENCH: We assumed that the water is air saturated.

DR. PLESSET: But no other sources except what is coming out of solution.

MR. MUENCH: The pressurizer vapor space has noncondensibles in it. That was also allowed to enter the reactor coolant system as it expanded out of the pressurizer.

DR. CATTON: In any of the scenarios that you looked at, do you reach a UHI set point or even get close to it?

MR. MUENCH: In the studies so far we have not looked at the UHI plan, but in the break analyzed here, yes, we would have reached the UHI accumulator set point. This is a two inch break which is the upper bound of where you would see the steam generator forcing it in periods of time. It was an hour, I think. We would get down to 900 or 1000 psi.

DR. CATTON: So for the UHI break, maybe a more serious look at noncondensible sources would be in order.

MR. MUENCH: For UHI, a break like this would result in a very minimal amount of additional standard cubic feet of nitrogen being added. That was just dissolved in the coolant system.

I'd like to ask Pat Dochedrty to expound on that.

MR. DOCHERTY: I'll go through that later on in my UHI applicability and show you the relevant percentages.

DR. PLESSET: But you're quite sure you don't get to the passive injection set point at any time? The tanks which are injecting water and nitrogen? The UHI is supposed to have multiple valves, but these tanks, they're at a lower pressure that inject -- a passive ECCS system. They do let nitrogen go right into --

MR. MUENCH: Dr. Plesset, you would have to bring --

DR. PLESSET: How far away?

MR. MUENCH: You would have to bring a reactor coolant system down to a pressure of less than 200 psi.

DR. PLESSET: Is that true of all the plants, that that's a set point?

MR. MUENCH: It's not a set point, Dr. Plesset; it's just where the water would empty.

MR. MICHELSON: It depends on initial pressure in the tanks and the amount of water in the tanks. It's generally around 600 pounds.

DR. PLESSET: They start to inject much higher, yes, 600.

MR. MICHELSON: 200 is probably a good guess.

MR. MUENCH: It's more than a guess for us.

(Laughter.)

MR. ESPOSITO: Dr. Plesset, we will discuss the UHI in the fourth agenda item. Mr. Docherty will address that.

DR. PLESSET: I think what we're concerned with is a failure of the shutoff valves for UHI, but aside from that, you're sure that the tanks never contributed significant nitrogen, never get that low. Is that right?

MR. MUENCH: Yes, that's right.

I want to clarify that. I won't say it doesn't contribute significant nitrogen, which means I'm looking at a cold leg accumulator now. I'm forgetting about UHI for a later discussion.

The break that will get you down to 200 psi is like a six inch break or larger, and for that break you do not need steam generators to remove heat from the system, and that would not cause you a problem for a six inch break. By the way, 200 psi is really less than that. It's where you start getting what I called free nitrogen into the cold leg piping instead of the nitrogen blanket, and you'd have to expand on down.

As the reactor coolant system would expand, it would bleed out of the accumulator as fast or as slow as the transient would allow.

DR. PLESSET: You take into account the expansion of the nitrogen in the vessel presume?

MR. MUENCH: I'm sorry, I didn't understand the question.

DR. PLESSET: The nitrogen heats up quite a bit in the reactor vessel. Right?

MR. MUENCH: We do not have noncondensibles in our evaluation model, so we do not do that type of calculation.

DR. PLESSET: All right.

MR. MUENCH: This is a phenomenological qualitative type discussion.

Okay. We also looked at the model we used for the mixture level in the core. We looked at what we've been using all these years for break flow models, which you're going to hear a discussion of later on today. And we did our first TMI looking I should say at natural circulation with the models that we had available.

Then we started looking at the general behavior of small LOCAs. The staff had asked us to describe the characteristics of the various types of small LOCAs which depressurize down to stay above the steam generators, which get down to equilibrium above the steam generators -- those which get down to equilibrium and inject accumulator water. We did provide a very detailed set of analyses and discussions on the characteristics of small breaks.

We also looked at vapor space breaks, and we also provided a discussion on HPI termination in light of all the break analyses we performed.

(Slide.)

Moving on, we did some specific scenario analyses that the staff had requested.

DR. CATTON: Before we get to the specific scenario, I recall Ebersole asking on many occasions for a heat flux map for small breaks -- I'm not sure for small breaks -- but a heat flux map or energy flux map as a function of time, it seems to me, would be a very interesting type diagram.

MR. MUENCH: You're talking about heat to the steam generator?

DR. CATTON: Right. And to the various -- where is it all going as a function of time during any particular scenario so you get a better feel for what pieces of the system are important.

MR. MUENCH: I think if you look at the transcript from the May 9 ACRS you'll find one or two of those in there where we said, where we broke it down at least between the break and the steam generator for a few of these breaks. I think you'll find a couple of those.

DR. CATTON: May 9?

MR. MUENCH: Yes.

DR. CATTON: Okay.

MR. MUENCH: We thought that was a very interesting thing to look at, too. We talk a lot about what breaks need steam generators and which ones don't, and this is a nice way to demonstrate that.

DR. PLESSET: Did you refine this to the point where you considered the fluid loss through breaks of various kinds along the lines of what Dr. Fabic was telling us this morning?

MR. MUENCH: I have to apologize that I didn't make it from Pittsburgh early enough to hear all of Dr. Fabic's comments.

MR. ESPOSITO: I think you'll see in the discussion of the break flow model what we've considered in our sensitivity studies.

DR. PLESSET: All right.

MR. MUENCH: Any other questions before I go on?

DR. PLESSET: Please go on.

MR. MUENCH: One of the things that was asked for was an analysis, seeing whether the reactor coolant pumps were tripped consistent with our recommendations, 1250 psi plus instrument uncertainty. We performed those analyses and showed that the results were consistent with what was reported in the FSAR for all the plants. We looked at something which was roughly called an operator action time scenario where a loss of feedwater was the initiating event. We assumed that there was no aux feedwater to begin with, with and without a small break. The idea was to find out how much time he needed before he uncovered the top of the core.

MR. MICHELSON: Excuse me. Are you going to talk in more detail on the reactor coolant pump trip?

MR. MUENCH: Yes, we are. I guess it's the next presentation.

This small break -- the definition of that small break was that it was small enough so that you did not get an -- where you were drying out the steam generator. We also did an analysis where we isolated the steam generator in one of the loops to see what the impact would be on a small break. We also ran various small breaks that could be isolated, like the letdown line and the vapor space PORV break.

MR. MICHELSON: In those cases, are you going to tell us more about this later, as opposed to just saying, "This is it"? Could you flag it? If you're not going to tell us in more detail later, could you so indicate now?

MR. MUENCH: Yes, I think I have hopefully for the most part indicated which ones we're going to talk about more later. We're going to give you a summary.

For the most part, we won't be talking about these, since these --

MR. MICHELSON: Let's talk about isolating breaks, then, if you're not going to talk about them later. That's why I stopped, because I wasn't sure whether we were just seeing an overview here or this is it.

MR. MUENCH: Dr. Michelson, before we do, I might say we will summarize at the end which ones we will give further presentations on.

MR. MICHELSON: Reactor coolant pump you indicated you are going into further detail on, so we can hold those questions. But isolating breaks, you said you looked at the letdown line break. Are you going to give us some results indicating how low the pressures got and so forth before you decide to isolate the breaks? What I'm leading to, so there is no misunderstanding, I'm wondering how low the pressure gets and whether the accumulator tanks have dumped nitrogen into the system before the operator finally figured out how to isolate the break, and then what consequence that isolation would have on reestablishing acceptable conditions on the primary side.

MR. MUENCH: Okay. I hadn't planned to show slides of the transient. However, there is -- we analyzed the letdown line, which is the spray line that can be isolated, the PORV which can be isolated. None of those should result in the emptying of the accumulator. Some of those will result in an accumulator injection of water. None of those should result in the total depletion of the accumulators.

MR. MICHELSON: When did you isolate?

MR. MUENCH: What we chose to do, and this is half way arbitrary I believe, we looked at the modes of natural circulation, and we decided that the worst time to isolate was the time when pressure had gotten down to a minimum or the mixture level in the core had gotten down to a minimum. We were in the pure core boiling mode where we thought we had to go the furthest distance to repressurize and to get good condensation in the steam generator.

MR. MICHELSON: That's a good assumption for that particular thought process. But now following Dr. Plesset's question, maybe you needed to leave the line open a while longer. The question is, well just how does the pressur tail down when you indeed start transferring large amounts of nitrogen and then decide to close the valve?

MR. MUENCH: The letdown line is a four inch schedule 240 to 60 pipe, which has an equivalent three inch inside diameter which would lead to accumulator injection, but which would only lead to a minimum pressure of 500 psi, 400 psi.

MR. MICHELSON: Why do you say that's as low as it can get?

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MR. MUENCH: Okay. That's a good question. It's as low as it would get with the assumptions that we were making in the whole analysis.

MR. MICHELSON: Yes. The assumption as to when you close the valve, for instance.

MR. MUENCH: Not that assumption.

MR. MICHELSON: You're saying that if I leave it open indefinitely, the pressure never drops below 500 pounds?

MR. MUENCH: That's right. If you would leave it open indefinitely in this analysis, you would show a leveling out, and I say four or five hundred pounds. Is that about right?

Yes, it would be about four or five hundred pounds.

By the way, that would be slightly larger than the break we analyzed in WCAP for the generation of noncondensibles, so there would be a little bit more noncondensibles. It can be shown with the two-inch break that there would be an insignificant amount, and, in one respect, not much more than a three-inch break.

DR. CATTON: How do you show that the amount of noncondensibles is insignificant?

MR. MUENCH: In the report, we did a study on heat transfer, and we provided some discussion on the impact of hydraulics, and basically so that there is enough driving force, for example, to keep natural circulation in place if that set of conditions would lead you to natural circulation.

DR. CATTON: You were going to come back to this when you talk about the steam generators?

MR. MUENCH: Yes, to a certain extent, I think it would be a good idea to wait and see what we got, and then if there are any other questions we will try and answer them.

DR. ZUDANS: I think I got slightly off the track. When you said indefinitely the pressure will not drop below, say, 500, with the break existing, are you bringing some water from other sources into that system?

MR. MUENCH: Yes. What's happened, at that point you have reached a place where safety injection flow is matching break flow; therefore, you are maintaining an equilibrium -- let's call it a "stable condition" -- in the reactor coolant system.

DR. PLESSET: So, it's really a question of how confident you are of the analysis, which I don't know how one establishes easily. 400 pounds, you know, might not be the value; it might be 200. I don't know. Can you tell me for sure that it won't go below, during this transient, 400 psi, so the accumulators will give you that amount of nitrogen?

DR. ZUDANS: You have to know how much you have to fill, how much goes out.

DR. PLESSET: Operator action could, of course, distort that, as Karl says. Well, it's just a concern.

MR. MUENCH: I feel like I should point out that we feel we have a lot of confidence in our evaluation models due to the conservative nature of them.

DR. PLESSET: I am not always sure that an evaluation model is really conservative. I believe it for double-ended guillotine break, which Dr. Shewmon tells me is never going to happen. But we're talking about things that I think will happen, and using these same kinds of ideas I am not always sure that they're truly conservative.

What's Westinghouse's opinion? Are they always really conservative?

MR. ESPOSITO: Dr. Plesset, Westinghouse's opinion of the information that we have available to us today is that the evaluation model is conservative.

DR. PLESSET: I am thinking more in terms of its leading to suggesting actions which may not be desirable which might not be the result if you did a best-estimate calculation. I am sure you are saying that the decay heat is 1.2, and that's conservative. But does that mean that your course of action is the most desirable one to use these evaluation model figures? You're confident of that?

MR. ESPOSITO: In terms of the assumptions that were made in the analyses here, no operator actions were included. In developing the parts that you will hear later, the analyses themselves are not totally relied upon; they're used as a guidance rather than a strict reliance on.

MR. MICHELSON: In that regard, let me ask another question. Is there going to be some kind of operator guidance that says for these very slowly developing conditions, that the operator perhaps has to intervene and isolate the accumulators prior to their final starting filling with nitrogen?

DR. PLESSET: That's a very good question, Carl. I am glad you raised it.

MR. JOHNSON: We can get into this at a later point when I discuss the procedures. But to directly address your question, the operating procedures were not called for, isolating safety injection accumulators or breaks in which the system is naturally depressurized thereby losing inventory. Since the intent of those accumulators is to provide inventory for breaks which do stabilize, such as the one that Rick's presented here, that pressure above the accumulators, instructions are given during the eventual cooldown and depressurization plan.

DR. PLESSET: Thank you. Okay.

MR. MUENCH: Can we proceed?

I think we were down to the point of saying that we provided a discussion of natural circulation, and the staff pulled out of several reports that Dr. Michelson has written, several concerns, at least 15 main concerns which we addressed in the report.

We also did discuss the natural circulation modes that were falling under the small-break LOCA. They've provided guidelines for E-0 and E-1, what we call "E-0" and "E-1," which is a diagnostic procedure and a LOCA procedure in this report.

(Slide.)

Just to review the summary and conclusions from that report, we felt that the report continued to support the safety of the Westinghouse NSSS design. We felt we, of course, learned a lot of things, as you do from every exercise. On the other hand, we felt like we didn't find anything which refuted the Westinghouse NSSS design. We felt that the models and methods used to evaluate that statement are conservative but acceptably realistic in order to make those types of judgments.

Next, we did provide a comprehensive review of the smal-break transient, and provided analyses to demonstrate those discussions.

One of the things we did in the study -- or we reported in that WCAP -- was an estimate of the uncertainty that we felt existed in the small-break model, and this was not done in any high-powered mechanistic fashion. But what we did was take the two areas which we -- and, in fact, staff had mentioned to us -- in areas where perhaps both uncertainties may exist and maybe are very important to the small-break transient, and showed that with very upper-bound type assumptions on those models, we would only get an increase of 150 degrees in our small-break FSAR results, which would still leave you well below 2200 degrees.

We also showed that the Westinghouse recommended HPI termination criteria agree closely with the NRC criteria, at that time, from the standpoint of when, if everything worked correctly, you would get the signals that you would want to terminate HPI. We showed that for the opening of one to three PORVS, that there would be no core uncovery. These are Appendix K assumptions.

DR. ZUDANS: What were these assumptions in the last item?

MR. MUENCH: Minimum safeguards, which means one train of safeguards, one high-head safety injection pump set up, and one go-ahead safety injection pump, with a spilling line and a broken loop, with the accumulators filling in the broken loop, loss of off-site power -- assumptions like that -- 1.2 x A&S decay heat.

DR. ZUDANS: What is the absolute minimum requirement in terms of other equipment for this not to happen, for the core to remain covered? What's the critical piece of safeguards equipment that you need? You have listed a large number of assumptions.

MR. ESPOSITO: The high-head safety injection is critical.

MR. MUENCH: For these breaks; that's right.

DR. PLESSET: Well, one idea that I had in my mind when I was talking about whether this was really conservative or not, on it led to a certain sequence of actions, the turnoff of the main cooling pumps and you would keep the high-head injection going. Now we have an event -- and it doesn't take a lot of imagination today -- in which there is no break at all, but simulates a break: the pressure falls but I have no break in the system.

How does that fit in with these procedures now? Is that a good idea? Is this a safe way to proceed?

MR. MUENCH: A little later on we will discuss the guidelines for the other type events. We feel like we have adequately covered the various types of events, off-LOCA and on-LOCA, that can occur.

DR. PLESSET: And the operator has a pretty good idea of what he's doing?

MR. MUENCH: We feel that's correct.

MR. MICHELSON: Just one comment on these conclusions. If you just read them -- at least I was kind of led to believe that what Westinghouse was doing -- gave adequate results, direction, and so forth, and that really there was nothing real new as far as TMI effects. Is that a correct observation, from reading that summary sheet?

MR. MUENCH: Dr. Michelson, I think that everyone who has been involved in activities since Three Mile Island has learned a lot about the details of the system and various scenarios that you can get into. So, the idea here was a very broad bottom line. There was a lot of learning that took place in the last six months.

MR. MICHELSON: The one in particular that I have in mind -- you can correct me if I am wrong -- that is that the reactor coolant pump trip was indeed a surprise. I

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gathered that your plants, really, if they had continued to run their pumps until they were lost by accident, means might not have -- indeed, your predictions might not have indeed been conservative as to the consequences. Is that correct?

MR. MUENCH: If we would have done an analysis several years ago where we tripped reactor coolant pumps parametrically through transient, we probably would have seen the same results we'd gotten. Otherwise, I think my answer to your question is that we always advise in our operating procedures, the one that has been discussed earlier, which are dated -- what? -- '74, to trip the reactor coolant pumps following a loss-of-coolant accident.

Actually, it says on the emergency procedure, after you've gotten an S signal, to trip them. Those were sort of -- I am not sure if it is that interesting at this point because we have procedures, but it is something we learned a lot about during the last six months.

MR. MICHELSON: You're also saying that Westinghouse knew all along you only trip the reactor coolant pumps?

MR. MUENCH: No. All I am saying is that procedure all along had been to trip them for a variety of reasons.

MR. MICHELSON: That means you told your customers

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then to trip them.

MR. MUENCH: In a reference operating procedure, yes.

MR. MICHELSON: Prior to TMI?

MR. MUENCH: Prior to TMI? Yes.

DR. ZUDANS: Only for a LOCA.

MR. MICHELSON: Well, yes, these are all LOCAs.

DR. PLESSET: Zoltan?

DR. ROSZTOCZY: Is it correct to state that Westinghouse recommendations which were in effect prior to TMI provided no information to the operators when the reactor coolant pump had to be tripped? In other words, a strict following of the procedures could have resulted in tripping the pumps at the worst possible time.

MR. JOHNSON: Let me respond to that. The Westinghouse reference emergency operating instructions was an issue prior to the TMI event. In each of the emergency procedures -- that is, E-0, E-1, E-2, E-3 -- which are all procedures which provided post-safety injection, the first active operator instruction in each of those procedures, which is where the operator will immediately go post-safety injection, was to trip the reactor coolant pumps.

DR. ROSZTOCZY: It was listed as No. 1, but without any indication that it has to be accomplished right away because there is only two, three, or five minutes available for it; is that correct?

MR. JOHNSON: The intent of the instructions was to have the operator follow those instructions sequentially, and when he came to No. 1, that would be the first operator action.

DR. PLESSET: Suppose he had high-pressure injection and didn't have a break. What would the operator do?

MR. JOHNSON: I propose to defer that until I discuss our procedures.

DR. PLESSET: All right.

Zoltan, you have another question?

Carl?

Okay, why don't you go on?

MR. MUENCH: I think what I will do is summarize some of the other activities as an introduction into some of the next presentations.

(Slide.)

Some of the other studies that we have done -- some in response to bulletins and orders and some not -- one of the studies that we did was a delayed reactor coolant pump tripping following a small LOCA, which is reported in WCAP 9584, which was submitted September 1. This was in response to IE bulletin 79-06C, but it was an extension of work, as I mentioned earlier, that we'd already started, and finally were able to form, I think, a consistent set of well-based conclusions.

Item 2 and 3 here is a set of studies that we initiated, in fact, after our last discussion with the Advisory Committee on natural circulation. We felt that it would be very useful to initiate some studies, more detailed studies, on natural circulation, using an advanced code that we had available at the time.

The first installment of that study is available. It's called "WCAP 9586," and it was submitted also about September 1.

Both of these first two items we will have detailed discussion on today.

The next installment would be little more microscopic look at what's going on in the steam generator in various tubes and so forth. We will also have discussion on that today. The report for that segment of the study is not completed at this time.

We have also been looking back at our UHI plans to make sure that all the conclusions we've drawn from our various studies are applicable to UHI plans, and we'll also be able to field any questions later when Pat is talking in that area.

Lastly, in terms of activities that are relatively complete, Vinnie is going to summarize some areas that are still in progress, at the end of the meeting. We have performed a pre-test projection of Semiscale Mod-3, the small-break experiment. The date is a little bit ambiguous right now. We submitted, I think, what we could call a "preliminary result" on Friday, and preliminary from the standpoint that we had completed our internal review and are completing our internal review of the results of that calculation.

Without further ado, then, I would like to go on into discussion on reactor coolant pump tripping.

MR. ESPOSITO: Mr. Chairman, Ray Skwarek will make the presentation on reactor coolant pump tripping.

DR. PLESSET: Thank you.

MR. SKWAREK: Thank you.

As Rick had pointed out, throughout the studies performed for WCAP 9600, there were some preliminary studies done with respect to reactor coolant pump continued operation throughout the small-break transient. And after that report had been submitted and Westinghouse had received bulletin 79-06C, we began another, much more intensive, study on the topic.

And as a result of that, we submitted WCAP 9584, analysis of delayed reactor coolant pump trip during small-break LOCAs at Westinghouse nuclear plant. This report was submitted 30 days after receipt of bulletin

79-06C. The report is broken down into four major sections, and this presentation will follow right along with that.

The first part of thd study was to take a new look at some of the analytical methods that are utilized in the small-break codes and to doublecheck to see that they are indeed appropriate for analysis of LOCAs with the delayed reactor coolant pump trip.

The next and probably most important part of the study was a very large number of analyses that were performed for the study. Various break sizes, various plant types, and various reactor coolant pump trip times will be summarized a little later in the presentation. Presenting those results is included, as well as an evaluation of the system behavior that could exist due to continued operation of the pumps.

The next section is pretty much a synthesis of all the results in an attempt to determine the critical reactor coolant pump time that will assure that peak clad temperatures will remain below Appendix K limits considering any break size.

Finally, I will just put up some summary and quick conclusions for your reference.

(Slide.)

Just to set the record straight as I start here, because there was talk of what model was used in previous analyses, for all these studies here except for one that I mentioned specifically, for all the analyses that were done, we used essentially an evaluation model with Appendix K assumptions, minimum auxiliary feedwater, minimum safeguards, ANS plus 20 percent decay heat, and the like.

In terms of the analytical methods that were given a second look, the first thing we wanted to do is verify the WFLASH reactor coolant pump model to reassure ourselves that it would predict reasonable flows and pressures, given two-phased and in fact even all-steam inlet conditions to the pump. So, with the FSAR analyses that each plant would have in their documents, the reactor coolant pumps are tripped off very early in the transient and they coast down and they're essentially dead by the time the void fractions in that pump inlet path start to rise.

So therefore, that was the reason why the study was now needed. We did a number of calculations that are presented in the WCAP, that indicate that the WFLASH pump model does indeed predict the expected degradation in the two-phased region and pump recovery in the single-phased, either all-liquid or all-steam regions.

DR. PLESSET: What does that mean, pump recovery?

What do you mean by that? In what sense does it recover?

MR. SKWAREK: That the pump head that's predicted is a function of the speed and density, and there is not a two-phased degradation factor, that all pump tests in fact do demonstrate, once you get back to a single phase, there is a recovery of performance.

DR. ZUDANS: Is the pump able to function for any length of time with a two-phased mixture at all from the mechanical point of view?

MR. SKWAREK: That's a good question. I guess there isn't a final conclusion in on that.

I'm going to talk about the EVA pump test. It was a one-third scale pump test, and those pump test results -- it appears that the pump can operate for a period of time with two-phase and even all steam going through the pump.

DR. ZUDANS: All steam I understand, but two-phase?

MR. SKWAREK: Two-phased as well. But I'm not sure that the pump division at Westinghouse, I don't know that they would necessarily approve of that position at this time. Would someone like to comment from Westinghouse?

MR. MUENCH: Rick Muench from Westinghouse.

The one area of main concern is the possibility of performing slug flow near the reactor coolant pump with a huge flywheel sitting up on top. In our tests we did not simulate slug flow. So where in our tests for two-phased flow we got fairly smooth pump performance, we did not slug the pump. That's where the area of uncertainty still lies.

DR. PLESSET: Does the test model the axial flow and tip speeds of the prototype? It does?

MR. SKWAREK: I beg your pardon?

DR. PLESSET: Does the one-third scale test model properly the axial flow and the tip speed, the axial flow speeds and the tip speeds of the prototype? Otherwise they might not be too meaningful.

DR. MUENCH: Dr. Plesset, we'll be giving this in more detail later in the proprietary session.

DR. PLESSET: Okay. We'll pass that on.

DR. ZUDANS: Without any tests whatsoever, I think you could probably say that the pump will not function in slug flow.

DR. PLESSET: Well, it might function, but it won't be happy.

DR. ZUDANS: It would just go to pieces. It's a homogeneous mixture.

MR. SKWAREK: But anyway, for the purpose of the discussion right now, there was good comparison between the WFLASH analytical pump performance and the CENA one-third data pump test results.

The next step that we wanted to do in looking at the analytical methods was to take a second look at the appropriate control volume steam-water mixing assumption here, during the reactor coolant pump operation. Here I'm talking about homogeneous control volumes, where all the steam and water is assumed to be completely mixed within the control volume and there's just one void fraction for the entire mixture, and a heterogeneous option where there is a distinct mixture-steam interface and above that interface is saturated steam and below that interface is a mixture with bubbles and some void fraction, and you have bubbles rising and escaping from the mixture and into the steam space.

The first area that we looked at to determine what would be the most appropriate representation is the break location control volume. For a cold leg break, that's just downstream of the pump.

In order to determine what model we should use, we again drew upon the EVA test results, and I do have some proprietary information that could be shown later. But the EVA test results would justify a heterogeneous assumption of the control volume just downstream o[illegible] pump during reactor coolant pump operation.

DR. CATTON: The break flow model that you use, though, isn't that homogeneous, or do you allow the break to act somewhat as a steam separator?

MR. SKWAREK: The break model is homogeneous.

DR. CATTON: So when you say heterogeneous, you're not referring to your break flow model at all, and if it were indeed stratified or whatever, your break flow will be wrong. If the physical picture were to be stratified, your break flow will be incorrect as calculated.

MR. SKWAREK: No.

Pat, do you have a comment? I don't believe that's accurate.

MR. DOCHERTY: Pat Docherty from Westinghouse.

The break flow model reflects fluid conditions at the location where you specify the break. For a mode where you have separation, the break flow model takes the conditions from the lower phase. And if you specify the break at the top of the pipe, it will take the conditions at the top of the pipe. So in that way it does reflect the separation.

DR. CATTON: But some of the work, some of the discussion that we had this morning had to do with the fact that a break can act as a steam separator. In other words, if there is homogeneous flow past the break, the mixture ratio will change.

MR. DOCHERTY: What comes into the break is the condition that's near the break. What occurs, it's a non-equilibrium condition.

DR. CATTON: We're not communicating.

MR. DOCHERTY: Are you talking about a crack?

DR. CATTON: We're talking about a break that's just downstream of the pump. That's a pretty big pipe. We're talking about a small break, so that must mean a crack.

MR. DOCHERTY: Or a whole.

DR. CATTON: Or a hole. And a cross-section of that hole happens to be 90 degrees to the flow direction, so it's going to act as a steam separator.

MR. DOCHERTY: You're talking about a preferential pull on the voids of the lower mixture.

DR. CATTON: That's correct.

DR. PLESSET: Let me ask him: Did you hear the discussion that Dr. Fabic gave this morning?

MR. DOCHERTY: What we do is we bound the situation by looking at the break at the bottom. We take the homogeneous load phase mixture and look at a break at the top, and we take whole steam discharge.

DR. CATTON: When you do that, did that lead you to different conclusions about whether or not you should turn on the pumps? The reason I ask this question is because I read in the documents that one of the reasons you turned off the pumps is because the pumps homogenize the flow and if you have homogenized flow you wind up with greater mass implementation. But if the break acts as a steam separator, that reason seems to disappear. So there must be other reasons.

MR. DOCHERTY: I think what it says if that if the break flow acts the way it's modeled to be, then it's prudent to turn off the pumps at the time that we say. If it acts the other way, if it acts so that you discharge pure steam, it's probably not so important whether you turn off the pumps or not.

DR. CATTON: I'd like to quote Vinnie's predecessor, Jim Cermak: One has to be awfully careful for operating on Appendix K space.

MR. DOCHERTY: I agree.

DR. CATTON: And it sounds to me like there's a little bit of that here now. You're operating in Appendix K space and making operating decisions, particularly about turning off the pumps.

MR. ESPOSITO: Dr. Catton, our underlying assumption here, we're also operating in a conservative mode.

DR. CATTON: I think it was with respect to that that Dr. Cermak was referring. In any event, very frequently Appendix K space may lead you to a conservative peak clad temperature, but there are a lot of things along the way that are not conservative.

DR. PLESSET: Or it might be conservative in a particular circumstance or might not be conservative in another whic is apparently similar. This is one idea, I think, that we had already expressed. So conservatism, you know, has a variety of interpretations, and I think when you say, well, we're conservative, be sure that you give a good value for the loss of the break, higher than it is going to be. That may sound conservative and it would be in one particular circumstance, but not perhaps in another one where you didn't have a break at all but you had the same symptoms to start with, for example.

MR. ESPOSITO: What we have attempted to do is to do as much bounding of the phenomenon as we can by sensitivity studies and using those analyses in those studies, in those many studies, to try to bound it.

DR. CATTON: I guess, then, if you've done this, then you could tell me if the break acts as a steam separator or are you led to the same conclusions with respect to turning off the pumps. If you get -- if the break somehow takes the steam out of the flow and lets the water go by, are you led to the same conclusions?

MR. SKWAREK: It is more conservative to assume that more liquid flow goes out, and that is the way that we have performed the sensitivity studies.

DR. CATTON: I hear what you're saying, but you're not answering my question. You've concluded, because the pumps homogenize the flow, this leads to more mass flow out the break. Therefore, you should turn off the pumps. Now, turning off the pumps may not always be conservative. I don't know how better to ask the question.

MR. SKWAREK: If there was less liquid break flow, we would still want to turn off the pumps, but it would be a less severe transient than the case we have considered.

DR. CATTON: In other words, you would always want to turn off the pumps and the fact that the pumps homogenize the flow is not the main reason?

MR. SKWAREK: Yes, that's correct.

DR. CATTON: Okay, I understand that.

DR. PLESSET: And always keep the high pressure injection going.

MR. SKWAREK: That's a good idea, yes.

DR. PLESSET: All right, now. I don't have a break at all, but the pressure has fallen for some other reason. Is this conservative, what you're suggesting?

MR. JOHNSON: I think we'll be addressing some of that.

DR. PLESSET: I'm sure you will.

(Laughter.)

DR. PLESSET: But you can say yes or no now.

MR. JOHNSON: Our procedures have been written such as they are conservative, to assure core coolability with safety injection on, permitting termination in the event of non-breaks, to provide sufficient flow to assure core integrity, and turn them off only after it's been established that there is in fact no break.

MR. SKWAREK: There was considerable thought put into the Westinghouse criteria of tripping the pumps at 1250 psia to give adequate protection for the small break, but also to increase the margin for non-LOCA accidents as well. We're going to have a presentation on the non-LOCA accidents.

DR. PLESSET: Okay, we'll wait, then.

DR. CATTON: Just a question for my own education. In looking through all of your different plants, I notice there's a large range in HPI set points. They run from 1750 to 1850 psi. Is there any reason for that or is it an idiosyncrasy of the plant?

MR SKWAREK: I don't know the answer to that question. But if you're asking in the context of the small break accident, for small breaks we're going to drain the system, and would you want the safety injection to come on sooner, as soon as possible. The reactor coolant system would depressurize very quickly through all those pressures.

DR. CATTON: I understand that. It's just that when I looked at them I could see nothing obvious about a given plant specification that would give me any clue as to why there was about a 135 psi difference.

MR. SKWAREK: I don't know the answer to that question myself.

DR. CATTON: Then I don't feel too bad.

DR. PLESSET: Can anyone answer Dr. Catton's question?

MR. STEITLER: Bob Steitler, Westinghouse. The set point for safety injection is typically set at some value lower than the reactor trip set point. I'm going to show some graphs of that in my presentation. On some of the earlier plants, okay, it was perceived that more margin between reactor trip and SI would be a nice thing to have. In other words, some of the SI set points in some of the earlier plants were set a little lower. Newer plants, okay, or current plants, the SI set point is set about 100 psi below the reactor trip set point.

DR. PLESSET: Thank you.

MR. SKWAREK: So, from comparative WFLASH analysis that considered different assumptions at the break, we considered that the heterogeneous assumption, the separate assumption with the break at the bottom of the pipe, tended to maximize the discharge out the break and was conservative for these analyses.

We also took a look at the core control volume and downcomer control volume, and arrived at basically the same conclusions, again through a comparative WFLASH analysis that indicated that the heterogeneous assumption utilized throughout the transient for bbth the core and downcomer would yield conservative results.

DR. ZUDANS: How heterogeneous is this heterogeneous?

MR. SKWAREK: For some times when the pump is operating --

DR. ZUDANS: No, in your analysis model how do you analyze it? What do you mean by heterogeneous precisely?

MR. SKWAREK: By heterogeneous, precisely, I mean that a control volume -- we have inlet flow paths and exit flow paths that are at various elevations, and you have a calculated mixture void fraction, mixture level, and corresponding, above the mixture, steam volume. And as things come in and go out of that control volume, they are apportioned and put in or taken away from the correct phase, depending upon the elevation of the mixture height with respect to the elevation of the flow paths.

DR. ZUDANS: But it's still one fluid two-phased or two-fluid two-phased or what?

MR. SKWAREK: One fluid two-phased.

DR. ZUDANS: These phases react separately or mix? You have two phases and each phase is analyzed as if it existed alone in that space, or is it mixed with the other phase?

MR. SKWAREK: It's mixed.

DR. CATTON: I thought that was homogeneous.

MR. KELLY: The difference is that you have an interval of the separated steam mass in each control pump. That's the additional one that you need to make this analysis.

DR. ZUDANS: That's still really not heterogeneous.

MR. SKWAREK: It is heterogeneous.

DR. CATTON: Doesn't homogenized mean mixed? Also, this is non-uniform flow. I think that's what Dr. Zudans would like to hear: how non-uniform is the mixture?

MR. KELLY: The model is a standard bubble-rise model. As Mr. Skwarek pointed out, the incoming and exiting fluids drag according to whether they were coming from a separated steam phase or from the mixture phase. The mixture phase is treated in a homogeneous manner in and of itself. There is bubble rise at the interface, which we add to the steam phase.

DR. CATTON: So the heterogeneous aspect of it is just steam separation. You're just getting the void distribution. You're really still treating it as homogeneous. What about from a fluid mechanics point of view?

MR. KELLY: From a fluid mechanics point of view.

DR. CATTON: That's homogeneous flow.

DR. ZUDANS: Then it's heterogeneous/homogeneous.

DR. PLESSET: Have you taken the temperatures to be the same?

MR. ESPOSITO: Yes.

DR. PLESSET: So that the change in steam volume is just a pressure effect, is that it, a local pressure change, is that right?

MR. KELLY: No, it's still a true separation effect.

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Within the control volume, if you have the separated steam space above the homogeneous mixture of steam and air, with respect to the momentum equation, if the flow path is contacting the mixture and it looks like homogeneous flow out of the mixture; if it's contacting the steam phase, it looks like pure steam.

DR. PLESSET: I think I'm going to have to defer to an expert. Dr. Fabic, do you want to make a comment?

DR. FABIC: We have struggled with this problem for years.

DR. PLESSET: It sounds a little mixed up to me.

DR. FABIC: We've struggled with this problem of nonhomogeneous flow for years, and as you probably remember, years ago there was something called pancaking problems. You have two or more control volumes, one on top of the other. You end up with an unrealistic situation where you have a layer of vapor with water below and then above that control volume.

There's another similar situation, a layer of vapor and a layer of water. And so, this is why people then started to introduce slip or drift in their energy equations, to try to have the water communicate, to go down through the junctions and have another equilibrium. But this was always done in some kind of a band-aid fashion, all right? In other words, the calculations are done on the homogeneous model, and after the fact a separation is done and we adjust the fluxes of each junction to do again a homogeneous calculation next time.

So I do not regard this as really a very defensible calculation.

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DR. PLESSET: It sounds pretty slippery; doesn't it?

(Slide.)

MR. SKWAREK: The next step of the study was to take a look at the results we obtained from various analyses, and to determine what the effect of a continued operation of reactor coolant pump trip is in terms of peak clad temperature, and to understand the behavior. And in general, the very overall view of the reactor coolant pumps operating is that it would tend to keep mixture levels throughout the system at higher elevations due to the much increased flow rates as compared to an FSAR calculation, where the pumps trip at time zero, essentially, and there is a distinct point in time where the break flow void fraction becomes one, which corresponds to the time when the reactor coolant system drains down to the break elevation.

But with the pumps running, since levels are higher, you can continue to put out two-phased from the break, which yields in a reduced primary liquid inventory for continued operation of the reactor coolant pump.

We found through the analyses -- and what we used to get this slide mostly was the three-loop plant analysis, although two and four loop show the exact same behavior. But I am going to refer to two and fours a little differently later. But it turns out that there were really three distinct points in the transient that yield different types of behavior.

The first case would be if the reactor coolant pumps are tripped prior to the time that the reactor coolant system drains to the break elevation, for the FSAR case. And, again, the FSAR case is a case where the pump tripped essentially at time zero. For this case, then, the break void fraction goes to one at approximately the same time as the FSAR calculation. And therefore, the primary liquid mass is approximately the same as the FSAR calculation and yields almost equivalent peak clad temperatures.

And this category here is really represented by the Westinghouse procdure on high-pressure injection. High reactor coolant pump trip of 1250 psia. If you do follow that procedure and indeed trip the pumps, 1250 psia plus uncertainties, you will result in a case that is described there as "Case A," and indeed the FSAR calculation is still appropriate for that situation.

The next point of interest are cases where the reactor coolant pump trips after the time of the reactor coolant system drain to the break elevation for the FSAR case. This results, as I said before, in a prolonged period of liquid mass discharge out the break that results in a reduced primary liquid mass.

This reduced primary liquid mass has two effects after the pumps trip: One is deeper core uncovery and therefore high clad heat outbreaks. The second effect is reduced total time of core uncovery due to two things: one, a late or first uncovery of the core because the operation of the pumps would hold the levels up in the core longer; but secondly, an earlier accumulator injection, which really occurs because of the deeper core uncovery.

As you uncover the core deeper and deeper, there is less of the decay heat that enters the fluid, and therefore, the depressurization rate is greater and you can reach the accumulator injection set point earlier in the transient.

DR. CATTON: I missed that. If I am comparing A and B at a given time would I expect the pressure in the system to be higher or lower than in A, all things being the same except the pumps are off in A?

MR. SKWAREK: I don't understand your question.

DR. CATTON: I get the feeling that there are two competing effects.

MR. SKWAREK: There are.

DR. CATTON: If I turn off the pumps, I am going wind up with -- I think I should wind up with higher pressure because I will have colder fluid in the bottom and maybe superheated steam above.

MR. SKWAREK: While the pumps are operating, there

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isn't a great deal of difference on the reactor coolant system pressure. After the pumps trip, the pressure in the system is driven, in part by the break and also in part by the amount of core that's uncovered.

DR. CATTON: What I am trying to get at is the difference between pumps on and pumps off. Will the pressure be higher for the pumps-off case than for the pumps-on case?

MR. SKWAREK: Yes.

DR. CATTON: Now, if the pressure is higher, isn't it going to depend strongly on where the break is? Some of these conclusions you're reaching, if I have higher pressure, I can sure drive more mass up the break.

MR. SKWAREK: We've analyzed the spectrum of breaks in the study. Yes, there is an effect on break size that I will talk about on the next slide.

DR. PLESSET: The location is a very important question.

DR. CATTON: If I put it just upstream of the pump.

DR. PLESSET: That's right.

DR. CATTON: I don't care whether the pump is running or not.

MR. SKWAREK: I think while the pump is running, there isn't a strong effect on the reactor coolant system

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pressure and therefore not a strong effect on break flow.

DR. CATTON: If I have a break low in the cooling system and the pumps are off, it seems to me the mass flow is going to be higher.

MR. SKWAREK: No, with continued operation of the reactor coolant pumps you can push out more liquid mass than you can for a case where the pumps are tripped regardless of where the break is located.

DR. CATTON: I guess I just don't believe that.

But let's go on.

DR. ZUDANS: There has to be a reason. Is it because it's a more homogenous mix?

MR. SKWAREK: Unless I am not interpreting what you are saying, while the pumps are running there isn't a large effect on the reactor coolant system pressure. Therefore, while the pumps are running, the break flow between the two cases are approximately the same. So, the difference in liquid mass out the break only arises in that in one case the pump's off, you uncover the break elevation sooner than you will when the pumps are running, that you have a prolonged two-phased.

DR. PLESSET: You talk about uncovering the break. Dr. Catton's talking about a break, say, just upstream of the pump. That's a low point in the system. Would it drain down to that point or uncover the system to that point?

MR. SKWAREK: Oh, yes, for all these breaks, you can completely drain the system.

DR. PLESSET: That's what is a little disturbing.

DR. CATTON: It just doesn't fit.

DR. PLESSET: Just a little disturbing.

DR. CATTON: Because the pressure is higher, then the mass flux is going to be higher up to the point where the break is uncovered.

MR. SKWAREK: The pressure is approximately the same while the pumps are running.

DR. CATTON: You are arguing that one should turn off the pump. So, I ask the question: is the pressure going to be higher or lower with the pumps running? If it's going to be lower with the pumps running, then I am going to have higher mass flux out of a break that's low in the system and the pumps are not running because the pressure is higher.

MR. SKWAREK: Prior to the time the break uncovers, the pressure with the pump running or not running is approximately the same.

DR. PLESSET: Now, we go to the point where the break is uncovered. That's what he was talking about.

DR. CATTON: And that's different. What he's saying is different. He's right. If the pressure remains the same until the break is uncovered, then you're right. But now I can conceive of a situation, gee, I think, in which it was apparent in the data from Three Mile Island where the water below the core was cold and the steam was superheated. Now, in that set of circumstances, if I were to mix up the system, I would get a pressure drop; right? So, it would depend upon where the break is.

MR. MICHELSON: That's like a restart of the pump flow.

DR. CATTON: I mixed it up to make a point. I have regions where the system is, in essence, subcooled and regions where it's superheated. If, under those circumstances, I am going to have a higher pressure --

DR. ZUDANS: You say whether the pump is running or not, until the break is uncovered the pressure is about the same. What maintains that pressure?

MR. SKWAREK: What's maintaining the pressure there is really a balance of heat removal from the primary system through to the secondary system. And you find that the RCS pressure tends to hang up at a pressure just high enough above the steam generator safety valve to maintain a complete removal of decay heat because at this point in time the break is still removing liquid flow, so it's removing relatively little of the decay heat. So, it's really the steam generator secondary side that determines the reactor coolant system pressure early in the transient.

DR. ZUDANS: And that means that the heat removal rate at the secondary system is about the same whether you have pumps on it or not. Is that likely or possible? Or is that true? I understand your point. You remove the heat at the same rate in either case on the secondary side, and you generate the same amount of heat and remove the same amount of heat through the break; then your pressure will stay put.

MR. SKWAREK: Yes.

DR. ZUDANS: Now, is the heat removal rate different in case of the pump running or not running?

MR. SKWAREK: The analysis doesn't show significant difference, no.

DR. ZUDANS: It means you establish it instantly or immediately or shortly, natural circulation that's able to transport the same amount of heat through the primary system to the secondary as if the pumps were running?

MR. SKWAREK: That's right.

Rick, do you have something to add?

MR. MUENCH: I hope I can clarify just a little bit. I think that the heat rate indeed is different when you have the reactor coolant pumps running versus not running. But the steam generator set point is the same in either case.

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DR. ZUDANS: Does that have something to do with the fact that you run the heat pumps and they also add a lot more heat to the system comparable to what your decay heat is?

MR. MUENCH: I don't have a good handle on that. Really, I wasn't really addressing that. Certainly there is more power added to the system when you have reactor coolant pumps.

DR. ZUDANS: You're probably right in what you are saying, but it's very difficult to imagine, just by listening, that you really will have such a nice, balanced situation. There has to be some difference, maybe not significant.

DR. PLESSET: If I understand what you're saying, you say that the heat removal rate is about the same whether the pumps are running or not.

DR. ZUDANS: That's the point.

DR. PLESSET: Is that what you're saying?

MR. SKWAREK: Yes.

DR. PLESSET: So that the only reason for turning the pumps off is to affect the loss of inventory rate?

MR. SKWAREK: Yes.

DR. PLESSET: So that leads to another question. Are you calculating that correctly? And my hunch is that you aren't, in most cases. That's my hunch. I don't have

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any demonstration.

Dr. Catton indicated some concern about this, which I share, calculating the rate of loss of inventory, which really is the central question in this whole analysis -- is that right -- because you already told us that the rate of heat removal doesn't change very much. That's a little surprising, in itself. To me, it is. I don't know about you.

Would you say you're a little surprised? Let's grab that for the moment.

DR. ZUDANS: I would be even more surprised, because if the rate of heat removal does not change, then your pressure should increase with pump operation because it adds some more heat. Maybe it's just the 10 percent; I don't know.

MR. ESPOSITO: I would like to make two comments, one that Pat Docherty will make with discussion on the break flow, and then a comment to Dr. Catton's concerns on the TMI situation, what happened to the pressure there.

I think we have left it open. We haven't gotten closure.

MR. DOCHERTY: Pat Docherty, from Westinghouse.

As I indicated, our break model does take the local conditions at the break location, so we don't preferentially poll steam and water. So, if we have a separated mode with a two-phased mixture and steam space above, what you do when you put the break at the bottom is that you calculate an inventory loss based on a separation, and the separation is almost complete because the lower-phased mixture is very low quality.

That situation is a situation where you have a very good separation mechanism and you have a large inventory loss. What do you have to do to your pumps? The answer is that you have to trip them and you have to trip them in about 10 minutes. So, it does make a difference.

The other case is that if you have complete steam flow at the top of the pipe, what happens then? Well, it's indicated from the results of the studies that pump trip is not so critical.

All we're saying is that if the situation exists -- and our data indicates that it would -- that you do have separation, and good separation, in that pipe, then you'd better make a decision on pump trip based on that situation. That's what we're doing.

And the situation that you talk about, of preferential voids moving towards the break, is somewhere in between those cases.

DR. PLESSET: I think there is another point. You're supposing that the break doesn't affect the state of the liquid near the break. Right? You're supposing that the break, the presence of the break, doesn't affect the state of the liquid in the neighborhood of the break?

MR. DOCHERTY: That's correct.

DR. PLESSET: But it does.

MR. DOCHERTY: In that it would preferentially pool more voids.

DR. PLESSET: It becomes a superheated liquid now because it knows that the pressure just outside that break is very low and in the region of inflow. It's the kind of thing that Dr. Fabic was describing for us a little while ago. So, that liquid could very well flash there even though you wouldn't, in your model, assume that it did.

MR. DOCHERTY: That phenomenon is part of the break flow model. I will go through that discussion.

DR. PLESSET: Oh, you're going to talk about that. Maybe we'd better wait, then.

MR. DOCHERTY: You have to be very careful about break geometry before you apply break flow to correlations. And what we did was go back and look at the possible break geometries and decide whether our break flow correlations are sufficient.

Further discussion is what's happening upstream based on the break flow.

MR. SKWAREK: Just to repeat again one more time. In that last slide, where I said we did studies at the break

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node, by having a heterogeneous assumption at the break node, it didn't tend to maximize the liquid discharge from the break in terms of the system. The two characteristics, then, A and B, really have opposing effects on peak clad temperature and give rise to a maximum function of peak clad temperature versus reactor coolant pump trip time.

And we have found for some break cases that, given the assumptions in the model, that peak cladding temperature calculations may be calculated to be greater than the FSAR case and greater than 2200 degrees.

The last type of behavior that we have observed would be indicative of a case where the reactor coolant pump has continued to remain operational essentially indefinitely. And for this situation we maximize the liquid mass discharge period. The longer you keep the pumps running, the more liquid mass you push out the break. So, this clearly maximizes that effect.

However, there is another effect that you have with the pumps running that more than compensates for that; that being that as the pumps remain running, the top of the downcomer becomes pressurized and the level in the downcomer is depressed by the pressure applied by the pumps and it tends to depress the downcomer down to the elevation where steam now can flow around the bottom of the core barrel and up through the core. And in fact, large amounts of steam are calculated to flow around the bottom of the barrel into the core and this yields very good steam cooling flow rates, like an order of magnitude higher than steam cooling flow rates that would exist if the pumps were tripped.

And for these cases where the pump is running throughout the entire transient, the peak clad temperature remains well below the FSAR case.

MR. MICHELSON: Before you leave that slide, could you give me just a brief discussion of how you handled the break at the top of the pressurizer in terms of the modeling and flows and pumps running or not running?

MR. SKWAREK: The break at the top of the pressurizer, we utilized -- we did utilize a better estimate break flow model that was based on the geometry and found that there is still, as the results that Rick showed before, from an area of one PORV to three PORVs, that there is still no core uncovery if one assumes that the PORVs are stuck open. It assumes this better estimate break flow model.

MR. MICHELSON: What I am really getting at is: describe to me mechanistically now what is flowing out the break as a function of time, particularly as the void fraction gets very large in the circulating fluid, and what happens to the inventory of water that was up in the pressurizer that never gets back out or becomes homogenized with the rest of the system?

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In other words, walk through the hydraulics of it.

MR. SKWAREK: As the break starts out, the mixture level rises in the pressurizer and rises right to the elevation of the break and then there is two-phase flow out the break. And depending upon the break model that's assumed, that determines the amount of two-phased flow. And you would continue to have the two-phased flow out the break, and you'd deplete the mass within the rest of the reactor coolant system.

MR. MICHELSON: Yes. Something's got to come in as something is coming in. What's coming in during this time now? I understand, of course, there'll be two-phased going out. What's coming into the surge line?

MR. SKWAREK: Earlier in the transient, it would still be two-phased flow. But as you continue to deplete the mass of the primary system, eventually it would go to steam flow.

MR. MICHELSON: That's the question. Is the fluid in the pressurizer now of the same void fraction as the fluid in the valves of the reactor coolant system, or is it some other void fraction?

MR. SKWAREK: It's likely to be a different void fraction.

MR. MICHELSON: Do your calculations track this?

MR. SKWAREK: Certainly. Yes.

MR. MICHELSON: Because that's the only way you can track the mass lost from the system out through the pressurizer break, so you must have some way the results of this. Are they reflected in any of the reports that you handed out to us?

MR. SKWAREK: Well, WCAP 9600, we did the analysis of the power-operated relief valve breaks, and there were, I guess, 50 different plots of various system parameters. One of them was pressurizer level, void fractions and qualities throughout the system.

MR. MICHELSON: I guess my difficulty with 9600 is the same as with your explanation; that is that it's a whole lot of answers but I don't understand what's going on in the system.

Maybe, indeed, the calculation does take care of all of this. I will take your word for it now. But you can see my difficulty. This is clearly a unique break and doesn't behave like a break in the hot leg or the cold leg. And if something happens to the large inventory of water, I am just trying to figure, visualize what's going on. And it's not entirely clear to me what the answer is, and I can't find it in 9600. But that was an awful lot of paper to go through to find it. I thought maybe you could just answer.

DR. CATTON: I would just like to second

Dr. Michelson's comments about WCAP 9600. Other than being 9600 pages and being very difficult to read, I found very little descriptive material of the physical processes you're trying to model, just kind of a verbal description and then a whole bunch of answers. What that leads to is asking probably what are a lot of stupid questions here.

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MR. ESPOSITO: I'm sorry, Dr. Catton, that you feel that way about 9600. We thought we did a rather significant piece of work in understanding the behavior of small breaks. Section 3 of the report is probably one of the best exposes on what you would expect and what is going on. The reason for the large amount of paper in there was the need for putting all of the plots that were required. It made it bulky, but we were hoping that it would not take away from the meaningfulness, especially of Chapter 3, where you talk about phenomena and behaviors that are going on in a small break.

Besides WCAP 9600, however, there are a number of references which go back and talk about some of the details, perhaps, that we had been requesting, some of the calculations in the models that had been previously submitted. So, yes, indeed, it's not all very simply in one place. I can appreciate that statement, but we were hoping that the report indeed was quite clear in its explanation of the phenomena going on.

MR. MICHELSON: I would just for my own benefit like to point out that I thought it was a very fine piece of work. I didn't have any difficult accepting this one case. But in this one case I just didn't seem to be able to find the answers we're looking for.

MR. ESPOSITO: For that particular case, then, I think it would be well to put together the follow through and the walk through of that particular case.

MR. MICHELSON: I wasn't attempting to pass any reflection on the balance of the report. But this particular one, and I thought it was an important thing to consider, and I couldn't find the descriptions of the phenomena that were going on, but rather just some answers, and I didn't understand clearly that that would be the answer.

MR. ESPOSITO: We will put together the description of the phenomena as the transient proceeds.

MR. MICHELSON: I think it's very important because it will bring to light, then, a few of these other parts of the discussion earlier today and the concerns I had.

DR. CATTON: I think it depends on what you're looking for. I was very interested in the reflex mode steam generator, and I tried to find where the effects of noncondensibles had been assessed, and all I found was that the heat transfer coefficient is 200. And I find that somewhat unsatisfactory.

MR. ESPOSITO: We do not have reflex mode in the present evaluation.

DR. CATTON: Maybe I'm getting the reports mixed up.

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DR. ZUDANS: I have just one question. One comment was made by you there that left me a little confused. You said that when you put the break in the control volume near where the homogeneous mixture was, you calculated that you had about ten minutes time to shut the pump down. Now this, in my simple minded interpretation, is contradictory because I thought the pumps homogenized the flow and leads to a larger discharge. But the flow is already fluid.

What is the scenario in this case?

MR. SKWAREK: The pumps tend to cause the fluid levels to remain at higher elevations due to the high flow rates, but you still have a draining effect. The EVA pump tests do show, even with the pumps operating, that a heterogeneous assumption downstream of the pump is most appropriate.

DR. ZUDANS: I see. That means if I shut the pump down, this fluid will disappear from that location.

MR. SKWAREK: Yes. With the pumps running, the void fractions below the mixture height tend to be higher than they would be with the pumps off. Then as soon as you shut the pumps off, because you have expelled more liquid mass but still have a mixture at higher void fraction and a higher elevation, a level and the system does just kind of drop out as soon as you trip the pumps. And that's when the deep core uncovery occurs for some break sizes, and sometimes a reactor coolant pump trip.

DR. ZUDANS: Well, I was just trying to put those ten minutes in better perspective. I don't think it's quite clear to me, but leave it at that.

MR. DOCHERTY: What I'm saying is is that when the pump's running, it brings fluid into the cold leg, and the EVA tests show that it brings water into the cold leg as opposed to the case when the pump is not running and water is not being brought into the cold leg. Now once that mixture is brought into the cold leg, the pump tests show that it separates out, so that you do model the break at the bottom of the cold leg. And then you would be discharging fluid.

DR. ZUDANS: Okay. If you shut the pump down, you will not have that.

MR. DOCHERTY: You will not be bringing that water in.

DR. ZUDANS: Thank you.

DR. PLESSET: This, of course, assumes that the most important case is a break in the cold leg. And I presume you've established that.

MR. SKWAREK: Yes, we have. I'm going to talk about other break locations on a further slide. But I just wanted to explain the phenomenon first. Then we'll expand to different plant types and different break sizes and locations.

Just to show one more time a little bit of analysis results, I'd like to show you the effects of A and B that I just discussed -- deeper core uncovery and a reduced total time of core uncovery -- that I put up, and they're on your next two slides.

(Slide.)

This curve is actually a connection of points that were developed from a number of analyses. There may have been six or eight different analyses that have established this curve. What we did is look at the three loop plant, and at this point in time looking at a three inch cold leg break, we plotted reactor coolant trip time from the analysis versus the minimum core mixture elevation. And as we see as the time of the reactor coolant pump trip is delayed more and more, then you have a deeper and deeper core uncovery.

Eventually, even with the case where the pump is continuing to run, the break flow void fraction would arrive at one all steam for that case as well. That occurs right out here. So you would expect to see this line then kind of leveling out, as it does.

DR. ZUDANS: Where was this break that you showed this curve for -- the break location for this curve?

MR. SKWAREK: This is a three loop, three inch cold leg break.

DR. CATTON: Where in the cold leg?

MR. SKWAREK: At the bottom of the cold leg.

DR. ZUDANS: Before or after?

MR. SKWAREK: Downstream of the pump. I'm sorry.

DR. ZUDANS: Downstream of the pump discharge.

MR. SKWAREK: Discharge of the pump.

DR. ZUDANS: Why would that affect -- I guess it would.

MR. SKWAREK: The longer you keep the pumps running, the longer the mixture levels tend to stay up in the system. Therefore, the longer is your period of liquid discharge before you switch over to all steam discharge.

DR. CATTON: What is the lowest point in your system?

MR. ESPOSITO: The bottom of the vessel is the lowest point in the system.

DR. CATTON: Okay.

(Laughter.)

DR. PLESSET: He's thinking of the loops, not the vessel.

DR. CATTON: The lowest point in the loop.

DR. PLESSET: Do you want to talk about a break there?

(Laughter.)

MR. ESPOSITO: We did.

MR. MICHELSON: The curve showing minimum core mixture height is an important one. Could you give us just a little feeling though what it also did to duration of experiencing this minimum core height? Doesn't it tend to stretch out the exposure time considerably?

MR. SKWAREK: Yes, that's what the next slide will show you.

(Slide.)

And here I'm plotting B, which is again -- it's for the three loop, three inch break and reactor coolant pump time versus the total time of core uncovery. And as I said before, as you delay the reactor coolant pump trip, the total time of core uncovery tends to decrease.

DR. PLESSET: What is this critical break size? What break size is referred to? Is that three inch?

MR. SKWAREK: This is the three inch we've done here. The critical break size I'm going to talk about in just another slide or two. That's the largest break that you must trip the reactor coolant pumps in order to maintain peak clad temperatures below 2200 degrees.

DR. ZUDANS: Looking at these two plots, it seems like something is missing in terms of additional information. One case showed that you would have covered further down. This case shows that you uncover for a much longer time if you were in a hurry to shut the pumps down. Isn't there some kind of an optimum point, combination of uncovery versus duration of uncovery in terms of damage?

MR. SKWAREK: There is. I wouldn't call it an optimum point, though. I'd call it a worst point.

DR. ZUDANS: It would be an optimum point, because you're looking for the least damage -- not for the most damage. For the most damage, just keep it open. There's an optimum minimum damage as a function of uncovery versus duration of uncovery.

If you shut the pump down soon, you uncover it for a longer time, but if you shut the pump down sooner, you have according to your other plot QQ

DR. PLESSET: I think damage is kind of unfortunate. It may even be an unpleasant word.

DR. ZUDANS: A higher core elevation, so you uncover for a longer time but small amount. So it's contradictory need. You understand?

DR. PLESSET: I think, Zenons, the point is that you don't have core damage.

DR. ZUDANS: I'm not talking about that in a qualitative sense. Your first plot shows that if you trip at 600 seconds, you uncover or your minimum core mixture elevation is five feet, but your last for a total time of

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core uncovery --

MR. SKWAREK: 600 seconds. Yes.

DR. ZUDANS: If you trip the pump at 800 seconds, your minimum core mixture elevation is only a foot and a half. It's more core uncovery but for less time.

MR. SKWAREK: You're wondering what the trade off is?

DR. ZUDANS: Obviously, there is an optimum point.

MR. SKWAREK: I have it drawn on a slide later. I'll finally bring this all back together and peak clad temperature, and you'll find that peak clad temperature tends to go up here and then come back down again. So there's really a maximum point of peak clad temperature somewhere for this case, tripping the pump in this region here.

DR. ZUDANS: So that would be something that you should avoid?

MR. SKWAREK: Yes, sir.

DR. ZUDANS: According to the way you draw that line, it would appear that the longer you wait for shutting down, the better it is -- certainly beyond 800 seconds.

MR. SKWAREK: That's probably right. If you could ensure that those pumps could keep running beyond 800 seconds, you probably would be okay. That's right. But it's getting through this point that is the problem.

DR. ZUDANS: Then the statement someplace else that we heard this morning, that we'd have to shut it down within 13 minutes is incorrect? You have to go beyond some point and then shut down.

MR. SKWAREK: The 30 minutes, if I recall correctly, it's on the time that the core would uncover, given a PORV stuck open.

DR. CATTON: I think the 30 minutes was steam generator dry out time.

MR. SKWAREK: Yes, that's another 30 minutes. Bill?

MR. JOHNSON: We may have missed a significant point here in that if, in fact, the reactor coolant pumps can continue to operate throughout the transient, it's clear that the results are improved over the point where they are tripped. What we're trying to address here is the possibility of, for some reason, pumps operating up to a point in time in the transient and then for a spurious reason or the fact that the operator is sensing damage to the pumps beginning, he should shut them off, shutting them off at a particular time relatively early in the transient where potentially undesirable situations can occur. But if the pumps can operate through the transient, the results are the best.

DR. ZUDANS: I misunderstood your previous presentation then. I thought you were directed to trip the pumps.

MR. JOHNSON: We do that because w cannot guarantee that the pumps will not trip at an undesirable time at some point in the transient. If I could gurantee that the pumps would always operate, I would not trip the pumps. I can't do that.

DR. ZUDANS: I understand. The only thing that these two slides tell me is that there is a time before which you should not trip the pump.

MR. JOHNSON: No. I think the interpretation is that there is a time at which it would be undesirable to trip the pump, and if in fact the pump would eventually trip at that time, it is desirable to trip it prior to that time.

DR. ZUDANS: He says it should be tripped prior to something like 600 seconds.

MR. JOHNSON: That is if the pump would eventually trip at like 700 seconds. Since I can't guarantee that the pump won't trip a minute from now for some other reason, we are currently recommending that the pump be tripped prior to that point in time.

DR. ZUDANS: Okay. What my concern is, by your set of instructions, they only refer to one point at the pressure setting. You may just direct the operator to trip the pump right in the wrong place at the wrong time.

MR. SKWAREK: We've checked that for a number of plants, and that really falls in the category of the first type that I talked about on the slide which shows the analysis results of evaluation. We've shown by analysis that if the pumps trip at the 1250 psi, you're way back here. You're just like the FSAR case. It's essentially equivalent to tripping the pump at time zero in terms of the thermohydraulics of the LOCA.

You know, we've run the cases, and it's presented in WCAP 9600. If I showed you an FSAR calculation for uncovery transient and then showed you another calculation where I tripped the pumps at 1250 psia, they would appear identical to you. There's maybe some slight differences in the calculation, but looking at the transients, they would appear identical.

DR. ZUDANS: You are saying that they would occur before.

MR. SKWAREK: Yes, sir. It occurs back here, although this only goes to 500, so it's further back.

DR. PLESSET: I think we'd better move on. I think we're running behind a little bit.

(Laughtyer.)

MR. SKWAREK: Okay. I'll move on. So for any one break size, what we came up with was an interval of possible worst peak clad temperature, but it gets more complicated in that you can't predict what the break size is going to be.

(Slide.)

In fact, if you change break size, relationships in absolute time-space also shift. So we found that the break size affects the magnitude of the peak clad temperature. As we move to larger and larger breaks, there's a reduced peak clad temperature penalty, and when we move to smaller breaks, there's an increased peak clad temperature, and the larger and smaller at this point -- I'm still using as my point of base measure the three inch break for the time being. For very small breaks, for example less than one inch in diameter, there is essentially no peak clad temperature because the reactor coolant system will not drain for that case.

You will tend to maintain a two phased continuous circulation of fluid. In fact, for a break of three quarters of an inch or less, the equilibration pressure that Rick talked about earlier in the morning is about the equivalent of 1250 psia, so you wouldn't be instructing the operator to trip to pump for that size break. If he did trip it though, there would be no adverse consequences.

We've also found that the break size affects the length of the reactor coolant trip time interval of worst peak clad temperature results. And as we move to larger breaks, the interval decreases or vanishes. And as we move to smaller and smaller breaks, that interval of worst possible peak clad temperatures tends to get broader and broader.

In terms of a break location, we have verified by analysis that the hot leg break is much less limiting than the cold leg break really for two reasons. Well the main reason is that there is a much greater liquid mass inventory and thus much less core uncovery for the hot leg break, due primarily for two reasons. With the cold leg break, we assume that the line of pump safety injection of least resistance spills and never enters the reactor coolant system. But for the hot leg break, we include that line as part of safety injection systems. So we're putting more liquid in.

On the other hand, if you want to look at what's leaving the system if you have a hot leg break, entropies at the break location tend to be higher and therefore break flow up to any point of trip time in the transient is less. So the net effect is much greater liquid mass inventories and less impact in terms of peak clad temperature.

DR. ZUDANS: Could you define more precisely under Item 2 this time interval?

MR. SKWAREK: The next slide's going to show that pretty clearly. In addition, since we've submitted this

WCAP, there has been some question coming from the NRC to us concerning hot leg breaks, and their concerns were really of two issues -- the first issue being that they thought if a drain were allowed back from the steam generator, that it may be possible to make the hot leg break flow worse. In fact, the hot leg break may become worse than the cold leg break.

The second concern dealt with a more realistic assumption of the flow path between the lower plenum entering into the core. So to respond to them, we did make an analysis of the hot leg break that did include a slip in the steam generator and did include a revised lower plenum flow path elevation, yet still come to the same conclusion for hot leg breaks -- that they are in fact less limiting than the cold leg breaks for the same reasons that I have just stated.

MR. MICHELSON: Before you leave that slide, let me ask you about another break location, and that is the case of the steam generator tube rupture wherein the secondary side relief valve has to open and as a consequence sticks open. So now we've got a small break LOCA proceeding through the steam generator tube and then out through the stuck open relief valve.

How would that LOCA behave?

MR. SKWAREK: When you look at a tube rupture like that, it probably still gives less inventory lost from the primary system than with the same size break of a LOCA directly to the containment.

MR. MICHELSON: It's a little more involved, of course, than simple inventory loss. There is the question of heat removal. How does the scenario go? Have you considered that one in your analysis of small breaks?

MR. SKWAREK: I have not done an analysis of that situation. We have done analyses of tube ruptures.

MR. MUENCH: Rick Muench from Westinghouse. From time to time we sit down and we come up with something to consider. So I'm shooting a little bit from the hip here in trying to respond, and I want Ray to help me along a little bit.

We have, let's say, a full double-ended tube rupture. That's a three-quarter inch tube. And if it's double-ended, maybe we can approximate that as a one-inch small break.

And you're proposing that the atmospheric relief valve perhaps in that steam generator, or whatever you want to assume there's a break or whatever in the secondary side, the secondary is also blowing down, which essentially makes it a combination LOCA and tube rupture.

I think in the limit, that looks just like a one-inch small break, for a one-inch small break.

This is why I need Ray for a little help here. When it's small break, we would not drain any reactor coolant system, as long as we had minimum safeguards.

And Ray had a slide showing that there were three categories of small LOCA -- those which would equilibrate above 1250 psia and not drain the reactor coolant system. Therefore, reactor coolant pump operation would not significantly impact the situation.

This would fall into that category.

MR. MICHELSON: Not quite because the pressure will drop below the 1250. I'm assuming now that you never reclose the relief valve, of course.

So it's a combination of rapid cooldown involved, as well as the small break.

There's a combined primary and secondary side blowdown.

MR. MUENCH: I still have the other steam generators.

MR. MICHELSON: Yes, the other steam generators are still functional. I just wonder, have you worked through an analysis of the situation.

MR. MUENCH: We have not done an analysis of the tube rupture, plus the steamline break, the equivalent of a steamline break.

MR. MICHELSON: I'm not talking about a steamline break, but rather, the single-failure criteria on an unqualified piece of equipment. But it does seem to be a little bit different. I wasn't able to track that answer, you know, looking at your results so far, and I just wondered, it may not take much more homework to be able to track that answer.

I just don't know.

But it is, I think, a legitimate scenario to postulate.

DR. PLESSET: And there could be some effect on your heat sink. I'd like to know any ideas that you had in mind.

MR. MICHELSON: It's a fast cooldown combined with a small primary-sized blowdown, combined with whatever else happens in a case like that, all because of a single failure after the tube rupture.

MR. SKWAREK: If in general, if you would have like a LOCA with a more significant cooldown, it tends to decrease the break flow and increase the pump safety injection flow that would be entering the system.

So from a gross mass inventory standpoint, that appears to be an attractive situation.

MR. MICHELSON: By the way, there are those who might wish to postulate -- I shouldn't say that. Let me take a different way.

Certain types of plants have atmospheric dump systems which are automatically controlled by a number of valves, not just necessarily one. That is also in operation in the process of closure. If one failed to close, or perhaps in the process of generating the signal, none of them closed because the automatic control circuitry was set to stay open. That's a more severe cooldown.

But I don't know if we've looked too much at these possibilities.

DR. PLESSET: I guess that we'd better get through this and get on to some more.

(Slide.)

MR. SKWAREK: The next slide kind of puts together the question that I promised to answer about the effect of various break sizes.

This is somewhat complicated but what I'm plotted here is reactor coolant pump trip time versus the peak clad temperature in degrees Fahrenheit.

Again, all these cases are peak clad temperatures as calculated with the evaluation model with all FSAR minimum safeguards assumptions. And we have our three-inch break that we've talked about before, which is the solid line here. I have a dashed line that results from a two-inch break with a three-loop plant that I've calculated. And then there's also a plot of a four-inch break, a slightly larger break than a three-inch break that we calculate.

And these curves, for example, for this curve here, it's made up of 4, 5, or 6 different analyses, each with a different reactor coolant pump trip time. The same with the 3-loop plant as well. The 2-loop plant, we didn't fill it in with as many cases because it's easy to see the general idea.

So, as I said, for any given break size, there appears to be an interval of worst possible peak clad temperatures. But if you now assume an infinitely large, different number of breaks that may exist, instead of its being an interval now, you may have a continuous time with a minimum point wherein the pumps must be tripped prior to that point to keep peak clad temperatures below 2200 degrees.

Let me just explain what these vertical lines are here. These vertical lines are the time and the FSAR calculations when the break flow void fraction went to 1.0.

As I said a couple of slides back, that determines the difference between the Type A transient and the Type B transient, where the Type A transients are less severe than the FSAR calculation and the Type B are greater.

You can see pretty clearly that your FSAR calculation for this three-inch break, for example, would be 1708 degrees peak clad temperature.

That assumes a pump trip of like zero. As you increase pump trip time, peak clad temperature decreases somewhat. Then just as you trip the pumps is the time when, in the FSAR case, the break flow went to 1.0.

You now start prolonging the period of two-phased discharge out the break resulting in high peak clad tempertures.

From this plot, however, we develop the concept of an critical break and I'll go through that, really, on the next slide.

(Slide.)

From the previous analyses that I've shown, I make the distinction that for the 3-loop plant, at any rate, the largest break size that yields peak clad temperatures greater than 2200 degrees is approximately a three-inch break. As you move to the four-inch break, you can see that the maximum peak clad temperature is decreased significantly.

The second point is, as represented by that vertical line, that the reactor coolant system drains the break elevation at approximately ten minutes after the accident initiation for the three-inch coldleg break on this 3-loop plant.

You come up, then, with a critical time of 10 minutes, and conclude then that if the reactor coolant pumps can be tripped prior to 10 minutes, the peak clad temperatures will remain below 2200 degrees, regardless of the break size that's assumed.

Again, I just point out the conservative assumptions that are in this analysis, such as the ANS plus 20 decay heat, the fact that you have minimum safeguards rather than maximum safeguards, and the fact that I've assumed a minimum accumulator injection pressure for all cases.

And our conclusions are then for the 3-loop plants, that the 10-minute number is a reasonable number to assure that the peak clad temperatures will remain below 2200 degrees.

DR. ROSZTOCZY: Mr. Chairman, you mentioned that all these calculations were done with minimum safety injection. Have you done any calculations with full safety injection, the question being should the safety injection work as it is designed to work? Is there a need, then, to trip the pumps?

MR. SKWAREK: With full safety injection, there would still be a need to trip the pumps. But that time, the critical time that would be calculated would be a slightly longer time.

But, yes, with full safety injection, we would still see the need to trip the pumps.

DR. ZUDANS: Mr. Chairman, I still -- you still didn't define this interval. You may do that later. But I am still looking at your critical reactor coolant pump trip time equal to 10 minutes.

I'm looking for an interval either before or after 10 minutes, or after some other time, physically.

MR. SKWAREK: It must be tripped before 10 minutes. If the operator knows he has exactly a 3-inch break, then he either has to trip it before 10 minutes, or he knows that maybe he can trip it after 800 seconds and still be okay. But he doesn't know what break he has.

So when you bring in the concept of all the possible breaks, it's no longer an interval. It becomes, you know, a whole time period. It's just a minimum time when one considers all the possible small breaks.

If I wanted to plot a 2-1/2 inch break here, that curve would fall in here somewhere.

DR. ZUDANS: Okay. So he doesn't know what size break he has. He cannot precisely define intervals. And because you don't know what size break he has, you cannot define the other end of your safe time of tripping the pump.

MR. SKWAREK: This end? That's correct, sir.

DR. ZUDANS: So instead of specifying that you trip it before 10 minutes or after 30 minutes, you are not sure about 30 minutes.

Is that right?

MR. SKWAREK: That's right, because 30 minutes, if he has a 2-inch break, it looks like he may be in trouble.

DR. ZUDANS: Okay. Now that means that you have to be pretty darn sure about this lower end, uncertainty in the lower end.

What kind of uncertainty bounds, let's say what kind of uncertainty do you have on those 10 minutes?

Is it plus or minus 1 minute, 5 minutes, or 10 minutes?

MR. SKWAREK: We really didn't do a quantitative estimation of the uncertainty, but we feel that with the conservative assumptions that are in the analysis, that the time of 10 minutes is, indeed, conservative if we were to include a number of better estimate models within the code.

DR. ZUDANS: Well, the three-inch line was the one that sets you up for 10 minutes. What about the 4-inch line?

MR. SKWAREK: Well, the 4-inch line, we did analyze a number of cases, tripping the pumps at many different times. And the worst peak clad temperature here was only about 1700 degrees. Peak clad temperatures did not go that high.

DR. ZUDANS: So the peak clad temperature is function of the size of line and also, when you trip the pump -- in other words, if you go below three inches, then your peaks don't go up.

MR. SKWAREK: That's correct.

DR. PLESSET: I think that we should move along.

MR. MICHELSON: Dr. Plesset, let me ask just one question for just a brief answer.

If pump trip becomes an important consideration, how much importance do we have to place on the equipment that assures that we're able to trip it.

These are non-qualified breakers by non-qualified DC power supplies for tripping purposes and things of this sort.

How important is it now that we have our ability to trip the pumps, if it is, indeed, important to trip the pumps?

MR. SPEYER: Daniel Speyer of the Westinghouse owners' group.

Currently, the trip is not automatic. In fact, that's one of the reasons that the 10 minutes is important. However, Westinghouse will be looking at that further. But right now --

MR. MICHELSON: Maybe you missed my point. I wasn't so concerned about using the operator to do the job, but rather, making sure that when the operator trips the breaker, the breaker opens.

That's a non-qualified DC power trip. And just a number of questions of that sort. How important is it to be sure that besides the operator has got time, that the equipment needs to work?

This might have been an earthquake. I don't know.

DR. PLESSET: If the pumps can keep running, then everything's all right.

MR. MICHELSON: That's also true. But now the small break is going to eventually have a consequential effect.

MR. ESPOSITO: Dr. Michelson, we will supply an answer to you on this.

DR. PLESSET: All right. Let's go on, then. We'll keep it in mind.

MR. SKWAREK: So far we've done a lot of computer runs in the 3-loop plant in determining critical reactor coolant pump trip time. But we've wanted also to come up with a criterion that was valid, in fact, for 2- and 4-loop plants as well.

(Slide.)

And I hope to economize as much as we could on the computer runs, given the time we had. We attempted to use what we learned from the 3-loop plant and develop a criterion and then check it.

In general, it doesn't matter if it's a 2-, 3-, or 4-loop plant. If you want to think about what peak clad temperature for a small break is a function of, it's really a function of the time of first core uncovery. It's a function of the depth of core uncovery, which is actually a function of the decay heat and the safety injection.

You can also say that decay heat is a function of the power level of the plant and the time of first core uncovery. It's also a function of the time of core recovery, which for these breaks is accumulator injections. But for some other small breaks, it may just be due to safety injection becoming greater than break flow.

So --

MR. MICHELSON: Let me interrupt just a moment on this one. Could you tell me how you modelled in, though, the amount of pump heat that went into the system besides the amount of decay heat, if your pumps are running, you're putting some energy in? That's a function of whether it's a liquid or two-phased pumping, or whatever.

How did you model that?

MR. SKWAREK: The pump heat is not included in the calculation.

MR. MICHELSON: Isn't that a pretty -- I mean out of 100, 300, 500, 600 seconds, it's getting to be a large fraction of the total energy.

You know, decay heat's dropping down fast. The pump heat is dropping down maybe some, as you go into two-phase or eventually into steam flow. But it isn't zero.

I just wondered, what did you assume? And apparently, you don't include it.

MR. SKWAREK: It's not included.

DR. PLESSET: It's still a pretty small fraction.

MR. MICHELSON: Well, in liquid phase, it's about what, 8 to 10 megawatts, then 20 megawatts. Decay heat at the end of 600 seconds or so, you know, is becoming comparable, and now you ask, I don't think that there's any longer 20 megawatts going in at that point from the pumps, but what is going in?

MR. SKWAREK: There's just two things that come to mind with reactor coolant pumps operating, at least in this period of time. Earlier in the transient, before we assumed they tripped to get the worst peak clad temperatures, and at that point in time, since the break is not yet drained, the steam generators are being relied on for heat removal.

So if there is additional pump heat, it may just be reflected in a slight increase in the delta T across the steam generator to remove the heat.

The second effect could be brought about if the pump heat was included and it tended to increase the quality somewhat at the pump outlet. But that would tend to reduce the break flow for the coldleg break.

That's assuming that the pump discharged.

So, in a way, by not including the pump heat, we tend to maximize the subcooling at the coldleg break location and therefore, maximize the break discharge.

To get back to the 2- and 4-loop plants, as I said, then, really, the peak clad temperature, if one wants to resume a plant where the safety injection system is pretty much sized to the overall core power level, and for the Westinghouse plants in general, that's true, then the main things that have an effect on peak clad temperature are really the time of first core uncovery and the accumulator injection time.

And the timing of these two events is really a function of only the total reactor coolant system volume and the break size, given that the steam generator secondary side and safety valves are designed similarly between all plants.

And that's true that they are.

So we could come up with a relationship between plant types determined by a concept of what I'll call an equivalent break and just simply now I'll say that the plant volume divided by the break area for one plant is about equivalent for the plant volume divided by the break area for another one.

If I say, then, that for a 3-loop plant the critical break size is the 3-inch break, I can calculate what I think equivalent break will be for a 4-loop plant, maybe about 3-1/2 inches, and for a 2-loop plant, maybe 2-1/2 inches.

So just generally now, I'll assume that the critical time of reactor coolant pump trip for 2- and 4-loop plants then is also approximately 10 minutes, because for low plant types, for those size breaks, the reactor coolant system will drain to the break elevation at 10 minutes as well.

We have a method of verification that we used here. It was really through analysis. We did consider breaks larger than this critical break size for 2-loop plants. We've analyzed the 3-inch break for the 2-loop plant. That's included in the WCAP.

We've also analyzed the 4-inch break for 4-loop plants. That's greater than the equivalent break size. And if what I'm saying is true, then I would expect that regardless of the pump trip time for those two cases, I would never expect to exceed 2200 degrees.

And in fact, analyses have verified that.

We did not see analyses greater than 2200 degrees. So the idea of this equivalent break size appears valid.

Another validation -- not validation, but another feeling that we have that the 10 minutes is conservative -- is the 3-loop plant that we assumed to develop to 10 minutes is conservative with respect to the 2- and 4-loop plant in that it has less safety injection as compared to the overall core power, and secondly, as compared to the 2-loop plant, it has a lower accumulator, coldleg accumulator injection set point.

For the 3-loop plant, it's 600 psia, and for the 2-loop plant, it's 700 psia.

So we believe that the idea of ten minutes for the 2- and 4-loop plants is justified. Just let me prove to you a little bit about this idea about the equivalent break area.

What I did is just went to a number of analyses from WCAP 9600, WCAP 8970, and a number of recent WCAPs that we've submitted on small breaks.

(Slide.)

And just decided to correlate different break sizes, different plant types and see what I get.

What I've plotted here is 2-loop plant, 3-loop plants, and 4-loop plants, and I looked at various break sizes, 2-inch, 3-inch, 4-inch, 6-inch breaks. And what I plot here is the time of first core uncovery that I say is one of the main significant events in determining peak clad temperature. And the second one, which is accumulator injection time for core recovery, which is the other one, and found that I just plot all of the various plants up and you see a fairly linear relationship between this ratio that I defined before, the reactor coolant system volume, divided by the break diameter squared, by timing the transient when these significant events occur.

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In fact, if one wants to look at the critical time that we're looking for reactor coolant system pump trip of 600 seconds, we find that we have a number of points within that range that tend to further validify that relationship, at least within that range of 600 seconds or 10 minutes.

I think I've covered all of the conclusions. I was put up the last two slides that were just reprints of the conclusions from the report. But they're included there from your reference. But I won't take any more time.

DR. PLESSET: I think we'll move on since we're getting pressed for time.

MR. ESPOSITO: What we wanted to also do for briefness was to discuss the impact of the non-LOCA events. That will be given by Mr. Steitler.

DR. PLESSET: About how long will your presentation be?

MR. STEITLER: I hope to terminate my presentation in about 15 minutes, Dr. Plesset.

DR. PLESSET: Okay.

MR. STEITLER: Good afternoon.

I'd like to, as Vinnie said, go over the non-LOCA aspects with regard to tripping the pump. And I'd like to break up my presentation in three parts.

(Slide.)

A very brief restatement of the bases for tripping the pump. Then I'd like to go through all the various non-LOCA events that are analyzed as part of the routine Chapter 15 analyses and look at them in the context of whether or not the pump criteria would be in vogue or not.

Having looked at that, I would also like to look at the

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severity of those results given the reactor coolant pump trip.

(Slide.)

And as a restatement, and Bill Johnson will get into this a little bit later this afternoon, the basis for tripping the coolant pump from the Westinghouse point of view is the verification that high head injection is in operation and the reactor coolant system pressure is, in fact, below 1250, plus instrument errors and decreasing.

And this is the assumption that I have made in these analyses, although it is not critical.

(Slide.)

As stated in the criterion, one of the things that we're looking at is the depressurization. What I would like to do is break up the non-LOCA events into two broad categories: One, the reactivity excursions and the second group being the primary and secondary side mismatch.

What I'd like to look at is the initial response of the system transient and whether or not that transient results in a depressurization.

Obviously, if I'm not going to have the depressurization, I'm not going to have to worry about the pump trip criteria.

In these events, if I look at the reactivity additions, and these are basically the rod withdrawal from sub-critical, rod withdrawal at power, boron dilution, single rod withdrawal rod ejection, and also the start-up of an inactive loop.

These result in a reactivity addition, which leads to a pressurization. Hence, the no.

I've also done this for completeness, and I think it was raised several times this morning, but I want to look at it from an SAR basis, which you all are familiar with, and I also want to look at it from what I'll refer to as a better estimate basis, in which I'll use different reactivity coefficients which maybe more representative other than the FSAR basis.

I'll use decay heat and what have you.

I just want to make sure that I've covered both aspects. For the two cases for non-LOCA events that result in a reactivity addition in the reactivity part of it, I will get form a reactor trip and rod drop. I get the same type of response. I get a negative addition to reactivity. This results in a cooldown and a depressurization on the primary side, as one would expect.

(Slide.)

To continue on, and for completeness, this is the rest of the analyses that are looked at in the Chapter 15. Again, I'm looking at the same type of bases. These are the first four -- primarily loss of heat sink-type transients. In all of those cases, they tend to be pressurization events. Again, I'm not depressurizing eventually.

The loss of off-site power in a FSAR basis is pressurization because we make very conservative assumptions with regard to when we get the reactor trip.

If I actually had a loss of off-site power and it's verified by plant data, the initial response is to take the power off the MG sets, and it looks very similar to a reactor trip. But there is a difference in the FSAR.

The next two are excessive feedwater and excessive loan increase. These appear to the primary side as a cooldown or a reduction in inlet temperature. Again, these result in a depressurization.

I'll get to the severity of the depressurization in a minute, but I want to try focusing, initially.

The feedline rupture that's analyzed in the FSAR is a heat up event, primarily because, again, of the time of trips that we've assumed the initial conservative inventories that are assumed in the steam generators and what have you.

The FSAR base, in the real world, we would expect that a feedline break would initially result in a depressurization before a heat-up due to the fact of the quality of the fluid that we assume exits the steam generator during a feedline break.

And the final accident or class of accidents are the steamline ruptures and these are obviously accidents we're going to discuss in a little more detail this morning. They will result in a depressurization from an FSAR and also from a better estimate basis.

DR. ROSZTOCZY: One question. The steam generator tube ruptures seems to be missing from this list. Is there any specific reason for that?

MR. STEITLER: It may be more semantics, Zoltan, than anything else. I don't refer to a tube ruture as a non-LOCA event. That will be addressed by Bill Johnson later.

MR. MICHELSON: Let me ask you a question. Where in this listing now do you include the small breaks which don't get your pressure down very far?

MR. STEITLER: Small steamline breaks?

MR. MICHELSON: Small LOCAs where the pressure doesn't get down below 1250.

MR. STEITLER: I'm talking about the non-LOCA events not.

MR. MICHELSON: How do I know that this is happening versus a non-LOCA?

MR. STEITLER: Could I ask that that be preferred to the procedures which will be addressed in, I think, a great deal of detail in terms of the --

MR. JOHNSON: Thank you.

(Laughter.)

MR. STEITLER: In terms of the diagnostics, in terms of a LOCA or a non-LOCA.

(Slide.)

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What I'd like to do now is test the severity of these depressurizations. By severity, I am referring to the potential for reaching a condition where I'd be tripping the reactor coolant pumps, and for the initial reactivity addition accidents, where I have the trip and rod drop, the design basis as a reactor trip will not result in a safety injection.

I'll show you a transient on that in a minute. The loss of off-site power, again, it's similar to a reactor trip in terms of the consequences. The excessive feedwater, again, is a cooldown event. It is less severe than a steamline break.

Let me cover that with the steamline break. Excessive load increases the design basis accident, the way that we analyze it, and for that particular case, we guarantee no reactor trip and hence, obviously, no SI on the pressure.

The feedline break, even on a better estimate approach, will keep the pressure in the 1700, 1800 psi range, which is above the criteria that we're pushing or recommending of 1250 plus errors.

DR. ZUDANS: What feedline?

MR. STEITLER: The steamline, the main feedline break.

The steamline rupture, the minimum pressure on the steamline rupture is somewhat analogous to some of the stuff that Ray was presenting this morning in that it's sensitize to break size in terms of the depressurization rate you have. It's also sensitive to the capacity and shut-off head of the safety injection pumps, as one would expect, and it's also sensitive to the fact that the operator can isolate various breaks on the secondary side.

So in this case, the operator can actually terminate a break and hence, end the depressurization.

(Slide.)

From this, I conclude that the one that I really wanted to look at, or the one that has the potential for the criteria being met of low pressure is the steamline rupture.

I think there's a couple of things that should be said about steamline breaks. The first of them is that we're talking about a constant mass transient, if you would. We do not have a vehicle in a steamline break to relieve fluid from the primary side, unless additional failures are assumed.

So we're talking in a cooldown event that we're not losing mass from.

The forcing function is obviously an uncontrolled release from the secondary side. This forces the cooldown on the primary and depressurization of the primary. The cooldown and depressurization will continue until I've isolated the break, if that's possible.

If not, I'll wait until the steam generator boils dry.

The role of the reactor coolant pumps in a steamline break tends to couple the forcing function and the primary side cooldown.

I'll show some graphs of this in a minute that I think will demonstrate that.

If I trip the coolant pumps during a steamline break, the effect I have is to tend to decouple the system. The net effect of that is basically to retard the cooldown and retard the depressurization rate.

And I think it's also been pointed out this morning that during any steamline break, you will eventually repressurize the system. The ability to repressurize that system or the amount of repressurization will go up to the SI shut-off heads if I do not have spray available.

And depending on plant type, that may mean that the PORVs or safeties are lifted and I can have a limited repressurization or a controlled repressurization, let me refer to it as, if I have spray available to control other pressure.

DR. ZUDANS: What is the capability of the pressurizers to respond to any such pressure changes in the system?

MR. STEITLER: There is obviously a class of very small steamline breaks which do not empty the pressurizer, which the pressurizer heater can keep up with.

DR. ZUDANS: In your case with that LOCA --

MR. STEITLER: I'm not talking about LOCA. There is a steamline break that results in a shrinkage which will tend to empty the pressurizer. If I have a small enough break, I can keep the heaters covered, okay, and I may be able to keep up the pressure decay with the heaters only.

That's a very, very small break, though, a very small secondary side break, okay?

MR. MICHELSON: Would you clarify what you mean by "limited repressurization with spray"?

MR. STEITLER: What I mean, Mr. Michelson, is the fact that if I have spray available, I can control what kind of maximum spray pressure I will go to.

MR. MICHELSON: I find that difficult to believe. If the capability of the pump is several hundred gallons a minute and its head is that of the relief valve setting, what does spray have to do with preventing the relief valves from opening?

MR. STEITLER: You're right. If I continue high head safety injection and fill the system up, obviously, it will go water solid.

MR. MICHELSON: Obviously, in every case, unless the SI is shut off, it will go water solid.

MR. STEITLER: That's correct. It's a very long-term process.

MR. MICHELSON: It isn't too long in some cases. I think North Anna found out that it wouldn't take too long.

MR. STEITLER: I'm referring to 10 and 20 minutes as a reasonably long period of time. Okay.

(Slide.)

We have done a great mini-analyses. I'd like to show a representative case here. This is for a 3-loop plant. This represents a secondary side break of .2 square feet per loop. In the sense of it, it's an intermediate-sized steamline break. It's representative of plant type. Larger breaks would have more adverse or bigger consequences. Smaller breaks would be a little bit smaller here.

Again, the effect is steam flow starting off at time zero, you have a break. This is at full power also. You get a reactor trip at turbine trip, okay, which isolates the steam flow and the steam flow continues on it.

This forces a cooldown event in the primary side. I've here plotted the coldleg and the hotleg temperatures, and I've also plotted, for convenience, the saturation line on this same plot, which gives an indication of subcooling, if you would.

This depressurization is also accompanied -- this cooldown is also accompanied by a depressurization. This initial drop here is due to the reactor trip. This space here is for the condition where the pressurizer is emptying. After the pressurizer is empty, the system drops at a little faster rate until I get to a point of hotleg saturation in the upper head, at which time I retard the pressure. And sometime later in the transient, I start to refill the pressurizer and I begin slowly to repressurizer the system.

Now the flow is just -- I'm going to assume a constant flow here. This is mass flow and increased with flux and density change due to the cooldown.

Now this is assuming that the pumps are continually operating.

MR. MICHELSON: What is the signal now that told the main steam isolation valves to close?

MR. STEITLER: Low steamline pressure on the secondary side.

MR. MICHELSON: You got below 600 pounds, I gather.

MR. STEITLER: Yes. Now what I'd like to do is overlay --

(Slide.)

MR. STEITLER: -- this graph, a similar graph that says I want to trip the pumps. Let me do it one at a time

The steamflow plot on this graph, in reference to the previous graph, are identical, very, very close, and I apologize for these things don't overlay exactly.

A point I'd like to make here is that the effects of the primary side, as they reflect back to the secondary side forcing function tend to be second order effects for steamline break transients. Steamline break, you basically have a hole in the secondary side and it blows down. The rate of cooldown depressurization on the primary side does affect it, but it's to a very limited extent.

The cooldown rate, as I was referring to previously, the case with the pumps tripped at about 1250 psi tends to retard the cooldown. The temperatures hang up higher, obviously, than in the case with the pumps moving. The pressure goes up at a much higher rate than it did before. And I think this shows the decoupling aspect of tripping the pumps in a steamline break.

If I had tripped the pumps at other pressures, at higher pressures, I would have effectively changed this and phased farther back.

Also, this is a representative break of approximately .2, .3 square feet. A larger break would tend to depressurize faster and you effective move these curves this general direction. A smaller break tends to go in this general direction.

Okay. So I could have shown you a multitude of curves, but the general results would have been identical to these. The concern that was explicitly addressed for this presentation is given the reactor coolant pump trip, does that interfere with the potential for natural circulation?

The graphs that I have just shown --

(Slide.)

-- indicate that there is a high degree of subcooling between the outlet of the core and throughout the transient. This being the case, it is very easy, and we have presented this slide, I guess at the last May ACRS, that you can define the natural circulation flow rate as a relatively simplistic equation.

And these are basically geometry terms, terms of the height difference, resistance terms, some thermodynamic terms, and terms of what state conditions one's at. Also the forcing function of the decay heat or power level that one is at.

This is for a sub-cooled natural circulation. The system is totally sub-cooled, and I think given the fact that we are sub-cooled by the previous graphs, the ability to go into natural circulation is very straightforward following the steamline break with the coolant pump trip.

MR. MICHELSON: Let me ask you, where is the pressurizer water level going during the time in which the reactor coolant system pressure is dropping downward to 750 pounds?

MR. STEITLER: The pressurizer level -- there is a class of breaks.

MR. MICHELSON: Okay.

MR. STEITLER: There's a class of breaks, obviously

MR. MICHELSON: Right. Now for that class of breaks, what is the nature of the system pressure as you turn the corner and the system starts to repressurize?

In other words, the pressurizer is starting to refill. You're pumping the bubble up, but it's not being refilled with saturated fluid. It's being filled with sub-cooled fluid and there's quite a time delay during which the heaters are working very hard to try to bring this thing back up to a pressurizer control condition.

That kind of thing is what I'm wondering about in terms of natural circulation.

You just made the statement that you have sub-cooling. It's not real clear that you can just say that out of hand without some consideration about what's going on in the pressurizer.

MR. STEITLER: The pressure that's defined for this particular case -- and I apologize for not having another graph -- with the pumps tripped here, I don't believe I emptied the pressurizer completely. So the concern of whether the saturated fluid at the top of the pressurizer is somewhat moot for this particular case.

There obviously are cases that, given a coolant pump trip at this time or this pressure and the larger break, that you would come down. I think what would happen is that you would continue to maintain your pressure at the upper head conditions. This is approximately, or that is where the thick metal is that's trying to hold the temperature at around 550 degrees and flashing in that condition for around 1,000 psi.

MR. MICHELSON: By upper head, you mean the upper vessel head, and that means that you're maintaining -- you have no overpressure under that condition. You have saturation pressure.

Now, if there is heat in the metal, it can be transferred sufficiently rapidly beyond the first little boundary layer, yes, the vessel could tend to try to become a pressurizer itself. I'm only asking the question, what is the model here in the cases where the pressurizer is empty, and is it realistic to talk about having highly subcooled fluid in the system. It may very well be correct, but I'd like to hear the story.

MR. STEITLER: When we start to refill the pressurizer, our model assumes that when the fluid comes into the pressurizer it is subcooled, and we tend to condense and to squeeze the steam space in the pressurizer, and that forms the pressurization that was shown on that graph here. This is the case with the pumps running, okay. But I think it's indicative of the time frame that you're talking about with regard to refilling the pressurizer.

As one can see, it's a very slow process.

MR. MICHELSON: Yes, of course. You're spraying the pressurizer in that case, too, probably.

MR. STEITLER: Not in this particular case.

MR. MICHELSON: How do you know you're not spraying the pressurizer?

MR. STEITLER: I know it in my analysis.

MR. MICHELSON: It takes a single failure to cause the pressurizer to be sprayed, I guess. But you're under pressure already.

MR. STEITLER: All right.

MR. MICHELSON: With single failure you'd have a problem. So you're depending upon the recompression upon the bubble and the heating of the bubble by the metal walls of the pressurizer to reestablish an overpressure condition.

MR. STEITLER: That's correct.

MR. MICHELSON: That is in your model?

MR. STEITLER: That's correct. That's also consistent, Mr. Michelson, with the recovery procedures that will be outlined.

DR. ZUDANS: Are you saying that your model takes heat transfer from the metal of the container?

MR. STEITLER: No, it does not. That would be in addition.

MR. MICHELSON: He's stressing that bubble with safety injection. He's using it to build up -- he's using, really, a safety injection that's pressurizing the system and he's using the bubble there as one of the mechanisms. It's an adiabatic condition, I guess.

(Slide.)

MR. STEITLER: So in conclusion, what I've tried to do this afternoon is to focus down on all of the non-LOCA events that could potentially be of concern in regard to the tripping of the reactor coolant pumps. From that look, I find that the steam line break is the limiting non-LOCA event with regard to tripping of the reactor coolant pumps. The results of tripping the coolant pumps are the following:

Because the pumps are tripped, it does make pressure control more difficult if one does not have the spray available. Likewise, since I'm repressurizing the system without a control mechanism, I've increased the potential to open the power-operated relief valves and the potential of the safeties, also.

Also, through the transients I've presented, I think I've demonstrated that the effects of the pumps extend to the coupling mechanisms between the primary and secondary side. And I think I've also demonstrated that natural circulation can be easily obtained for steam line breaks.

Thank you.

DR. PLESSET: Any comments?

MR. ETHERINGTON: Just one question. Your formula for natural circulation seems to imply that you have turbulent flow in all points of the system. Is that a fact?

MR. STEITLER: The equation -- I don't believe turbulent flow is a necessary condition for it. What this equation is based on is matching the total driving head from the heat generation source to the heat sink source, times an elevation, and comparing that to the friction losses that one would have to overcome.

MR. ETHERINGTON: The K/a^2 suggests that the velocity depends, and that would be turbulent flow. So would you assume that you have turbulent flow? You probably do have turbulent flow, but is this really true in the steam generator tubes, for example?

MR. STEITLER: You're talking flow rates for natural circulation on the order of about 5 percent.

MR. ETHERINGTON: That is still turbulent?

MR. STEITLER: Yes.

DR. PLESSET: What's your next item?

MR. ESPOSITO: The next agenda item is the discussion of a summary of the procedural aspects, the guidelines. That's the next agenda item that we have.

DR. PLESSET: What would follow that?

MR. ESPOSITO: Following that would be the proprietary session.

DR. PLESSET: All right. I think we should go through this open session before we recess.

MR. ESPOSITO: Mr. Johnson will present the guideline summaries.

MR. JOHNSON: Thank you.

I'd like to discuss several aspects of the revised emergency operating procedures or instructions which Westinghouse has prepared as a reference for utilities. In doing so, I'd like to cover several areas: number one, briefly, the historical perspective and a procedural perspective in the mode of how these procedures have been generated;

Second, some philosophic distinctions as to the objectives which we were trying to meet in the development of these instructions, as well as any overall philosophy by which we chose to try to address those objectives;

Finally, then, I'll go through in an overview of what is contained in these procedures or instructions.

(Slide.)

Westinghouse immediately took note of the fact that some effort regarding revised emergency operating guidelines was necessary following post-TMI activity, immediately in response to I&E Bulletin 79-06A, which required addressing several items which ihcluded SI termination, reactor coolant pump status, and to ensure that instructions were provided to the operator to utilize multi-instrument indications as a basis for operator actions and decisionmaking.

With these in mind as a need, Westinghouse set forth several objectives in the near-term actions for immediately getting out revisions which Westinghouse was recommending as guidelines to our operating utilities. These basic objectives were to utilize multi-instrument indications as a basis for action; Secondly, to complete immediate actions which were required to assure that the plant is responding as the automatic protection systems would have it respond in order to make it an event prior to jumping into accident diagnosis or event diagnosis; thirdly, as an overall philosophy and objective with which to achieve procedure or guideline development, was to minimize differences in operator actions for each different event until the diagnosis of the event is complete and substantiated and overall event recovery is in progress, such that we would try to make as uniform a set of procedures to cover all basic events in the event of event misdiagnosis or the event turning in a direction not previously contemplated.

DR. ZUDANS: At this point just a remark. Complete immediate action would imply that you would have analyzed the entire range of all possible scenarios and come up with actions that are the same, regardless of which scenario you have.

MR. JOHNSON: Our objective was to do that, yes, in the immediate actions.

(Slide.)

The philosophy with which we undertook this task was as follows: Number one, in order to assure that we could provide as uniform a set of procedures as possible and to take account for event trajectories which weren't previously contemplated in the overall development of saying, this is a loss of coolant accident, this is what I'm going to treat, or this is something else and this is what I'm going to treat, it's to provide continuing diagnosis and rediagnosis throughout the procedures, to assure that the operator is fully aware of the condition of the plant and the means by which that event is transpiring.

Secondly, in our instructions or our guidelines which are given to utilities, we would provide more detailed instructions and notes than may in fact actually be required in a particular plant-specific operating procedure. By this, we thought it would be easier and more straightforward for a utility to take those notes, those cautions which we were placing in our recommended guidelines, as his aid in guiding him in interpreting and writing his own plant-specific instructions.

Thirdly, again, this is the sense of verifying the immediate actions prior to event diagnosis, and subsequent to individual plant recovery from individual events was to take credit for the fact that the automatic systems should stabilize the plant prior to the operator attempting to take control of the situation and altering the course of the event to the maximum extent practical.

DR. CATTON: Excuse me. Is there any interaction between Westinghouse and the utility to see to it that when they put the procedures together, the procedures are going to accomplish what you think ought to be accomplished? An iterative loop?

MR. JOHNSON: That has been addressed in response to a question by the staff on particularly that event by the owners group. The loop is being closed at the current time to this extent: that Westinghouse is providing, as a service to the owners group, a seminar regarding these revised procedures, to assure that the utilities have a good understanding of: number one, the transients; number two, the procedures themselves, the procedural steps; number three, the basis for each particular step and why the steps are in the order in which they are, since they have a very good idea of how and why each particular step should be implemented in each plant-specific response.

DR. CATTON: So you actually don't go looking at their procedures?

MR. JOHNSON: We are not at the current time required to approve in any approval process of plant-specific operationg procedures.

DR. CATTON: I understand the meaning of approval. But you don't even advise?

MR. JOHNSON: We are not in an approval loop, if you will. We have advised with these emergency guidelines. This is what we feel the basic basis, if you will, the fundamentals of your procedure, should incorporate, and we are conveying that view to this seminar. We are not specifically reviewing each plant's operating procedure.

DR. CATTON: Do you know of any point at which each plant's procedures would be reviewed to see that they're meeting the Westinghouse guidelines?

MR. JOHNSON: No, I do not.

DR. CATTON: I think that's an important aspect, and it seems to be missing everywhere.

DR. ZUDANS: I have another small point. For any emergency action that depends on diagnostics of a given case, there's a certain time window that you have at your disposal.

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If you compare that time window to the amount of time required to consult the procedures, would they be commensurate? Would it take an hour to read an instruction on an action that takes five seconds?

MR. JOHNSON: That's been a very important consideration involved in our writing of the guidelines and our recommendations to the utilities as to the format and structure of their own plant-specific operating procedures. They should be brief enough and accessible enough -- they are definitely accessible. They should be brief enough and accessible enough such that they are a useful tool to be consulted during the course of an event. That has certainly been one of our foremost concerns.

DR. ZUDANS: If that is your concern -- and it's a good concern -- how can you live at peace without ever really checking that the particular set of procedures is as recommended? It's the same question Dr. Catton raised. I mean, there has to be some interaction. If there is no interaction, it just doesn't seem to be right.

MR. JOHNSON: Let me digress for a moment as to the interaction between Westinghouse and the owners group in the development of these procedures. The owners group themselves have a subgroup regarding the procedures, which has a representative sample of plants represented by the Westinghouse owners group.

The process which we have evolved to is, Westinghouse has generated essentially a draft set of reference guidelines and presented that to the procedures subgroup of the owners group, okay; received their comments, both formally in writing and at a series of ongoing meetings with those people at Westinghouse who have been involved in the writing of the Westinghouse reference guidelines and those people of the owners group represented by the procedures subgroup to get their feedback from their utilities, which are a representative sample of those.

That has resulted in a culmination of a general agreement between the owners group and Westinghouse regarding these revised guidelines, and it's that agreed-to set of procedures which is currently in the process of undergoing transmittal and subsequent implementation by the rest of all the operating plants.

The fourth philosophy was that if SI is terminated during the course of an event in which SI was, of course, initiated at one point, then plant control would be maintained by the operator. Essentially, that was required to bring the plant eventually down, depressurization and cooldown.

The last two are also, in my mind, two of the most important philosophies which we undertook in overall development. One was to minimize the required operator actions and decisions, particularly early in the event for the initial accident mitigation, in order to minimize the potential for either operator errors of omission or commission, okay, such that the procedures would be as clean, as early as possible.

Finally, as I alluded to before, it's to maximize procedural uniformity such that, to the maximum extent possible, each of the procedures, if I go through them as far as I possibly can, will act to mitigate the response of another event which may be one which the operator has not diagnosed. And I think that's been a very important aspect of going through the development of these procedures.

DR. ZUDANS: A question again: Have you looked at your procedures and made some kind of a cross-plot, saying, here is a time scale, given an accident for which you have a diagnostic which is correct, when you put the time on another scale and then just summarize the number of actions at a given point in time as far as their windows are concerned, you have a certain action that he has to take within four seconds, four minutes or what-not? How would that plot look like?

MR. JOHNSON: I think we have done quite a bit of exactly what you've mentioned, and I'm going to show you a chart, if you will, of a summarized E_1 procedure, which is the loss of reactor coolant procedure, okay, which I think will give you some flavor for that kind of evaluation that we perform. If that doesn't address it at that time, please let me know.

DR. PLESSET: How long do you think your presentation is going to take?

MR. JOHNSON: Well, let's see. I will attempt to be brief and give you a thorough and exhaustive description.

DR. PLESSET: Exhaustive, that's obvious.

MR. JOHNSON: I think in general I would anticipate 45 minutes.

DR. PLESSET: Is there any possibility that you could shorten that a little bit?

MR. JOHNSON: I'll make every attempt to do so.

DR. PLESSET: All right, we'd appreciate it.

DR. ZUDANS: This subject is very interesting.

(Laughter.)

DR. ZUDANS: And I think maybe I make a proposition that we break for lunch now.

DR. PLESSET: I think we should get through a little more of it, if it's going to be 45 minutes. If you could make it a half an hour?

(Laughter.)

MR. JOHNSON: Okay.

The next slide I'll essentially skip. I'll leave it included in your handouts for reference, which is really the process by which we assure that we have all the disciplines represented in the development of these procedures to get the proper balance for those people who are most concerned with the accident analysis, et cetera, and those people who have a good handle on what plant operation was actually like.

(Slide.)

Now, as regards the basic structure of the procedures, Westinghouse chose to maintain that basic structure, which had been part of the Westinghouse reference guidelines for some time, which is to immediately get into a procedure which is consisting only of immediate actions to be taken in the event of any event which requires safety injection, as well as then going further into subsequent accident diagnosis as the first step.

Now, as you will see later, the mechanism of getting into this procedure which Westinghouse has termed E-zero is the action of reactor trip and safety injection will immediately put one into the procedure E-zero.

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At that point, the immediate actions immediately required for determining the probable event trajectory which will take place to ensure that the proper systems are on operation and the proper alignment of those systems is in place. After those are completed, the E-zero procedure then allows for accident or event diagnosis in order to determine which one of the subsequent E or emergency procedures should I follow to best mitigate the consequences of this event, keeping in mind that all of the subsequent procedures have been written with a specific purpose in mind, to make them all, to as large an extent as possible, uniform.

At this point, we have written four procedures, E-zero to E_3. E_1 is a loss of reactor coolant procedure and would encompass any size loss of reactor coolant, small break through large break.

E_2 is a loss of secondary coolant and would encompass all size loss of secondary high-energy line breaks.

E_3 is a steam generator tube rupture procedure and it is specifically culled out of E_1 because at some point in time during the recovery from a steam generator tube rupture operator actions are significantly different from those required in the loss of coolant accident.

MR. MICHELSON: Here's a philosophical kind of question: To what extent do you give guidance to the operator as to what to do if certain types of single failures were to occur in the process of tracing them down through the E-zero and on to E_2 or whatever?

MR. JOHNSON: In the immediate actions, which are concerned with verifying that the proper systems are on line and functional, guidance is given to the operator to assure that you are delivering flow, okay. No specific guidance is directed on single failure, since the safeguard systems are designed to fulfill their functional requirements in the presence of a single failure.

MR. MICHELSON: The particular example I had in mind was under E_3, which you say is the steam tube rupture. What guideance does he have if there is a stuck open relief valve on the secondary side?

MR. JOHNSON: In particular, those kinds of things which would result in a subsequent tertiary or secondary event, if you will, are dealt with not on the basis of that particular part undergoing an active failure, but rather, how that results in a change in the system transient, and then that change is identified and is meant to be coped with.

MR. MICHELSON: Is that presently in your scheme of plans?

MR. JOHNSON: It is currently.

MR. MICHELSON: So I could go to E_3 and find out what I would do in the steam tube rupture case if the relief valve stayed open?

MR. JOHNSON: You would find out what to do in a steam tube generator rupture case if, subsequent to this event, I get continued primary side depressurization.

MR. MICHELSON: So by inference, even though, because I may not know that the relief valve is stuck open?

MR. JOHNSON: That's correct.

MR. MICHELSON: So by inference there is a guidance in there as to what to do if there's a continuing depressurization?

MR. JOHNSON: Yes.

DR. ZUDANS: The same way -- your diagnostics, do you have some kind of a computer-oriented type system that, feeding in certain observed elements, it helps you to produce the diagnostics, or is it something the operators have to come up with themselves?

MR. JOHNSON: This description of these revised guidelines is meant for our current operating plants, okay, and the diagnosis that I'll show you -- and I'm going to get to that in two slides -- is operator-performed.

DR. ZUDANS: But you give guidelines?

MR. JOHNSON: Yes.

(Slide.)

MR. JOHNSON: This figure essentially shows the method by which an operator during an event would find himself moved into the E-zero procedure. Essentially, if I look across the top, this is nothing more than a nuclear power plant producing power, okay, which the operator would always be doing.

If, however, the operator would sense -- either recognize that a reactor trip has occurred or sense a need to manually trip the reactor for some reason, he would end up with a reactor trip verifying the fact that the rods are in.

The next thing that the operator would be instructed to be looking for would be has automatic SI occurred. In fact, if either automatic safety injection signals are generated or the operator feels that the event trajectory is such that he would wish to manually initiate safety injection, he would end up with either manual safety injection or automatic safety injection.

This box is essentially the E-zero, the entrance the E-zero procedure, okay. Once I have reactor trip, either manual or automatic, and safety injection, either manual or automatic, this allows him movement out of here, such that if I have a reactor trip, either manual or automatic, but I do not need safety injection, that's a reactor trip and I would go to an abnormal operating instruction which deals with recovery from a reactor trip.

DR. ZUDANS: You say these are immediate actions, if they required some diagnostic, some decisionmaking, like top block, you had to make a decision whether you wanted to have a reactor trip or not?

MR. JOHNSON: That's correct, the operator must do that during the course of normal plant operation, not via any emergency procedures.

DR. ZUDANS: So there is some diagnostic associated even with this?

MR. JOHNSON: With normal plant operation, yes.

MR. MICHELSON: Well, is there some kind of a guideline on deciding when you need safety injection? Is this going to be a part of his training program?

MR. JOHNSON: It is a part of the reactor operator's training program, and Westinghouse has provided the utilities with some guidance in this area in terms of this evaluation.

MR. MICHELSON: It'll be virtually an automatic operator response. He will very quickly evaluate in his own mind whether he should start SI and he will do that on the basis of training.

MR. JOHNSON: Yes. So at this point I have entered the E-zero procedure and this is the E-zero procedure.

(Slide.)

Now, this figure is in fact in the E-zero procedure and it is the essential diagnosis phase, to provide the basis for moving to one or the other E procedures for subsequent operator action. I immediately come into E-zero and I'd like to step our way through this because I think this relates to some of the questions which have been asked earlier this morning.

The first question that the operator is asked is: Is this pressure less than the pressure for reactor trip or pressure decreasing? Remember, I've gotten into this point because I've already gotten a safety injection and reactor trip. My first action in here is to determine, really, whether or not I have a spurious safety injection, which I think, Dr. Plesset, is one of the areas in which you were requesting information earlier, or whether or not I have an event in which I'm going to have to follow another E procedure. This is the differentiation mark for that, which is the very first thing in the E-zero procedure: Does the reactor coolant system lessen the pressure for the reactor trip or is it continuing to decrease?

If in fact the answer to these two questions is no, I look for plant environmental and radiation readings. In other words, it appears at this point my plant has undergone what could have been a spurious safety injection. So I'm going to look for any other things which may be indications that I have a real event in progress. If in fact I do see some of these other readings, I would come down and evaluate, essentially, my SI termination criteria.

And essentially, this line here on this side of the chart is a spurious SI, what the operator would be following in the event of a spurious safety injection, this vertical line down to here. He would evaluate his SI termination criteria as defined by pressure in the reactor coolant system being greater than 2,000 pounds and increasing, and pressurizer water level greater than programmed no-load water level, which is generally around 20 percent, and at least one steam generator water level in the narrow-range span.

If each of these criteria are met and he has normal plant environmental and radiation readings, he then is instructed to terminate safety injection and transfer his plant control system to normal pressurizer pressure level and control. At that point, he's instructed to look and watch what happens when he does that. And if the reactor coolant system pressure does not fall below the SI actuation set pressure, which in general is about 150 pounds below that 2,000 pounds, or pressurizer level does not drop below 10 percent of span -- in other words, he is controlling pressure and level as he expects -- he then can assume that he has a spurious safety injection and recover the plant by going to the abnormal operating instructions for spurious safety injection.

If, however, even getting all the way through this diagnosis, he finds that reactor coolant system pressure does drop below the SI actuation set point, again, a subsequent event has occurred or something else has happened, he is instructed to manually reinitiate safety injection, go back here and start over, at which point he's got safety injection on.

This is merely in the event that he makes it all the way through all these check statements which have determined whether he has had a spurious safety injection signal, for some reason his earlier diagnosis at an earlier point in time was faulty; he's now back into a situation with safety injection on and the reactor is tripped, and it rediagnoses the event.

MR. MICHELSON: I have a real quick question. I have a problem with the chart. For instance, with the steam tube rupture, if the experience is a single failure -- and I'm not even sure it's a single failure in all cases -- but if the main steam isolation valves immediately close, it seems to divert you into assuming something other than a steam tube rupture occurs.

MR. JOHNSON: Can I get into the event diagnosis, which is this line? I think maybe that might address that.

DR. ZUDANS: Just a very small point. I see this chart and in given blocks there are certain actions the operator is to take. Have you studied the time required to follow the chart as you just indicated?

MR. JOHNSON: Yes, we have. We have done it on a simulator.

DR. ZUDANS: Okay. Reading the instruments, making all those decisions until the action is taken? Or is the action too late or timely enough, even if he knows all the procedures by heart?

MR. JOHNSON: We have checked the procedures on the simulator for these events.

DR. CATTON: With an operator?

MR. JOHNSON: With an operator, yes. I couldn't do it.

DR. CATTON: I'm not sure there are many of us in this room who could.

(Laughter.)

MR. JOHNSON: Okay. Now, if in fact he sees that his reactor coolant system pressure is less than the pressure for reactor trip, or RCS pressure is decreasing, he now is not even going to consider spurious SI, okay. He comes down and immediately evaluates his pump termination criteria. His pressure in RCS is greater in this case, P-star, which is 1250 psi plus uncertainty, which is the reactor coolant pump termination criteria.

MR. MICHELSON: It would be a yes there yet.

MR. JOHNSON: For certain events, yes.

MR. MICHELSON: We're talking about steam tube rupture now.

MR. JOHNSON: I was going to cover them all.

That's correct, I would suspect. In particular, to address your question, for a steam generator tube rupture it would be about 1250. If the answer to that is yes, he would then check to see his component cooling water available to the pumps, because that is a required service to those pumps. If it is, he does not need to manually trip the pumps at this point in the procedure.

If it is not, if either of these boxes are no, he comes through and manually trips all reactor coolant pumps.

That is the first time that that instruction or that check on the reactor coolant pump termination is included in the procedures. As I'll show you later, it is also at the very beginning of -- well, it is at the appropriate place, put it that way, of each one of these subsequent procedures. And the instruction says to continuously monitor that.

So at this point he's either decided he's made his first check on whether or not he should terminate reactor coolant pump operations and he's now into diagnosis of events to determine which one of the subsequent E procedures he should follow. The first thing he looks for is this box, which says, are there any containment indications, is there an absence of containment indications, and is there high containment air ejector radiation or high steam generator blowdown line radiation? If that is a yes -- this is an "and" statement -- if that's a yes, there are indications of a steam generator tube rupture, he goes to E_3, steam generator tube rupture.

MR. MICHELSON: But if there are no containment indications, then he proceeds on down?

MR. JOHNSON: No. If the answer to these questions are yes, which is no containment indication changes, yes, he goes to E_3. No containment indication-changes and high condenser air ejector radiation -- in other words, to get to E_3 he must see an absence of containment indications and high ejector blowdown radiation or radiations.

MR. MICHELSON: What happens if he only has the latter and not the former?

MR. JOHNSON: Then he does not go to E_3.

MR. MICHELSON: So for a steam tube rupture, you don't see containment indications, so he doesn't go to E_3?

MR. JOHNSON: This block says are there no containment indication changes. For a steam generator tube rupture, the answer to that would be, yes, there are no containment indications.

I appreciate that confusion.

(Laughter.)

DR. CATTON: How does an operator react to that confusion?

MR. MICHELSON: They're smarter than I am.

(Laughter.)

MR. JOHNSON: We are schooling them on that.

MR. MICHELSON: You still don't go to E_3, of course, because you have to satisfy both requirements, and with the single failure, if you close the main steam line isolation valves, that is a single failure at that point and you haven't satisfied the requirement for a yes, I guess.

MR. JOHNSON: In fact, operating experience shows that the first indication you get on a steam generator tube rupture is high condenser air radiation.

MR. MICHELSON: So long as the main steam isolation valves are open.

MR. JOHNSON: That's correct, but you would have tripped.

Okay, and I'll show you -- we can discuss, there is conditions in E_1 for further diagnosis of E_3.

DR. ZUDANS: Since I asked about the timing, do you have the time to reach from the top through every one of those last boxes?

MR. JOHNSON: It's very short. I don't have a number for you, but on a complete walk-through of the board, which is what we did to diagnose these events, it took -- I'm not going to give you seconds or minutes, but as I was there, it took a minute or two.

DR. ZUDANS: Supposing how much time does it take to go from top to E_1 on the left down at the bottom?

MR. JOHNSON: Again, it depends on what that loss of coolant accident is. If it's a large break loss of coolant accident, it's immediate. He'll get that very rapidly.

DR. ZUDANS: Well, talk about new procedures, if not the accident itself.

MR. JOHNSON: The time it takes to go through this diagnosis, it depended on the event.

DR. ZUDANS: Okay.

MR. JOHNSON: Which is consistent, because that's also generally a function of the severity of the event.

Okay, so passing this box, if in fact he has not gotten a yes out of the tube rupture diagnosis, he is then instructed to look for a loss of secondary coolant. And his decision point there, is steam pressure lower in one generator than in others, okay, which would be an indication of a loss of secondary coolant. If it is, he goes to E_2. If it is not, he comes down to E_3 or he goes down to the next block.

In that case, he's looking -- now this is the converse of the prior question, is: Do abnormal or increasing indications exist for containment pressure or containment radiation or containment sump level? If they do, he's got a break inside containment, E_1, loss of reactor coolant. He hasn't verified that he had a loss of secondary coolant. If he comes through all this indication and he cannot identify via these checks which one of these events he has, he can't positively identify, he goes to E_2 loss of secondary coolant, okay --

DR. CATTON: What does he do if he has a combination of E_1, E_2 or E_3?

MR. JOHNSON: That has been somewhat addressed in the current procedures by placing a hierarchy of priorities with regard to what the operator is attempting to address, and if at any place -- now really, what's happened up to here is that all his automatic protection systems are functioning and are operating, okay. And really, about all the operator can do without going into an inadequate core cooling type construction is to ensure that his plant safeguards are continuing to operate.

What we've done is, if at any time in any of these other events he diagnoses any indications of a loss of reactor coolant, which is the most likely way to place core cooling in jeopardy, he must lose inventory in the system. In that case, he is always instructed to, no matter where he is, reinitiate safety injection, okay, and assure that he verifies that flow is being delivered to the system, and at that point go back and rediagnose the event.

Now, if there are multiple events going, he may come up with multiple events that he knows about. But at any rate, he's always instructed to maintain the safeguards equipment operating.

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DR. CATTON: One of the things mentioned earlier by Carl was the tube rupture stuck open, the relief valve on the steam generator. That seems to me that is not too serious if you do the right thing.

MR. JOHNSON: Pardon?

DR. CATTON: That doesn't seem to me to be too serious if you do the right thing, but I don't see it anywhere here.

MR. JOHNSON: On that one -- well, I don't know where he would go first, but if he goes to E-3, first, essentially in that case we have not done these analyses and we have not explicitly covered each possibility of multiple actions, multiple condition for events occurring simultaneously.

However, I think if you would go into an E-3 procedure and see indications -- well, I know what would happen -- he went to the E-3 procedure, and he saw indications of continued depressurizations on the primary side, which is what would occur, he would end up reinitiating safety injection and going to E-1. That is what the procedure, as written today, would do. He will treat the LOCA. That is the way the procedures have been written.

DR. CATTON: During the testing of these procedures with your simulator, have you been trying to gather information with respect to the kinds of errors that the operators can make?

MR. JOHNSON: No, we have not.

DR. CATTON: Is there any plan to do that sort of thing so that one can get a feel for it? How do you write a group of procedures so we won't make the errors?

MR. JOHNSON: In terms of writing the procedures, our basic philosophy in terms of trying to do it so you won't make an error is to try to minimize his decision points and actions. But as far as how to actually write a procedure, if you will, to the operator, that would actually be outside the scope of exactly what we are writing here because what we are writing are not procedures. Let me emphasize that. These are guidelines to be incorporated into plant-specific procedures.

DR. CATTON: If you tested this chart out on your simulator with operators, you have obviously written a procedure.

MR. JOHNSON: Not really. We didn't really write it down as a procedure. We went over with the operators what these things were and they could follow it in general. But a plant-specific procedure has multiple things in it which even take no time but are not incorporated in our guidelines.

DR. CATTON: Well, in some respects, the time factors that Dr. Zudans was talking about haven't really been fully tested, because I think to fully test them you have to read the procedure and comprehend what you've read and take an action.

This sounds like you've sort of work with the operator and say, "Hey, gee, why don't you follow your way through this chart?" He already knows what he's going to be doing before he does it.

MR. JOHNSON: What we tried to do in that case was to have the operators have an understanding of the procedure -- okay? -- such that he would be in that case of knowing what was in the procedures. And that is part of operator training.

MR. ESPOSITO: Dr. Catton, we are doing studies looking at operator action time. We are performing studies.

MR. JOHNSON: Not in the context of these procedures.

MR. ESPOSITO: Not in the context of those procedures, but in the context of response time.

DR. CATTON: This is a little bit beyond this discussion of procedures. But in your simulator, how adequate is the backup? In other words, the mathematics behind the screen. If the operator makes an error, will the simulator fall reasonably close to the true course of events?

MR. JOHNSON: It will do within the capabilities of the simulator. The simulators do have limitations. They do have areas in which, if you push them far enough, they will not respond. But we were going to use these to try and evaluate how long it took to get through this and to try to see how workable are our guidelines. We did not test operator errors.

DR. ZUDANS: Do I understand that you expect the operator to memorize all of these things and react instantly without consulting this set of written procedures?

MR. JOHNSON: The operators in each of these procedures is a section which is called "immediate actions" and a section which is called "subsequent actions." He must memormize the immediate-action section of each procedure. We try to keep that at a minimum. We recognize the fact that in E-1, E-2, and E-3, it's referred to E-0, essentially, because E-0 is where most of the immediate actions are, which are verification steps primarily, verifying that systems operate, verifying proper valve lines.

MR. ESPOSITO: It's going to be in the next slide?

DR. CATTON: Could I ask the representative of the owners group, what do you do in this regard? Do you want me to restate the question?

MR. SPEYER: Restate the question.

DR. CATTON: I am concerned about somehow a procedure resulting from all sorts of studies, and then it's who makes sure that there is proper interpretation.

Now, it seems to me that a good place to ensure that the operator would properly interpret the procedure would be by observing him going through the procedures on the simulator where he can make mistakes and have to recover from the mistakes. But I get the feeling that nothing is done in this regard.

MR. SPEYER: I don't know that I can fully address that. But I can say for our utility that we in fact do that. We do have a simulator. Other companies that belong to the owners group don't. And they use those people on simulators later. But all of us do step through it. We have our operators step through the procedures and assure that they do it correctly. I don't know the details on how we do that. That's part of their training, but I can't give you a detailed answer.

DR. CATTON: I would like to know whether there is an interim procedure, if procedures are ever changed as a result of having observed an operator working with them on the simulator.

MR. SPEYER: I think they probably have, yes.

MR. JOHNSON: Dr. Catton, that's what I attempted to allude to earlier when I stated the process by which

Westinghouse, coming up with these guidelines, worked with the owners group, the procedures subcommittee, who are people on that subcommittee who are very heavily involved in their own operating procedure-writing and their own operator training.

That, I think -- I am sorry if I didn't make that clear earlier — that's where a lot of this feedback is occurring, and that input has been melded into how our guidelines have been developed.

DR. ZUDANS: Just one more. Are these immediate-action procedures displayed someplace continuously, constantly, or in several places in the control room?

MR. JOHNSON: These particular, exist in the E-0 procedure, which is not displayed continuously.

DR. ZUDANS: Just like your instruments.

MR. JOHNSON: You must reach out and open the book.

DR. YAO: I have a thought about this.

DR. PLESSET: We're going to try to reduce the questions, maybe even eliminate them.

I think that Westinghouse and the other people have a pretty good idea of the questions and the line of thought that the subcommittee has, and I wonder if we're going to gain a great deal more of exchange of thoughts by going through all of your slides.

Now, that's a very pertinent question because we must finish with Combustion Engineering's presentation today. They can't stay all night.

So, could you answer my question: do we need to go through all of this in detail now? I will ask Mr. Esposito.

MR. ESPOSITO: Dr. Plesset, I don't think we have to go through all of them.

DR. PLESSET: You pick out the key one.

MR. ESPOSITO: I think the bases for the safety injection determination criteria may be the key one, since there has been so much discussion on that.

DR. PLESSET: Good. Let's do that.

(Slide.)

MR. JOHNSON: One of the key points of the Westinghouse reference guidelines is the SI termination criteria. What I would like to give at this point is the basis that we utilize in terms of coming up with indications that would satisfy these bases, or actually these objectives, in assuring ourselves that we had an HPI termination criterion that was meaningful and responsive to plant safety.

I would like to go through these one by one. One by one. We thought it was important prior to SI termination during any event, be it a spurious event or a nonspurious event, that SI would not be terminated unless one had previously assured system inventory.

If one could not verify system inventory, we did not wish to allow the operator to terminate safety injection.

Secondly, we wanted to allow safety injection to continue until it had been verified that, by operation of that system or by inventory addition, we could return the plant to near-normal plant control conditions. We're returning the plant to a situation which is somewhat akin to normal operation.

Thirdly, throughout this, that we would assure the capability for decay heat removal from the reactor coolant system prior to terminating safety injection.

Fourthly, we would not terminate safety injection until we had provided the capability for normal plant control because following termination of safety injection, it's still important that you are going to have to control pressure and level. So, you must establish those conditions which would allow you to establish that capability.

Fifthly, minimize the potential for subsequent RCS inventory loss. In other words, during one of these events, it may be that the reason you are terminating SI is because you have had an RCS inventory loss and it's desirable to terminate high-pressure safety injection prior to the time at which its action might result in additional RCS inventory loss. In other words, potentially lifting a power-operated relief valve on the pressurizer or raising the system pressure up to the safety valve on the pressurizer safetys.

Also, as an overall general basis, the criterion were chosen such as to account as much as possible to account for possible instrument uncertainties. The operator has very well assured himself that he is satisfied on those above bases.

Those are the general criteria by which we chose the criteria by which we did -- that I showed before, of 2000 psi pressure increasing the level in the pressurizer and establishing the level in the U tube steam generators on the secondary side above the level of the tubes. These are the bases by which we arrived at those criteria.

MR. MICHELSON: It isn't clear how those bases assure the statement which I heard you make repeatedly: that we know we have a subcooled condition.

MR. JOHNSON: I didn't say anywhere in here.

MR. MICHELSON: I know you didn't in this particular presentation at the moment. But you talked about subcooling a great deal, and yet here now you are going to ignore subcooling. Could you give us a little reason or background on why?

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MR. JOHNSON: These we felt were the most important things, that if I could assure that I had a level in the system, if I assure that I have the capability -- at least I had the capability -- of providing means to control pressure, by which I will later, at least in some subsequent time, assure systems subcooling, because that's pressure control.

MR. MICHELSON: How do you know you're controlling pressure? I could just have real hot water and keep 2000 pounds in the system at saturation. 2000 pounds, per se, is nothing magic.

DR. PLESSET: You might go for quite a while thinking you have a full flow, and be mistaken.

MR. JOHNSON: If I am sure I have a level up above the pressurizer heaters.

MR. MICHELSON: How do you know you've got it there? How are you assuring that?

MR. JOHNSON: A level greater than 50 percent.

MR. MICHELSON: But the level is meaningless. That was our earlier discussion this morning.

MR. JOHNSON: I am also requiring pressure and level to track together. The pressure is greater than 2000 psi and increasing, a level greater than 50 percent, if pressure and level are increasing.

DR. ZUDANS: And it still doesn't guarantee subcooling.

MR. JOHNSON: That's right. It does not guarantee subcooling. That's correct. In most instances, I will be subcooled if I satisfy these criteria.

DR. PLESSET: What's this tracking mean? How much in the way of observation is required?

MR. JOHNSON: What we're telling -- what we're instructing the operator here is that pressure is greater than 2000 psi and increasing, and my level has returned and has come back up to 50 percent. In other words, my pressure has come up and my level has come up; therefore, they are moving in the same direction. And if I had a PORV stuck open, say, and I was saturating the system, my pressure would be falling while my level would be either rising or constant.

MR. MICHELSON: Not if the pressure is coming up into a very rapidly heating core.

MR. JOHNSON: That's correct, which is an indication of inadequate core cooling. And Westinghouse is working on. This is not in consideration of inadequate core cooling.

MR. MICHELSON: I thought that's what we were talking about here. That's the whole name of the game is to keep the core cool, and I thought this was the means by which we were deciding that it's cool enough now that we can

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shut off SI.

MR. JOHNSON: And I think inadequate core cooling instructions are in the process of being written and are have benn on a schedule established via discussions with the staff in NUREG-0578. They will be included once they are written as also parts of these same procedures. In other words, giving me a kick-out of the normal recovery from one of these events to inadequate core cooling.

DR. PLESSET: We seem to be not all the way there, then. Is that right?

MR. JOHNSON: That's correct.

DR. PLESSET: So I don't feel so bad about shortening your presentation.

(Laughter.)

MR. JOHNSON: We'll be back in October.

DR. PLESSET: Okay, we'll see you again.

MR. JOHNSON: I am sure.

(Laughter.)

MR. JOHNSON: But that's correct, inadequate core cooling is being addressed separately via separate procedures which will be incorporated.

DR. PLESSET: Fine. Well, I apologize if I have cut you back in time. We will give you another chance, and you will have all the time you need.

Before we recess, let me make a couple of statements. We're obviously going to need to get together again, and I took the step, which might not have been a good one, of canceling the proprietary section, only in part because of the time, but also very importantly because I am suggesting that all the NSSS people be here tomorrow afternoon because the staff will be presenting some of their ideas and reactions to what they have gotten from the vendors, and they may want to come back again after they hear what the staff's ideas are at this point. They may not have heard the latest views of the staff, which we will get tomorrow afternoon.

And so, we promised them adequate time for this tomorrow afternoon, and I believe that Westinghouse people will have representatives here so they can be informed, and I presume that Combustion will, also. I also promised that Combustion Engineering can complete their presentation today before 9:00 p.m. or something like that.

DR. ZUDANS: Before the game starts.

MR. MICHELSON: It's got to be before the game, yes.

(Laughter.)

DR. PLESSET: We won't be going all that late. We are going to finish, so we will come back in open session at 3:30, and we will recess for lunch.

MR. ESPOSITO: Dr. Plesset, we are completed as

pv DAV

far as the Westinghouse presentations.

DR. PLESSET: For this time.

MR. ESPOSITO: Thank you, sir.

(Whereupon, at 2:30 p.m., the meeting was recessed for lunch, to reconvene at 3:35 p.m., this same day.)

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AFTERNOON SESSION

(3:35 p.m.)

DR. PLESSET: Let's reconvene.

Mr. Longo, would you take over on behalf of Combustion Engineering?

MR. LONGO: For the record, my name is Joe Longo. I manage the group that does the ECCS analysis at Combustion Engineering.

The purpose of our presentation this afternoon is to present to you some of the results of our small-break analysis and, in particular, those dealing with the role of the reactor coolant pumps.

(Slide.)

We have proposed the following agenda: basically, talk about the general features of the Combustion small-break model; then those special model features for which we felt it necessary to include the effects of keeping the reactor coolant pumps in operation; the fourth item, the results of the small-break analyses with the reactor coolant pumps running, a discussion about this effect on non-LOCA events; guidelines for the reactor coolant pump operation. And then from several notes that we had received on what you might like to hear, we also are prepared to talk about the loss-of-feedwater events.

If time is running short, I would recommend that we try to cover in some detail the first six items and use this as a throwaway item. We would be glad to come back to you and talk to you about it.

Basically, our bottom line -- and we have completed the results of the studies -- is tied up with our guidelines for the reactor coolant pump operation. Basically, they fall into this type of recommendation: that is, shut two reactor coolant pumps down, one in each of the loops, and continue within five minutes and keep two pumps, one in each loop, operating. If for some reason you haven't shut down the reactor coolant pumps within five minutes, then shut down all four pumps within 10 minutes.

So, basically, we have the same sort of guidelines as the morning session, in which we say: shut down all four pumps within 10 minutes. However, we have taken a slightly different turn, and I think we feel that this is another option that's available to us, and that is to shut down only two of the pumps.

This afternoon's session, we will get into the discussion on that, but I thought, as I sat here this morning and listened to the presentation, that it might help in looking at a summary of the two vendors' results, in some senses, it looks like we have different ends of the elephant and are trying to describe it.

(Slide.)

In the results area, we find that our limiting break location is in the hot leg, and in this morning's session the limiting break was located in the cold leg. The problem with the pumps on, we find that even if you continue to have the pumps running, you would get into a problem in that the core would uncover and you would have excessive temperatures even if the pumps didn't fail. Westinghouse did not find this.

The problem with minimum inventory -- and that is, in some cases, if you didn't get into problems with the pump on, did you get into problems because you had lost excessive inventory? We found that to be so. So did Westinghouse.

Dr. Rosztoczy asked this morning about whether Westinghouse would have a problem if they had all their safety injection systems running. I thought I heard the answer say that it was "Yes." We have done some analyses that say "No." If all the high-pressure safety injection pumps were running, that's an option that we would not have to shut the pumps off.

There are some physical differences in the plants, and I would just like to bring them to your attention. The number of cold legs to hot leg ratio for CE plants, we have two cold legs per hot leg, as opposed to one to one for Westinghouse plants. The HPSI shutoff head in our pumps in most of our plants, with the exception of one, is about 1300 psi, as opposed to greater than 2400. And in all but one of our operating plants, the safety injection tank pressure is 200. And in the Westinghouse it's 600.

There are some model differences, some of which I know, some of which I put X and Y on. We have chosen to look at this in a best-estimate type of approach as opposed to an Appendix K type. Basically, our best estimate differs from Appendix K in two significant areas. One, we use 1.0 x ANS as opposed to 1.2, and we use a break flow homoegeneous equilibrium model as opposed to Moody for the break flow. In all other respects, we have retained the conservatism of Appendix K.

In the results section, we came up with the five-minute shutoff time for two pumps. We did retain that you lost one HPSI. So, you have the conservatisms of Appendix K and we tried to use only those items that we had a good feel were not correct. 1.2 Appendix K heat, from data that we had seen, we have come to believe that the break flow of homogeneous equilibrium model is more accurate and more realistic.

MR. MICHELSON: Before we leave that slide, I thought I understood you to indicate that as long as you shut off two pumps in five minutes, then I guess you could run the other two indefinitely or lose them at any point and still be all right.

MR. LONGO: That's correct.

MR. MICHELSON: Now, I am trying to resolve that against your results in which you say you have a problem with the pumps on or the pumps are off. I don't understand that.

MR. LONGO: I did this sitting down, quickly, and I shouldn't have tried to confuse you. You are right. If we keep two pumps running, shut two pumps off in five minutes, we can keep two pumps running forever. And if they stopped at any time, we would have no problem with mininum inventory.

MR. MICHELSON: Okay. So, then, you don't have a problem with pumps running.

MR. LONGO: What I meant by this one is: if I kept four pumps running longer than 10 minutes, I would have a problem with minimum inventory.

MR. MICHELSON: Okay. Now, the other question, could we get a copy of your transparency?

DR. YAO: Excuse me. May I ask you one more question. Have you ever tried to run your program for 1.2 ANS decay heat?

MR. LONGO: Yes.

DR. YAO: Were your conclusions still able to hold?

MR. LONGO: We're going to be presenting that in the results section. But I will tell you, if you look at it in terms of time the effect of a combination 1.2 and Moody, you had to shut off four pumps in six minutes as opposed to shutting off four pumps in 10 minutes with 1.2 ANS in homogeneous equilibrium models.

So, there is a difference of four minutes in terms of need to shut the pumps off. But it's mixed between the break flow model and the decay heat.

MR. MICHELSON: Will you be explaining later now what problem you got into leaving all the pumps on after 10 minutes?

MR. LONGO: Yes. The next speaker is Dr. Holderness, who will present the general features of our small-break model.

(Slide.)

DR. HOLDERNESS: Actually, this afternoon I won't be presenting all of the general features of the small-break model. These will be discussed both by Gerhard Menzel, the next speaker, and myself.

What I would like to discuss this afternoon is present a view of the hydraulics models that Combustion Engineering uses to calculate the system response to a small-break loss-of-coolant accident. I would like to note that my talk will be nonproprietary; that proprietary details of our hydraulics models are contained in three topical reports: CENPD 137, CENPD 137 supplement 1, and CEN 114.

I would also like to note that the hydraulics model discussion which I will be presenting is the hydraulics model that we use when we assume the reactor coolant pumps trip concurrent with reactor trip. We have made some modifications to these models for the analyses in which reactor coolant pumps are assumed to remain powered. And for these model modifications, Tim Kessler will be presenting some details later this afternoon.

(Slide.)

The pieces of the small-break hydraulics model that I would like to discuss are shown in my next slide. Basically, I would like to discuss the reactor vessel hydraulics models, the hot leg hydraulics model, the steam generator model, and the cold leg hydraulics model.

This particular slide shows a section of a reactor vessel undergoing a small break in the cold leg. The point in time that I have shown in this slide is a point in time when the hot side of the system is saturated. You see a steam region in the upper head of the reactor vessel. Also, a steam region forming at the top of the steam generator U-tubes.

The core is boiling, and we've got delivery of two-phased fluid to the steam generator where condensation heat transfer is occurring. This particular point in time illustrates many of the hydraulics models I will be presenting today.

(Slide.)

I will begin my discussion with the reactor vessel model. The objective of this model is to determine the hydrostatic forces within the reactor vessel, both in the downcomer region and in the inner vessel region to determine the distribution of voids within the reactor vessel, particularly within the reactor core and ultimately to determine the effect of this voiding on the reactor core heat transfer.

The major feature of the reactor vessel hydraulics model is the use of a drift flux model to calculate relative motion between the steam and liquid in the reactor vessel. The drift flux model we use employs an empirical correlation of the drift velocity. This correlation gives the drift velocity as a function of pressure, and it's been based on test data over a fairly wide pressure range.

The model computes the local void fraction within the reactor vessel, based on a detailed axial energy balance. I should say the detailed void distribution is one-dimensional axial.

In performing the energy balance within the reactor vessel, we considered the following sources of energy: metal wall heat transfer from the reactor vessel structural members; core heat transfer, including details of the axial power shape. We take into consideration the subcooling of the coolant at the inlet to the core if subcooling is calculated to occur. And we also account for production of steam due to flashing of liquid during periods of depressurization.

DR. PLESSET: Do you have a multidimensional description in the core?

DR. HOLDERNESS: No, we do not. It's a one-dimensional model.

DR. PLESSET: Okay.

DR. HOLDERNESS: The core heat transfer model is level-dependent. We calculate a two-phased level or froth level, and below that load we have either forced convection to liquid or we have a form of pool boiling, nucleate boiling, film boiling.

Above the two-phase level we calculate heat transfer to steam through application of force convection correlations, and we take account of the superheating of the steam in our hydraulics model calculations.

An additional feature of this model is that we do calculate disengagement of steam from the two-phased mixture based on a local void fraction at the surface of that mixture. For this particular model, I refer you to CENPD

137 supplement 1, for proprietary details.

MR. MICHELSON: Before you leave that slide, you show the core barrel in the hot leg. In reality, of course, there is a gap between the core barrel and the hot leg of some sixteenth of an inch, more or less, and about a 50-60 inch diameter. How significant is the bypass flow from the annular region back to the hot leg through that gap going to be in these calculations?

DR. HOLDERNESS: In the calculations, the types of calculations we'd be doing without the pumps operating, we would actually get a little bit of benefit from modeling that gap, and then we'd get an additional path for steam venting from the reactor vessel.

In the calculations where we have modeled the reactor coolant pump operation, we have the opposite effect, where the annulus is pressurized with respect to the upper head, and we have considered that flow path.

MR. MICHELSON: That is in your calculational model, then?

DR. HOLDERNESS: Yes.

MR. MICHELSON: How large a gap did you put in the model?

DR. HOLDERNESS: I don't know the number offhand.

MR. KESSLER: Tim Kessler, from Combustion. I would imagine it's something on the order of about half a square foot total flow area, but I am really just guessing on that.

DR. HOLDERNESS: We've compared our reactor vessel model predictions to experimental data from two types of experiments. One is vessel blowdown tests, and the second is quasi-steady state boil-off tests in multi-rod bundles.

(Slide.)

My next slide shows a sample comparison to one of the vessel blowdown tests. This particular tes as part of the containment system experiment. Basically, the test facility consists of a large tank partially filled with saturated water at pressures of a thousand to 1200 psi.

The tank is then blown down through nozzles either at the top or at the bottom of the tank. This particular test was for a blowdown through the top nozzle. The two-phased level in the tank was measured as a function of time. And that's shown as the solid curve in this diagram.

We see, in looking at the test data, that there's an initial rise or surge in the two-phased level in the vessel. This is the result of the sudden initial depressurization. The flashing of liquid within the vessel and the steam thus formed not being able to escape the two-phased mixture rapidly enough; hence, a sudden rise in two-phased level.

As the steam disengages from the two-phased mixture, we see a period of prolonged gradual recession in the two-phased level within the vessel. Our prediction of this particular test, using our reactor vessel hydraulics model, shown as the dashed curve in this particular figure, in general, we see very good agreement between the measured and our calculated two-phased levels, even in this very dramatic sudden rise in two-phased level.

We did have a tendency in this particular test to slightly underpredict the amount of the initial surge, which would be indicative of the slight overprediction in the disengagement rate. In a small-break LOCA calculation, this would be in the conservative direction.

This is just one of a number of comparisons that we have made to CSE experiments. We've seen equally good agreement with other experiments in both top and bottom blowdown tests.

DR. ZUDANS: To what do you attribute those oscillations in the actual experiment? Does it relate to some structural aspect or what?

DR. HOLDERNESS: I don't think -- it may be the measuring technique. The two-phased level is measured with some sort of an acoustical control, as I understand it. There was no structure within this tank. It was an empty tank other than the fluid itself.

(Slide.)

The model has also been compared with quasi-steady state boil-off experiments, which are perhaps representative of the long-term quiescent core uncovery period in the small-break loss-of-coolant accident.

Basically, in these tests, which were multi-rod bundle tests, the hydrostatic head necessary to support a given two-phased level within the bundle was measured, so there are measurements of both hydrostatic head and some swelled fluid level within the heated bundle. These tests were run at two different test facilities, I believe, and both pressure and power were test variables.

What I have shown in this slide is the experimental value for the collapsed liquid level necessary to support a given two-phased level in the test. I have also shown what our model would predict as being the necessary collapse level, necessary to produce that same two-phased level. That two-phased level, of course, is not only a function of the collapsed level, but also power. And the test data we've shown here span a range of powers, although typically the powers are typical of the decay heat region, where we've been using them for small-break loss-of-coolant accidents.

(Slide.)

The second model I'd like to discuss is a hot leg hydraulics model. Basically the purpose of the hot leg hydraulics model is to provide a path for mass transfer between the reactor vessel and the steam generator. And the primary feature of the CE model is the use of a separated two-phase flow model for the hot leg in which we assume we have a liquid region or a low density mixture region at the bottom of the pipe and a steam region at the top of the pipe. We slip between the phases based on an empirical correlation, and for this particular model I refer you to CENPD 137

The basis for selecting a separated flow model for the hot leg is through a comparison of hot leg flow conditions calculated in a small break loss of coolant accident to two flow regime maps for horizontal two-phase flow pipes. Both of these flow regime maps are based on test data from simpler experimental geometries than a PWR hot leg, but the two choices of experimental data differed from each other quite dramatically in terms of geometry. And we feel they offered general guidance for determining a two-phase flow regime.

(Slide.)

This first model that I'd like to show is that which was tentatively proposed by Baker and Doppler based on horizontal flow of air and water in small diameter pipes. The coordinates of this plot are the traditional Baker chart coordinates, but basically it's steam flow rate versus liquid flow rate.

This particular flow regime map identifies three flow patters: segregated flow, intermitent or slug flow, and distributed flow regimes.

MR. ETHERINGTON: Could I ask, what happens to your speparated two-phase flow model if the pipe is not quite horizontal?

DR. HOLDERNESS: The model itself is for horizontal pipe.

MR. ETHERINGTON: But is the pipe in the plant always horizontal?

DR. HOLDERNESS: The pipe in the plant is horizontal. There is a bend going into the steam generator.

MR. ETHERINGTON: There's no deliberate pitch for drainage?

DR. HOLDERNESS: I don't believe so. If there is a ptich, it is certainly much smaller than the three and a half foot in diameter of the pipe itself.

MR. ETHERINGTON: Of course.

DR. HOLDERNESS: In this particular flow regime map, except for the appearance of the area on the Y axis, there is no other dependence on pipe size for the flow regime boundaries. It's not clear that this would be true for all flow regime boundaries, particularly the stratified flow boundaries where gravity terms might be expected to be influential.

DR. CATTON: What are the gammas?

DR. HOLDERNESS: The gammas are basically functions of property, ratios of surface tension, density, and viscosity, I believe. And I think the definition of the gammas appears in the chart. That's in our topical report.

We've taken a look at a second correlation, the proposed criteria of Wallis and Dobson for one particular flow regime boundary, and that's the stratified slug flow boundary, which is the boundary that we're really the most interested in. The data base for this particular correlation is quite different than that for the Baker-Loppler correlation. The Wallis-Dobson correlation is based on air-water flow in horizontal rectangular channels that varied in height quite dramatically from one inch channels which might be considered similar to a small diameter pipe up to a 12 inch channel, which is more equal to a large diameter pipe.

What I've done --

(Slide.)

-- is plotted the Wallis-Dobson correlation, evalu ed for small diameter pipes, one and a half inch diameter pipes on the Baker-Doppler flow regime map, and the Wallis correlation is shown as the dashed line in this plot. In general, what we're seeing is that there's relatively good agreement that these flow regime boundaries are certainly not distinct. But we see acceptable agreement in the regime boundary between these two correlations, if you would, based on quite different test data.

However, this is the Wallis correlation when it's evaluated through the smaller pipe diameter. Since that correlation contains a diameter dependence, I've also plotted that correlation for large diameter pipes.

(Slide.)

The size of our hot leg piping -- and we see the effect of pipe diameter is to expand somewhat the stratified or segregated flow regime boundary. Still we see the same general trends in this kind of flow regime map.

Finally, I'd like to put on some typical ranges of flow conditions that are calculated for the hot leg during a small break loss of coolant accident.

(Slide.)

And that's shown by the red cross-hatched line in this slide. I've plotted the conditions from the time when the pumps are assumed to trip, which is fairly early in the transient. At the time of pump trip, we would expect to see a distributed flow regime at least using the Baker-Doppler flow regime map during the pump coastdown period, which is this period in here. We would expect to pass through the intermitent or slug flow regime for a short period of time and ultimately end up in a regime of separated two-phase flow in the hot leg.

In this particular condition for this particular analysis, about two minutes after the pumps tripped, until 2000 seconds later, the steam flow rates in the hot leg are sufficiently low and the void fraction in the hot leg is sufficiently high to prevent either slug flow or distributed flow in the hot leg piping. Since the conditions for the largest period of time do fall within the stratified flow regime boundary, we have chosen to model in our computer code the hot leg flow as being stratified.

MR. MICHELSON: What was the time again for which you thought this would be valid?

DR. HOLDERNESS: The time here is 150 seconds. This is about two minutes after the pumps have tripped. This is well before --

MR. MICHELSON: Oh, those are times after pump trip.

DR. HOLDERNESS: No. That's time after break opening.

MR. MICHELSON: You're assuming pump trip times zero.

DR. HOLDERNESS: I'm assuming pump trip at about 20 seconds in this particular analysis.

MR. MICHELSON: That must be because of loss of off-site power?

DR. HOLDERNESS: Yes.

(Slide.)

The next model I'd like to discuss is the steam generator hydraulics model. The objective of this model is to determine hydrostatic forces in a major vertical component of our system and as such, determine the hydraulic conditions for the steam generator heat transfer calculations.

My talk will be limited to the hydraulics model, and the next speaker will discuss the details of the heat transfer model. Again, the major feature of the steam generator hydraulics model is the use of the drift flux model to calculate the relative motion between the vapor and the liquid in the steam generator tubes. The particular model we used is the same that I used on the reactor vessel, and we use the same correlation of drift velocity.

We do account for separation of phases that may occur at the top of the U-bend, and another feature of the model is that we do allow counter-current flow of liquid during the reflux boiling time period. I should note on that last point that the counter-current flow of liquid would only be from condensate on the hot side of the steam generator U-bend. And for more description of this model, I refer you to CENPD 137 and CEN 114.

(Slide.)

The basis for modeling the counter-current flow during the reflux boiling mode of operation is through a comparison of typical conditions at the inlet to the steam generator during this time period to a flooding criterion. On this slide, I've plotted the Wallis correlation for flooding. The coordinates are the standard dimensionless gas velocity and dimensionless liquid velocity at the one half power, and a range typical for the reflux boiling time period is shown as the cross-hatched area in this slide.

We see that in general steam flow rate and liquid flow rate during this time period are well below the flooding limit predicted by this correlation, and we would therefore expect that the liquid condensate on the hot side of the U-tubes would be able to flow counter-current to the steam, back into the hot leg.

(Slide.)

The final part of the hydraulics model which I will only briefly discuss is the cold leg hydraulics model. The cold leg model includes the pump suction leg piping reactor coolant pump itself and the pump discharge leg. Again, we use the drift flux model to allow tracking of the two-phase liquid level in the vertical components of the piping.

The horizontal components of the piping are modeled as separated flow, and for the reactor coolant pump, we have a dynamic reactor coolant pump model that's based on a single-phased pump performance.

That concludes my presentation of the fluids models.

MR. ETHERINGTON: Could I revert to a question? This question of pitch. I think ordinary good practice in design would call for a pitch to move fluids during cleaning and possibly any subsequent use. Could I suggest that you find out whether there is a pitch in the design, and if so, whether it does affect in any way your conclusions?

DR. PLESSET: Have you got some information?

MR. LONGO: Let me try it. As I understand it, the hot leg is strictly horizontal. If there is a pitch, it may be due to the manufacturing. We do have a drain line, however, in the hot leg.

MR. ETHERINGTON: That has to drain a considerably horizontal length, then.

MR. LONGO: That's true.

MR. ETHERINGTON: You can state definitely that there's no pitch? It's a matter of mechanical design?

MR. CALLAGHAN: I'm Vince Callaghan from

Combustion. There is normally some pitch, but it's due to the fabrication process, the way the pipe is welded up. It doesn't end up being perfectly level. But in practice, of course, there's no problem of draining.

MR. ETHERINGTON: So you'd say it's accidental, then.

MR. CALLAGHAN: Yes.

DR. HOLDERNESS: If there are no further questions, the next speaker is Gerhard Menzel, who is Section Manager of the ECCS Development Section.

DR. PLESSET: Is there any simple explanation before you get fully seated as to why you find the hot leg the critical break point, whereas Westinghouse finds the cold leg?

DR. HOLDERNESS: I think the explanation is maybe not so simple. I think it will become clearer when we discuss the reactor coolant pump modeling and some of those results.

DR. PLESSET: All right.

MR. MENZEL: My name is Gerhard Menzel. In my presentation, I will cover three items of how our small break model for which the Subcommittee has expressed some interest -- these three items are:

(Slide.)

the break flow model, the heat transfer model in the steam generator, and I will in addition touch on the effect of noncondensibles on heat transfer as well as on the effect of noncondensibles to return to natural circulation.

Finally, I will review our pressurizer surge line model. I will be starting out with the break flow model.

(Slide.)

And in the second slide here, I have listed the critical flow correlations which we use in our small break LOCA licensing model. We use for the discharge of subcooled water the modified Henry-Fauske model. For the two-phase flow, we use the Moody model which is required by 10 CFR 50, Appendix K. And for superheated steam, we use the modified Murdock-Bauman correlation.

Now one of the questions which we have been asked primarily by the staff refers to the appropriateness of using one single discharge coefficient for the subcooled and for the two-phased region. We approached this question two ways.

First, one approach was to find out what would be the effect of using different discharge coefficients on our small break results, and then we looked at appropriate experiments.

(Slide.)

Now the results of our analytical calculation are shown in this slide where I show a mixture level in the core versus time after the break. And what we have used is our discharge model for two-phased with the discharge coefficient of one and have varied the discharge coefficient for the subcooled model around the value of one.

The specific values here are proprietary. They are listed in CEN 114, Supplement 1, Figures 34-3. When you look at the results you basically see that there is very little difference what discharge coefficients we do use in our calculation. There's essentially no difference in the mixture level. The only effect, which is very small, we find by way of a time shift when a certain amount of mass depletion appears in our calculation. So basically from this plot, we really conclude that it doesn't make much difference what coefficient, within reasonable bounds, we use for our subcooled model.

Or we can turn that around. That basically tells us that we can use, without seeing much difference in our results, the same discharge coefficient for subcooled as well as the two-phase flow.

MR. MICHELSON: Excuse me. Where is the break located that you postulate?

MR. MENZEL: This is for a cold leg break.

MR. MICHELSON: Pump discharge?

MR. MENZEL: Typically, pump discharge for a cold leg break is located at the bottom of the cold leg.

Now how do we know that in our analysis we picked the right range of discharge coefficients for the subcooled region? Well, we have looked at experimental data. and we found in particular that the data of Southey and Sutherland are based on tests which resemble very closely a small break subcooled blowdown.

Okay. Basically, we found that Southey and Sutherland tested many break geometries, and they do find a difference between a fluid entrance with a little bit of a pipe stub compared to a sharp orifice. Now we found that if we use our subcooled break flow models, we can bound the experimental results by using the discharge coefficient which was slightly above one and going down to the discharge coefficients below one.

DR. CATTON: For your cold leg break, isn't this a bit academic, when it's probably a crack in the pipe?

MR. MENZEL: Well it could be a crack in the pipe. It could be -- I guess it could be a break.

DR. CATTON: If it's a small break near the pump discharge, I would guess that it would have to be some kind of a crack, I would think.

MR. MENZEL: We have lines coming in for shutdown cooling. I guess they are bigger lines. Yes, I think basically you referred to a point that both geometries which we have tested are somewhat irregular or somewhat idealized from what you would expect in a pipe crack situation.

DR. CATTON: That's correct, so this aspect of it becomes somewhat academic. Would the curve of yours shift if the breakthrough during the two-phase period acted as a steam separator?

MR. MENZEL: Acted as a steam separator.

DR. CATTON: I asked Westinghouse the same question, so it's only fair.

MR. MENZEL: Yes, okay. My guess is it would shift, because if it acts as a steam separator, you must throw out less two-phase.

DR. CATTON: More steam and less water.

MR. MENZEL: Which means you must inventory -- the inventory depletion must be different. I think it would go in the direction of -- you would be throwing out less mass.

DR. CATTON: So would this lead you to different conclusions with respect to running the pumps or nor running the pumps?

MR. MENZEL: I don't think so, because I think that eventually might be overridden. I actually don't know how big that effect that Mr. Fabic talked about this morning is. But it's overridden basically by the fact that by running the pumps you keep the water level up higher, for a longer time.

If you would have compared two cases where you had taken something like steam separation into account -- in the firtst case with no pumps running, and in the second case with pumps running -- you still would keep the fluid level up higher for a longer time.

DR. CATTON: So keeping the fluid level up higher for a longer time is bad?

MR. MENZEL: It's bad in terms of you through more mass our of the system.

MR. LONGO: Professor Catton, may I recommend that when we get to the small break description of why the hot leg is limiting, that you raise this question again?

DR. CATTON: Sure.

MR. MENZEL: Well, looking, for instance, at the data of Southey and Sutherland, where you do see differences for different break geometries, obviously that leads you to the question which was mentioned before: What about a real break, a crack; or, in particular, what aboutt a stuck open PORV?

(Slide.)

Well, the geometry of a PORV is quite different from some of the idealized test situations. What I've shown here is a schematic cutaway of a PORV. You have basically the valve housing here; the fluid comes in here and eventually goes out here.

You have the movable valve body, which rests against the valve housing here. And the seating phases are in this area. The movement of the valve body is controlled by a pilot valve, which is physically separated; and when the valve opens, this valve body moves down, and flow goes through here, out through the exit of the valve.

This area here is basically the narrowest area in the valve, and this is usually referred to as throat area.

Now, one question which we have been asked by the Staff and which we asked ourselves, also, is: How is the flow capacity of a PORV actually determined?

(Slide.)

Well, it turns out that the manufacturer determines on an experimental basis what the discharge coefficient for a particular valve is That's done simply by comparing the measured flow rate against the theoretical flow rate, a theoretical flow rate based on an equation which is described in the ASME code.

DR. CATTON: This is done for steam, isn't it?

MR. MENZEL: I'm just coming to that.

Based on verbal communication with that manufacturer, this is done for saturated steam at pressures of about 300 psi with a valve which is, in general, similar in design to the PORV which is in our reactors.

So on that first then you'll find what the experimental discharge coefficient is, so the next step -- that, again, is done by the manufacturer. They determine what's called the nameplate capacity of that valve -- again, now, for saturated steam. And the flow rate is calculated by using the measured KD, the valve area -- that's the narrowest area, which I pointed out before -- the set pressure, and then a constant, which takes care of the dimensions.

MR. ETHERINGTON: What is the theoretical flow rate? Is that through a simple orifice?

MR. MENZEL: Yes, it's essentially a formula which is derived from the orifice dimensions, again based on verbal communication with the manufacturer. In defining the nameplate or determining the nameplace capacity, a factor of KD of .95 was used.

Now, how do we use then that information?

Well, based on the nameplate capacity, we back out an equivalent valve area, and then we use this valve area to get in with our breakflow model.

Now, after discussion with the manufacturer, it does not appear to us a priori that that valve could not be stuck in a position which is halfway in between opening and closing.

So, based on that approach, the analysis which we have described in CEN 114 was done by varying the discharge area for a PORV, when we do calculations, where discharge through a PORV is considered.

(Slide.)

Well, that leads me to the conclusions on our breakflow model. And based on experimental evidence, we find this sub-cooled leak flow is strongly dependent on break geometry. Our analysis shows us that our breakflow results are insensitive to the subcooled leak flow over a range of applicable data.

Based on it, it appears appropriate to predice core uncovery if a constant discharge coefficient is applied for subcooled and two-phase flow.

Now, a general variation of this discharge coefficient can be applied through a variation of the break area. This is what we typically do, if we maybe do a licensing calculation, in order to find the worst break.

Finally, what I just mentioned before, because we don't think we can clearly specify the open area for a PORV, a spectrum of flow areas was analyzed in our response, which is written up in the CEN 114.

(Slide.)

Let me go now into a review of our heat transfer model in the steam generator.

By way of introduction, I wanted to show on the slide here basically a pressure transient for one of the largest small breaks and point out some of the main heat transfer periods.

Well, the break starts; the system depressurizes somewhere around here at 1500 psi; the pressure falls to the saturation temperature, the saturation pressure of the hottest liquid; you get flashing here, and eventually you come to the point where enough steam is created in the system.

Not all the steam which is created gets out the break, which means some of the energy has to be removed otherwise. The way it is removed is by way of the steam generator.

In order to remove the energy through the steam generator, you have to have a driving temperature differential between primary and secondary side, which means the pressure on the primary side has to be a little bit higher than the pressure of the secondary side in order to have the heat transfer, which now is what we call the former direction from the primary side into the secondary side.

Now, all during this time here, you're losing mass. Okay, the level in the system goes down; finally you find yourself at a point where the break is no longer covered by two-phase; steam is going out the break, so there is much more volumetric flow that goes out the break, and you start depressurizing relatively fa-t if you follow that line down here until eventually the safety things come one on.

Now, all during that time, the pressure in the primary side is lower than the pressure in the secondary side, because the system is at saturation. The temperature in the primary is lower than on the secondary side, and we have what we referred to as reverse heat transfer. Heat goes from the secondary side into the primary side of the system.

(Slide.)

With this short introduction, let me just show you basically a tabulation of the various heat transfer periods, regimes, and correlations which we use in our steam generator.

This is for the period of forward heat transfer temperature on the primary side, higher than on the secondary side. And basically the various flow regimes which Joe Holderness pointed out in his presentation before me, in the steam generator you can subdivide subcooled, forced convection flow, two-phased-forward flow with condensation, during the time the steam generators are draining two-phase countercurrent flow with condensation, and steam condensation for the time after you have broken off the pressure plateau.

Now, for the these four different heat transfer periods, we basically distinguish between two primary side heat transfer regimes. We have a subcooled forced flow.

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Well, we use subcooled forced convection as a heat transfer regime. The correlation we use is Dittus-Boelter.

For all the other periods where we have either two-phased flow or a steam with condensation, we assume the heat transfer regime, which is two-phase flow with condensation, and we use the correlation of Akers, Deans, and Crosser, which is a Dittus-Boelter type correlation, constant Reynolds number to the .8.

DR. CATTON: Isn't the Akers paper for condensation inside horizontal tubes?

MR. MENZEL: That is true. We have compared the Akers correlation against the correlation developed by Shaw, which is based on something like 500 experimental points, or something like 20 different sets of data points where we had horizontal, vertical, and inclined flow.

We do find that the Akers correlation for low quality flows directly together with Shaw for high quality show predicts high heat transfer coefficients.

DR. CATTON: Are there not Reynolds number limitations on that? For the Reynolds number, I don't believe that.

MR. MENZEL: First of all, Akers has basically two flow regimes, a high Reynolds number, and a low Reynolds number regime. It turns out there is a knee in the curve. It goes down the high Reynolds number like this; for the low

Reynolds number, it flattens out.

For our model, the way we use the Akers, Deans correlation we continue the steep slope of the correlation for the low Reynolds number, which means we get relatively lower heat transfer coefficients.

Now, we have also compared the Akers, Deans correlation for low Reynolds numbers for the case of a falling film against essentially two approaches. One is the Noessel theory for falling film, against the correlation developed by Professor Doppler, which covers falling film condensation from higher Reynolds number from intermediate to low Reynolds numbers.

We find that the Akers, Deans and Crosser correlation gives heat transfer coefficients which are lower than either of these correlations.

DR. CATTON: I guess you can't argue with it if it's lower. It's just that it seems wrong.

MR. MENZEL: It seems wrong?

DR. CATTON: Akers work was for a specific geometric configuration, and yours is different. I think it's just fortuitous that it's lower, but if you've made all these comparisons, I guess one can't fault you.

MR. MENZEL: Okay. For a more detailed description, let me just refer you to CEN 114. We have the curves in there.

DR. CATTON: I believe 114 is what we received in the mail. Maybe I didn't read it closely enough, but I didn't find all of the detailed discussion you're referring to.

MR. MENZEL: It's in Chapter 3.5.

(Laughter.)

DR. CATTON: That must be about page 700.

MR. MENZEL: It's page 3.5-something.

(Laughter.)

MR. MENZEL: Actually the pages are 3.5-18 and -19. I didn't mean to be flippant, but I --

DR. CATTON: No, no. That's fine.

MR. MENZEL: I remember, because I figured a question like this might come up.

(Laughter.)

MR. MENZEL: What do we use on the secondary slide? Pool boiling, and we use a modified Rohsenow correlation.

(Slide.)

For the case of reverse heat transfer, when the primary temperature is lower than the secondary temperature, we basically distinguish between two heat transfer regimes. One is steam superheat, and we use the Dittus-Boelter correlation. Or in the case where you start refilling, the heat transfer is nucleate boiling, and we use the Thom correlation.

In those cases, again, for the secondary side, we use -- we assume the heat transfer regime of natural convection, and we use the McAdams correlation.

So much about the heat transfer model in our steam generator.

(Slide.)

In terms of noncondensables, there are basically two effects which we think are of interest.

One is the effect of the steam generator on heat transfer, and there the potential for reduction of the condensation rate, which in turn would lead to an increase the primary rate, because you have to have a higher delta T to get the same amount of heat.

The second effect is quite different from heat transfer and pertains to what is the effect of noncondensable gases to reestablish single-phase natural circulation after you have been cold boiling and refluxing.

(Slide.)

Let's take briefly a look first on the sources of noncondensable gases here. We have dissolved hydrogen in the primary coolant, from coolant treatment essentially. We have hydrogen accumulated in the vapor space of the pressurizer, and we can have air introduced in the system by way of the HPSI flow rate, which takes its water from the refueling tank, which you have to assume is saturated with air.

The relative volumes are listed here, standard STP; and the massed are listed here. Just for comparison, we listed some of the possible causes of noncondensables you could have if you have massive core damage. Here it's for complete oxidation of the clad fuel gas, fission gases; and in the last case, for large breaks, large small breaks where the safety injection tanks will come on, and nitrogen from the cover gas will dissolve in the water of the safety ejection tanks and will be discharged.

Now, in our analysis, basically, we think that for the cases of small breaks which are of interest, these are the ones which do refill, which are small enough so that the leak flow does not remove all the energy; or, to put it the other way, for small breaks small enough for steam generator heat transfer. That is only the first three sources of noncondensables which we expect to have in our system.

Now, basically we would expect that actually with maturity these noncondensable gases would accumulate in the reactor vessel upper plenum.

Now, for the purposes of our calculations, we have assumed that all these noncondensables do collect in the tubes of the steam generator.

Let me discuss first the effect on the heat transfer coefficient.

(Slide.)

What we have done here, we took our Akers, Deans and Crosser correlation for two-phased flow and corrected it by using another correlation, which was based on work by Collier and again Akers --this time it's Davis and Crawford -- which was work in connection with the effect of noncondensible gases on condensation, and have calculated how much reduction in heat transfer coefficients we would see if we had gases in the steam generator for the maximum expected amount of noncondensibles, which is this line here.

We find that the heat transfer coefficient would reduce by something like 3 percent.

DR. CATTON: That particular experiment that you were referring to, was it a reflux experiment or was it through-flow?

MR. MENZEL: It was a condensation experiment for, I understand, a falling film situation, which would be close to the refluxing period.

DR. CATTON: Okay. I guess again I misread your report. I thought it was for the flow inside the tube, condensation inside the tube.

MR. MENZEL: It's flow inside the tubes, but it's condensing on the inside.

DR. CATTON: Well, that's correct, and that's the point I'm trying to raise, is that the flow is through the tubes. Under those circumstances, the impact of foreign gas content is markedly less than when you have this particular situation, where it can collect.

MR. MICHELSON: I believe it was also horizontal tubes, wasn't it, for their tests?

DR. CATTON: Air is a problem in the horizontal tubes. Air is more of a problem in something like this, where you have a tendency to collect it on your condensing surfaces and you don't have it swept away.

MR. MENZEE: Let me show you, I guess, a picture similar to one of the pictures Jim Holderness has shown before.

(Slide.)

It refers to a situation basically like this, where you have steam going up here in the tubes, the steam condenses on the wall here, and then liquid film is falling back.

DR. CATTON: That's right, your system is, in essence, acting like a heat pipe.

MR. MENZEL: Okay.

DR. CATTON: That's one of the big problems with heat pipes. It's just a few very small amounts of air starts to shut them down straight away. The reason is, you collect all the air at your condensing surface, and that's the same thing that's going to happen here. Your steam flow carries the air to the surface and it's going to stay there, where in the horizontal tube you'll sweep it in one side and out the other, and the concentrations stay about the same in the tube, they don't build up.

MR. MENZEL: Well, wouldn't the air collect up here?

DR. CATTON: That's an assumption. I don't think you can use the data you used to come to any conclusions for this particular system, because it's different.

MR. MENZEL: Well, we did use that correlation to make our analysis.

DR. CATTON: I guess I'm suggesting maybe another look might be appropriate.

MR. MENZEL: Okay. Well, let me continue with my slides.

(Slide.)

Using the work of Collier and Akers, Davis and Crawford, we find that the heat transfer coefficient reduction is something like three percent. Okay, if the heat transfer coefficient goes down, in order to get the heat load across the primary pressure has to go up. And again, for the maximum expected amount we find something in the order of three percent increase in pressure, which is negligible for the purpose of our analyses.

DR. CATTON: I understand three percent is negligible. Did you do a sensitivity analysis to determine whether that roughly linear relationship persists? In other words, if I get a 50 percent reduction in heat transfer coefficient, do I get a 50 percent increase in the pressure rise, or do other things in your system adjust?

MR. LONGO: Professor Catton, I think you asked a similar type question this morning.

DR. CATTON: I did.

MR. LONGO: We did do some rough parameter studies where we said, suppose you have 50 percent of the area not available to you; what would happen? Your pressure would rise. It doesn't rise double or anything like that. It rises until the driving force accepts -- until the temperature driving force across the steam generator is able to transfer the heat that you required.

As I remember the study, the pressure rose less than 100 psi when you have the heat transfer.

MR. MICHELSON: In your model, how do you account for the film blanketing now of the inside part of the tube? The condensation process is depositing a water film on the surface. It then turns back by gravity, and so forth. My recollection of the correlation, that was not quite the challenge they were even doing or using in the test, and it isn't clear that the film blanketing of the tube was really taken into account.

Do you want to comment on that?

MR. MENZEL: As I understand, in the experiments of Shaw, the situation where you do have condensation in horizontal tubes would mean you have some film on the side, which must go down, was taken into account.

MR. MICHELSON: Of course, the water film runs along the bottom of the tube in the case of the test data. And in the case of the steam generator, the water film was running down the length of the tube, completely around the circumference.

MR. MENZEL: Again, as I understand Shaw's data, it does include vertical tubes.

MR. MICHELSON: Yes, with through-flow, and I think without excessive condensation to the point of building up a large amount of water. Isn't it obvious that it must be somewhat a function of the condensation rates and the amount of water that's accumulating on the surface? Maybe I just don't see what this implies.

MR. MENZEL: Are you referring to the effect of noncondensibles?

MR. MICHELSON: I'm really referring now to the effect of the condensing vapor on the surfaces. Well, if you blanket the surface with water, are the condensation rates the same as if you had a clean inside tube surface?

DR. YAO: The thickness of the water film.

MR. MICHELSON: Right. If you try to push these very hard and build up a large water film, I think the heat transfer coefficients start changing. But I'm not sure how much, and that's why I'm asking.

DR. CATTON: It's my understanding that they compared with Russell's analysis.

MR. MENZEL: Yes, we did.

DR. CATTON: They found that the Akers correlation fell below it. So I think that aspect of it's properly taken care of.

DR. ZUDANS: The film thickness was settled.

DR. CATTON: They can calculate the film thickness. I don't know if you did that, but you could.

MR. MENZEL: Basically, the Akers correlation is a Dittus-Boelter type correlation. Basically, the analogy is with a liquid film.

DR. CATTON: I don't think I agreed with it the first time. I surely won't agree with it the first time. I think it's just fortuitous that that type of correlation is working well on this particular situation. But you did compare it with the nozzle film?

MR. MENZEL: We did compare it with the nozzle film, with the Doppler correlation, which covers those high and low.

DR. CATTON: That's right. The treatment for noncondensibles is just incorrect.

MR. MICHELSON: Isn't it also a function of film thickness?

DR. CATTON: Yes, the rate of condensation determines the rate of buildup of the air film that's on the surface that's blocking the condensation process.

DR. YAO: Are those correlations within -- I mean, your condition is within the experimental range of those correlations?

MR. MENZEL: Your question was, are the experimental conditions representative of what we see here? Well, certainly the many points in the data in Shaw are representative of the considerations we have here in terms of tube diameter, in terms of pressure, which goes from very low pressures to about 1500 psi. So we feel they are appropriate for the condition here.

DR. YAO: So some of those factors may not have been considered when they correlate the data, but they actually are included?

MR. MENZEL: That's right.

This is all I had, all I wanted to say about the effect of the noncondensibles on the heat transfer in the steam generator.

Now, the next point --

DR. CATTON: One more question. You indicated that the delta P was 100 psi when you decrease the heat transfer by a factor of two. At what system pressure was that?

MR. MENZEL: It must be about 1,000 psi.

MR. LONGO: 1200 to 1300.

DR. CATTON: So 1200, 1300, it went to 1400. Okay, thank you.

(Slide.)

MR. MENZEL: The second effect of noncondensibles is in connection with reestablishing natural circulation, and we think that basically we'd like to reestablish natural circulation in a system where you do have noncondensibles. It's very similar to the situation where you want to sweep out a bubble, which is shown here schematically on this slide.

You actually can see that if you take plastic tubing and introduce a bubble, and then have two containers here and try to get a siphon going, what you see first is that if you lift one of the containers higher, there basically develops a driving force between the higher container to the lower one. You see, the bubble which sits in the middle is swept to the side. It just sits there.

Well, if you raised that container even higher, then you would find that eventually the bubble moves down and out. Well, if you compare, then, how high you had to raise the water level in order to get the siphon going, you'll find it's about the size of the bubble, the length of the bubble.

DR. CATTON: Isn't this a rate-dependent process? If the flow velocity is very slow, it'll flow right around the bubble.

MR. MENZEL: It does here. There's a little bit of flow around the bubble, but it is something like a factor of 20 less than what you have after the bubble is swept out. So basically, from that situation we conclude that a useful approach is to postulate that you have to have a driving delta P between here and here which is equivalent to the pressure difference fluid columns would have which have the length of the gas bubbles.

(Slide.)

Now again, we use the sources of noncondensibles, the same which we used for the determination of the effective heat transfer, and found out how much bubbles could we have in the steam generator before we couldn't sweep them out any more. This is shown here in this slide, which shows the masses of noncondensibles against the primary side pressure. The bubbles become smaller the higher the pressure is. The maximum expected mass of noncondensibles is this line here, which works out to something like about 40 pounds. Again, it assumes that all the noncondensibles are collected in the steam generator.

And we find that, depending on the pressure you add, this line here shows the maximum amount of bubbles you can sweep out. And we see that, just fortuitously, down at about 300 psi, which is typically the pressure for which we initiate shutdown cooling, the expected amount and the amount which we can sweep out are approximately equal. For higher pressure, we expect something like half the amount of noncondensible gases compared to the one which we could sweep out.

Typically for breaks where you refill in your steam generator, heat transfer is important. You find yourself a pressure which is down in this area here.

DR. CATTON: I thought your chart said that there was 109 pounds of noncondensibles.

MR. MENZEL: This is when you take all the noncondensibles which are in the refueling water tank. This calculation is based on assuming that the HPSI pumps operate for something like eight hours. You wind up with a smaller percentage of the refueling water, consequently a smaller amount of gas.

Now, just for comparison, as I mentioned before, we really believe that the majority of the noncondensibles is really stored in the upper plenum. This line here shows, again for pressure, how much noncondensibles could be stored in the upper plenum. And we find that we have something like about 50 times more noncondensibles could be stored in the upper plenum compared to the ones which we either expect or could sweep out.

DR. CATTON: Except that when we're acting in a reflux boiler mode, that's almost acting like a purge of your system. It would tend to collect them preferentially, I believe. But even so, you have 50 pounds as your lower boundary.

MR. MENZEL: Yes. Well, a lot of the noncondensibles come in by way of the HPSI flow, which goes through the core first. And to me it does not appear unreasonable to assume that a fair amount comes out right then and goes right into the upper plenum.

DR. CATTON: That would mean it would have to separate from the steam. The molecular weight of steam and air are kind of close to one another. As a matter of fact, the air is a bit heavier. So I don't know. If you were concerned about helium or hydrogen or something like that, you might be able to argue that you would collect it in the upper head. But I thihk it's more difficult when you're talking about air.

MR. MENZEL: Okay. Well, that brings me to the conclusions on the steam generator.

MR. MICHELSON: Before you get into your conclusions, let me go back and ask you a question on your slide that showed the bubble being purged. What was the source of the delta H that you show? It's an elevation change, but what physically is creating that elevation change now to purge the bubble?

MR. MENZEL: Water flows from the water level which is higher to the lower one. Basically, the water goes from here to here, and what we do, we have a somewhat circuitous pipe which goes around this way.

MR. MICHELSON: But in the real world the two containers are somewhat one.

MR. MENZEL: That's right.

MR. MICHELSON: Somehow you have to consider that as well.

MR. MENZEL: Sure. I could simulate the same effect by leaving the container at the same elevation and just closing it and putting a little bit of pressure on it, and it would rise and the pressure difference between here and here is a pressure difference equal to the static height here.

MR. MICHELSON: It takes a driving force. You have to verify that such a driving force exists.

MR. MENZEL: The driving force is basically the potential energy.

MR. MICHELSON: That's on the assumption that the two containers aren't connected except by the tube. In reality the two containers are connected. There's a common return. In particular, I would like to ask about the gap now, again, between the core barrel and the exit pipe, which in essence bypasses and connects those two containers. It's not a very big area, admittedly. But it's not necessarily a very big area that would be needed to equalize these two pressures.

MR. MENZEL: That's true.

MR. MICHELSON: I mean, it's just all kind of hand-waving in a way, because you're saying that if a delta H exists, then indeed you can sweep the bubble. I don't think there's any doubt of that.

MR. MENZEL: If I want to get back into natural circulation, I must have a driving pressure differential. And that I get from the density differences on the hot side compared to the cold side. So I talk about pressure difference. Now, here I do have a pressure difference. The situation would not have changed if this container would go all the way down here. The pressure down here would be higher than the pressure down here.

It turns out that pressure difference is exactly that height of the fluid column.

MR. MICHELSON: I guess it bothers me a little bit to see you sweeping the bubble countercurrent to natural circulation. The natural circulation process is in the other direction normally.

MR. MENZEL: Yes, I can do that, and this is the reason that there is a limit. If the bubble is too big, I cannot put -- if the bubble is too long, then I cannot -- the static head difference is not big enough and I wind up in this situation.

MR. MICHELSON: Let me ask you a simple question to make sure I understand your drawing. Is the right-hand reservoir the cold leg, essentially, and the left-hand reservoir is the hot leg? Or is there something -- maybe this is unrelated to reactors. That's why I was looking at this, like you were showing the cold leg on the left-hand side and the hot leg on the right-hand side. And I guess this is not even related. But I've got to relate back now to reactors and natural circulation and the bubbles, which is what we're really talking about..

MR. MENZEL: I see some of my people are trying to rescue me.

DR. HOLDERNESS: Actually, I think we're viewing it as exactly the opposite. The right-hand side is the hot leg side and the left-hand side would be the cold leg side, with the hot leg having less dense fluid than the cold leg side.

MR. MICHELSON: Yes, but the hot leg side's elevation is lower, normally, than the cold leg during natural circulation process, as I understand it.

DR. HOLDERNESS: I think we would predict just the opposite.

MR. MICHELSON: It depends.

DR. HOLDERNESS: You could balance the hydrostatic heads. Basically, in one case you've got a collapsed level. In the other you've got some lower density flow.

MR. MICHELSON: Generally, you have a collapsed level on the cold leg of the steam generator. That's where your collapsed level is. Generally it's higher. It's a non-existent level as such. That's the driving force. It's that extra column of water in the cold leg that makes your thing go.

DR. HOLDERNESS: I guess I don't see how the extra column of water is collecting on the cold side.

MR. MICHELSON: That's where the denser fluid is that's driving the natural circulation process.

DR. HOLDERNESS: Exactly. The pressures are balancing. The heights are not.

MR. MICHELSON: This figure is unrelated to any reactor simulation, I guess; is that correct?

DR. HOLDERNESS: This is a simplification.

MR. MENZEL: It's a simplification. It's just meant to sort of give a qualitative, no more than that -- first a qualitative picture, and then a quantitative handle of finding out how much of a pressure driving pressure differential you would need to have in order to sweep out a gas bubble of a certain length.

DR. CATTON: What part of CEN 114 do I find this in?

MR. MENZEL: This is chapter 4, which is at the very end, and it must be what --

DR. HOLDERNESS: 3.2

MR. MENZEL: I'm sorry, 3.2.

DR. PLESSET: There's another comment here. Let him make his comment.

Would you identify yourself?

MR. BLAISDELL: John Blaisdell, Combustion Engineering.

There seems to be a disagreement between which side has the higher level. Prior to going back to natural circulation, we would predict that the cold side of the steam generator would have a level lower than the hot side, just to balance the pressures. And as the whole thing fills up, and if you have trapped noncondensible gas, you eventually get to the point where the noncondensible gas would be on the left in the picture up there, where the core is on the right-hand side of that picture.

And due to density differences in the core, that is the thing that is driving this thing around. You have cold fluid on the left-hand side, hot fluid on the right-hand side, providing the driving force for sweeping out the bubble.

MR. MICHELSON: Yes, that's quite right. But now you're talking about the real world and two different temperatures, also. Then that's right. The hotter fluid will have the higher level, there's no doubt. That's why I wondered what this picture really meant. I assumed that this was some kind of an equal temperature illustration.

MR. BLAISDELL: This is just a schematic.

MR. MENZEL: It's just basically something to visualize the effect of sweeping the bubble out.

DR. CATTON: That's at static conditions, too, because you have to have a head on the cold side to drive it forward.

MR. BLAISDELL: Once natural circulation starts, then there will be friction drops, which will balance out the differences.

DR. CATTON: If you have no flow, what you're saying is exactly right. But I hope we don't get into that situation.

MR. BLAISDELL: In the reflux mode, the pressure drops around the loop are very small. They are more or less statically filling up on both sides.

DR. CATTON: That's right.

MR. MENZEL: Okay. That brings me --

(Slide.)

-- to the conclusions I have on our steam generator model. We believe that our primary and secondary side heat flux transfer models are adequate to analyze heat transfer during the expected fluid flow conditions. It is a very conservative assessment, conservative in the sense that we assume that all the noncondensibles are collected in the steam generator.

We conclude that there is negligible impact on the condensation rate and that the return to single-phase natural circulation will not be prevented.

The last item I'd like to talk briefly about, our pressurizer model. Basically, we model the pressurizer as an equilibrium node, a thermal equilibrium node. The tank is a relatively long skinny tank. And one of the questions we ask is: During the refill period, the water surges into the pressurizer and cold water gets in contact with steam which is in the pressurizer and will be compressed. To the extent that we account for energy transfer between the inflowing colder water and the steam, do we always get the reduction in pressure which would occur under this condition?

Other than doing a noding study, we looked at a different pressurizer model where we do not assume any transfer between the incoming water and the steam which is in the pressurizer, so basically the incoming water pushes the steam and compresses the steam like a piston.

DR. PLESSET: Let me try to understand that. The picture that you're compressing the hot steam with cold water, I find that a rather awkward way to describe what would go on. I would say that the steam would condense out and the steam would collapse.

MR. MENZEL: With the equilibrium model, you do have condensation on the interface between steam and the water.

DR. PLESSET: So now it's back to a question of rate. The rate at which the liquid surface is advancing into the steam would, of course, be appreciably different from equilibrium.

MR. MENZEL: That is true.

DR. PLESSET: So what is the characteristic speed that would say that it deviates considerably from equilibrium?

MR. MENZEL: Okay. Let me answer the question a little bit different. Our concern was that after steam is condensed in the interface, you do have a layer of relatively warm water which is now in contact with the steam, and you would have no longer condensation. So if, in our analyses, we assume that we still have thermal equilibrium or energy exchange, we might overestimate the amount of energy between the steam phase and the water phase.

So for this reason, then, we took another extreme. We legislate that there is no energy transfer between the water and the steam, which would be the situation if it had gas sitting in the steam space of the pressurizer, if you compress it asymptotically.

DR. PLESSET: I still have difficulty with that model.

DR. CATTON: It's the rate of increase of pressure over time, as you suggest.

DR. ZUDANS: Wouldn't that limit the amount of water that you could put into a pressurizer dramatically?

MR. MENZEL: As you will see in my later slides, it has an effect, not so much on the eventual pressure you wind up with -- on the pressure plateau, they turn out to be the same -- but on the amount of liquid level.

DR. ZUDANS: It would be a much lower liquid level.

MR. MENZEL: That's right.

DR. ZUDANS: Because you don't condense it; you just compress it.

DR. PLESSET: I still have trouble with that model.

DR. ZUDANS: It's because it's not realistic. I have the same trouble. Maybe it's because of the effect of evaporation.

DR. CATTON: If you looked at both limits, what does that do to your bottom line?

MR. MENZEL: It doesn't do anything to our bottom line in terms of core covery, which is in terms of temperature it doesn't do anything there. It does point out that if we take our analyses as indicative of what the real pressurizer level would be, we might overestimate it by using the equilibrium model.

DR. ZUDANS: Overestimate what?

MR. MENZEL: Let me just go right ahead. The next slide I wanted to show is just the effect in pressure traces, which is very small. Let me show you what the effect in level is.

(Slide.)

This is for a very small break, a .05 square foot break. Here we have the collapsed liquid level in the pressurizer against time. Here these two lines show the difference between the piston model, no energy transfer with the steam, here you do have the energy exchange between the steam and water phase. And you find out that this level is predicted higher than the one you have with the piston model. And the conclusion we draw from it is that probably in reality you're somewhere in between these two models, and these two models can be used to estimate what range of level indications you might get.

DR. PLESSET: Well, I think that I have some questions. I don't like to keep us on this small point too long. But you can think in two limits. I can have a container that contains steam and compress it with a piston of very large heat capacity. It will just go up as if it were meeting nothing, collapse it.

DR. ZUDANS: If you condense it.

DR. PLESSET: Yes, there'd be no resistance.

On the other hand, I can take a piston with a very small heat capacity, in which case I would condense some water and just heat it up, which would mean it would go very much more slowly.

Now here I think you have something that is closer to the first picture than the second one.

DR. CATTON: If the rate of increase of pressure with time is large, that's right.

MR. MENZEL: I think you're right.

DR. PLESSET: Okay.

DR. ZUDANS: How does it affect your final results?

MR. MENZEL: As I said, in terms of what is the pressure I finally wind up when I refill the system, I don't see any difference. I come to the same pressure, because the HPSI pumps shut off at a certain pressure. So I come to the same end point in pressure.

What is different is the amount of water I needed to push into the pressurizer before I come to this pressure. If I take my piston model, all I need to do is push in a little bit of water and compress the steam and out goes the pressure. If I take this equilibrium model, I push water in and it condenses some steam and the pressure goes down a little bit, and I can push in some more water, and eventually again condense some water. And eventually I come to my plateau pressure, which is the same with the piston model, except I push more water.

DR. ZUDANS: That's right, you'd need a lot more water. Besides, even with non-equilibrium situations, at the surface this condensation model is definitely closer to reality than the piston model. The piston model just has no relationship to this process.

MR. MENZEL: It's not to be representative of reality. We did this in an effort to see what are the extremes and I'm not proposing that we use the piston model here in our calculations.

DR. ZUDANS: You just looked at the two extremes.

MR. MENZEL: It was an attempt to see what the effect would be.

DR PLESSET: You have bracketed it.

MR. LONGO: Is it clear to everyone that we do use the equilibrium model.

MR. ETHERINGTON: It's not clear to me what the equilibrium model is. Does that imply two-phased?

MR. MENZEL: Two-phased in the pressurizer. The level as drawn up here is the collapsed.

MR. ETHERINGTON: How does it be two-phased in the pressurizer? Is it the heaters or what is it?

MR. MENZEL: Okay. That goes back to a peculiarity in our code. Basically, the pressurizer model is a drift flux type separated node representation. We did find out we get numerical stabilities in the pressurizer node when we start refilling. So when we start refilling with the equilibrium model, we physically use a homogeneous formulation in that node, which would mean the steam and the water is all smeared out.

In this presentation, in this curve here what I've done is I collapsed the homogeneous mixture in the water part and the steam part and the water level is shown here. This is, for instance, the water level you would measure if the pressurizer level indication is at the level of the P cell.

MR. MICHELSON: What size break is this calculation for?

MR. MENZEL: A very small break, .0005 square foot.

MR. MICHELSON: So the figure you show there is .0005?

MR. MENZEL: .0005 square foot break.

MR. MICHELSON: The level that you're talking about here, is this the pressurizer level from the bottom nozzle? The zero is at the bottom of the bottom nozzle?

MR. MENZEL: Right.

MR. MICHELSON: And where do the heaters come in for pressurizer designs?

MR. MENZEL: They come in from the bottom.

MR. MICHELSON: You mean there's a cutoff. They don't even come out until you get above a certain water elevation.

MR. MENZEL: This analysis was done without taking the heaters into account.

MR. MICHELSON: No heaters operating, thank you.

And what did you assume for heat transfer or heat sink as far as the metal in the pressurizer?

MR. MENZEL: Metal wall heat is modeled -- I don't know offhand what the heat transfer coefficients are.

MR. MICHELSON: Your model was accounting for the cooldown of the metal?

MR. MENZEL: That's right.

(Slide.)

My last slide, I show you a comparison of one aspect for a different break, for a small break where the cause of the small break is a PORV stuck open. The analysis basically shows us that the water in the pressurizer remains during that accident. It does not drain down.

One question we asked ourselves: Is that consequence that the flash allows only cold current flow in flow paths, or would that be borne out if we had a formulation which would allow fallback of the water?

What we did is, we looked at what is the steam flow going up the surge line and compared it agains the critical steam flow rate based on the Wallis correlation which you would need to have to keep the water up or prevent the water from draining. This is the line down here. We see basically that the critical steam flow rate required to prevent fallback of the water is much lower than the steam flow rate, which indeed does go up.

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So even although the fact that we do have cold current formulation in our flow paths is adequate for this type of break situation, which gets me then into the final slide --

MR. MICHELSON: Before you go to that--I don't know if you'll get to it later -- I'll ask you the same question I asked this morning. It appears that for the break in the vapor space of the pressurizer, that the operator will never see his water level disappear, even if he should get into a situation wherein the reactor vessel was already partially or completely empty.

MR. MENZEL: That is true.

MR. MICHELSON: Were the operators in the past aware of this? Are they now aware of it?

MR. MENZEL: Okay. Let me refer this question, the answer to this question, to a member of our owners group.

MR. GASPER: Joe Gasper, representing the CE users group. Joe Gasper, Omaha Public Power, representing the CE users group.

There was an earlier meeting in Windsor in which all the users of CE reactors were represented --this was a week after TMI -- at which some preliminary discussions were gone over. The pressurizer reactor at TMI probably remained solid and the similar PORV in the Combustion Engineering plants would also properly produce the same results. In the documentation that was sent out to the utilities to answer

79-06B, which I believe came out the second week of April, there were guidelines recommended to the plants to verify inventory and pressure control in the reactor by turning on heaters, turning on sprays, or charging the system to verify that you did have full inventory in the system.

So yes, it was recognized the pressurizer would remain full and the pressurizer level would not necessarily be a good indication that the system itself was water solid.

MR. MICHELSON: Let me comment on that just a little bit. I think I recollect the approximate wording and my recollection was that all it really said was, don't trust the pressurizer level. But it didn't tell me that if you get a break in this location, you will expect the water to go up, to stay up there indefinitely, even if the vessel were to go dry. It didn't very clearly indicate what you were going to see.

And the other question that I wanted answered was, prior to TMI were operators aware of this phenomenon?

MR. GASPER: I believe in the old 6B guidelines, I tend to agree it was not well called out specifically in that letter. It was called out in the meeting, and then it was very definitively called out when 114 was issued this summer.

Prior to that I'm not 100 percent certain what the individual cases were.

MR. MICHELSON: It gets to be an interesting question because apparently TMI operators weren't aware of such a phenomenon. That applies to Westinhouse as well.

MR. GASPER: I don't think you need to know about CE reactors in that case.

MR. MICHELSON: That's just a particular instance. There was nothing unique about B&W's either, except there was another reason why it wouldn't work beside the possibility of levitation by a flow, so I just was curious to see if CE operators were aware that their pressurizers would never empty for a break in the vapor space.

MR. LONGO: I'd like to just make two points. One, the reactor trip is done on pressurizer pressure and not on pressurizer level. The other thing is that for most of our plants, all except one, the HPSI pumps would not have exceeded the pressure.

MR. GASPER: I just have one comment, i.e. that given the emergency procedures for the plants, it was not critical whether that level would return or not because there's no need to turn off the HPSI pumps in the combustion type plants.

MR. MICHELSON: It has a forgiving feature in that it can't lift the pumps. That's unique. I was just posing this as a generic question to see if you instructed the operators, but you're quite right. It didn't have to react in this manner.

DR. ZUDANS: I have a question. On all your operating reactors, did you ever experience this event — the PORVs opening?

MR. GASPER: I think — the joint recollection seems to be that there were two in-test programs. There has been at least one instance that I can speak of where if the reactor trips on high pressurizer pressure, there will be a momentary lifting of the PORV, since the signals are concurrent.

DR. ZUDANS: In other words, there has been experience with lifting PORVs?

MR. GASPER: That's correct. I guess I'd have to speak strictly for our reactor. We have gone on high pressure, and the PORVs momentarily lifted and reseated properly.

DR. ZUDANS: I assume you also have a record of what happened to both of them at the same time?

MR. GASPER: It was awful fast. I have looked at the traces, but I don't remember any specifics.

DR. ZUDANS: Almost too fast. Thank you.

DR. PLESSET: Does that complete your presentation?

MR. MENZEL: I just have a summary slide which

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sums up the conclusions --

(Slide.)

-- which I already mentioned before for the pressurizer model. I think the equilibrium model is adequate. The water level is possibly overpredicted. The range of water level can be determined by comparison with the piston model, and the co-current flow formulation in the surge line is adequate for analysis of pressurizer leaks.

That's the end of my presentation. If you don't have any further questions, then the next presentation --

DR. PLESSET: I think we might let them have a small break.

(Brief recess.)

DR. PLESSET: Well, Mr. Kessler, I think the floor is yours.

MR. KESSLER: Since my introducer has sat down, my name is Tim Kessler. I'm an analyst in the ECCS Development Section at Combustion Engineering. You've just heard a general description of CE's small break LOCA evaluation model. I'd like to now discuss the special features which were added to this model, specifically for the analysis of small break LOCA with operating reactor coolant pumps.

(Slide.)

My major topics will be the physical effects of

RCP operation on the course of the small break LOCA, modifications that we've made to our model to account for these effects, and finally the sensitivity of our calculational result to some of these model changes.

I had originally intended to restrict my discussion only to the models and to defer any discussion of calculationaly results to the next speaker, but apparently we took a vote, and I have been elected to try and explain why it is that we predict the hot leg to be the limiting break location. So I'll try to factor that into my presentation. If when I'm done, it still isn't clear, I'll be happy to answer additional questions.

(Slide.)

Based upon our experience and knowledge of primary system hydraulic behavior during a small break LOCA, we would expect continued RCP operation to affect this behavior in four ways. First, the RCP will redistribute the primary coolant mass inventory by moving water from the cold leg piping toward the reactor vessel, and second, while the pumps are operating and pumping two-phased flow, we would expect this flow to be moving at a sufficiently high velocity to maintain distributed rather than separated flow patterns in the cold leg piping as long as the cold leg void fraction was below unity.

Third, the RCPs will pressurize the up- or downcomer region. This will enable the downcomer level to be depressed and will support a correspondingly higher mixture level in the inner reactor vessel region.

And fourth, with all four RCPs operating for a limited period of time during the transient, the downcomer level will be depressed below the bottom of the core barrel, and steam will be pumped from the downcomer into the lower plenum.

These first three effects are short term in that they're important only while there is two-phased flow in the primary coolant loop. This two-phased flow period represents only about the first quarter of the small break transient and is over before we would predict core uncovery to begin.

However, these last two effects, while they may provide some short term benefits in terms of a slightly higher level in the core, provide a significant long term penalty for hot leg breaks by maintaining a two-phase level in the vessel above the elevation of the break, thereby increasing the duration of the two-phased discharge period and increasing the depletion of the primary system mass inventory.

DR. PLESSET: That's on the hot leg side?

MR. KESSLER: Yes.

MR. MICHELSON: Have you people looked at your reactor coolant pumps and are convinced that they could operate as two-phased flow with steam only?

MR. KESSLER: I'm going to defer that question.

MR. CALLAGHAN: Vince Callaghan again from Combustion. We have looked at the reactor coolant pumps with that question in mind. We feel strongly that the pumps will run with some amount of two-phase obviously. When the void fraction gets higher, the pump will eventually get into trouble and will exhibit problems such as high vibrations, possibly wide variations in amperage, which may cause the operator to conclude that the pump should be shut down.

But there's no question. The pump will run with some two-phase. There's no way to quantify when the pump would stop running as you get deeper and deeper into two-phase.

MR. MICHELSON: The reason I asked is because I believe that you people are the only ones who are advocating running two pumps throughout the event. I guess what you're telling me is that you don't really expect them to run throughout the event, and at some time later in time, the second two will be tripped.

MR. CALLAGHAN: That's true, and the guidance we provided our utilities included a warning that when you run the two pumps with the same tubulator velocity, that you don't run them blindly. As long as they're functioning, you run them, and providing a service. When they begin to get into trouble, it's time to shut them down.

MR. MICHELSON: Now the question I'm getting at is this. Is it really better to run the two as long as you can, or is it better to trip all four at the beginning? You've, I assume, done some kind of study to convince yourself that you're better off to trip only two to begin with and two later than to trip all four to begin with. You're already essentially -- you've told me that you're going to lose the other two later, reasonably sure.

MR. LONGO: From a LOCA consideration, there is no question that to trip all pumps, four pumps immediately is okay. Our concern is that you're not sure that you do have a LOCA, and we want to keep those two pumps on until we're sure that we understand what kind of accident we have.

DR YAO: I think on an earlier slide you indicated that the data is based on the single flow, and from your conclusion, this hot leg is more serious on your previous slide. You're sure in reality that this pump can pump steam very effectively and pressurize the downcomer and push the water level down?

MR. KESSLER: That's over a very limited portion of the transient, but yes.

DR. ZUDANS: Will it pump steam at all?

DR. YAO: Yes, that's my question.

DR. PLESSET: There is an answer here.

MR. CALLAGHAN: I think the basic position -- it will be borne out further in the presenation -- is that if the pump steam runs in that condition, their performance is factored into the calculation. If the pumps should no longer pump steam, we're back to -- for combustion at least -- the situation where the pumps have been shut off for whatever reason, due to failure or intentional operator shutdown.

DR. ZUDANS: Well, I think the statement, when you continue pumping, the water level will be pressed to the bottom of the reactor vessel, and you have to do that by pumping steam. You really have to have a compressor there.

MR. CALLAGHAN: That's true.

DR. PLESSET: I think that we all recognize --

DR. ZUDANS: It won't do.

DR. PLESSET: Yes. Go ahead.

MR. KESSLER: To model the effects that I described a few moments ago, we made several changes to the small break model that was described in the previous two presentations.

(Slide.)

The first change is to our fluid model. As Jim Holderness said, we use a drift flux model to calculate relative velocity between the phases. Now as this model is implemented in our CFLASH 4A computer code, it contains the implicit assumption that the net velocity of the vapor phase will be upward. In areas where we would expect to find co-current and two-phased downward flow, this model is therefore not equipped to calculate it. So we've chosen to go with the homogeneous representation of two-phase flow where we would predict flow in a downward direction.

Again as discussed by Jim Holderness, with the RCPs tripped, we calculate pump performance using single phase homologous data. With the pumps running, we do account for head degradation using a multiplier on the single phase pump head. This multiplier is a function of void fraction and was derived from data obtained by AeroJet Nuclear Corporation for the semiscale pump.

I believe Dr. Michelson previously mentioned that while the pumps are pumping there is significant potential for leakage between the up- or downcomer region and the upper plenum through this gap between the core barrel and the hot leg. As we've said, we have explicitly modeled this gap in our primary system representation.

The fourth difference is that since the pumps are running after the reactor is tripped, we must have offsite power available, which means that the control systems for secondary pressure will be energized. I'm speaking here specifically of the turbine bypass valves and the atmospheric dump valves. These valves are designed to maintain the secondary pressure, about 100 psi below the lift pressure, the secondary safeties.

The final two model changes were made especially for best estimate analyses which will be discussed by Fred Carpentino in the next presentation. As Joe Longo mentioned, we've fixed from a licensing Moody two-phased critical model to our best estimate two-phased critical model, which is the homogeneous model.

The final change is applied during those periods when we do calculate downcomer level pressurization and pumping of steam directly into the lower plenum. In these situations, we've modified the model that we used to calculate the two-phased void distribution in the inner vessel. This model was described briefly to you by Jim Holderness. The details of this modification are proprietary. They're described in Chapter 5 of CEN 115, which is our response to NRC Bulletin 79-106C. However, in a general sense, I can say that the modification was to simply add this additional source of voids into the calculations, and it results in prediction of a higher average void fraction in the vessel during the time we are pumping steam directly into the lower plenum.

MR. MICHELSON: In your model, do you include the heat input of the pumps?

MR. KESSLER: Yes, we do. We found that it is not significant, because it is a function of the density of the fluid being pumped which is decreasing at potentially the same rate as they decay heat.

MR. MICHELSON: Is the model you're using in your report?

MR. KESSLER: I don't believe the equations are described in the report, no. It's simply an application of hydraulic torque applied to the fluid and assuming that it's dissipated as heat.

MR. MICHELSON: But the density of fluid is changing with time.

MR. KESSLER: Which means that the heat addition is changing with time.

MR. MICHELSON: But I'm wondering just how. And is the how described in your report.

MR. KESSLER: No, it is not.

MR. MICHELSON: It's not like determining it for single phase flow.

MR. KESSLER: No, it is not, but we spend the majority of our time in this transient in a single phase flow, either single phase water or single phase steam. And toward the end of my presentation, I'll be showing you that.

DR. CATTON: Have you at any time made a heat balance as a function of time for your system?

MR. KESSLER: I'm not sure.

DR. CATTON: You're generating energy in the core, and there's sensible heat? Have you ever prepared a figure showing how these things behave as a function of time?

MR. KESSLER: No, I have not. I will temper my answer to that question by stating that over the range of break sizes for which we calculate the pumps to be an important factor, these are relatively large small breaks, so that the majority of the heat removal from the system is by the break itself.

DR. CATTON: You don't get into the regime where the heat generators --

MR. KESSLER: No, we do not. The bottom of the spectrum of breaks for which the pumps are important is essentially the top of the spectrum of breaks where the steam generators begin to come into play.

DR. YAO: Does your model satisfy energy conservation?

MR. KESSLER: Yes, it does, I believe.

DR. ZUDANS: It would be nice to know whether energy is being conserved.

DR. CATTON: That was the purpose for asking. You'd like to add up all the pieces and see if they total.

MR. KESSLER: I wish I had the figure. I'm sorry I don't.

DR. CATTON: You generate the information every time you run your codes. It would be worthwhile to just pull it out one time or another.

MR. LONGO: Dr. Catton, we have such a figure for the small breaks where the pumps were not running. That's in 114, I believe.

DR. CATTON: That Chapter 5?

MR. LONGO: I am being corrected. Where is it?

DR. CATTON: I didn't find it in 114.

MR. LONGO: I know I presented it to the ACRS in a slide, but I thought it was also in 114.

DR. CATTON: May 9th?

MR. LONGO: I think so.

DR. PLESSET: That wasn't to this Committee -- this Subcommitte, I mean.

DR. CATTON: Would it be possible for you to get that to me?

MR. LONGO: Yes.

MR. KESSLER: I'd like to return now to provide a bit more detail in Items 1 and 2 of the previous slide which we believe are of specific interest to the Committee.

(Slide.)

The first is just how we've implemented this homogeneous drift flux fluid model in our CFLASH 4SA computer code. On the hot side of the system, the normal flow direction is predominantly upward, so an assumption of an upward vapor velocity is still valid, even if the pump's running. We therefore continue to use the drift flux model with Dr. Holderness described in this region.

However, on the cold side of the system, meaning from the top of the U-tubes around the bottom of the downcomer, the predominant flow direction is downward, and while the pumps are pumping two-phased, we would expect the velocity in this region to be sufficient that we would predict dispersed flow.

For this reason, we've modeled this region of the system homogeneously until the flow in the region begins to stagnate. Now in practice, the flow in the coolant piping doesn't stagnate during the two-phased flow period. It remains high until the void fraction approaches unity, so we just continue to use our homogeneous model throughout the transient in that region.

However, in the downcomer, the flow area is quite a bit larger than the combined flow area for cold legs, and you are also supplying a continual flow of water from the safety injection system which condenses some of the steam being pumped from the pumps. For this reason, we calculate the flow to begin to fall off in velocity while there is still a significant amount of water left in the downcomer.

Once we would predict stagnation to occur, we would again like to use our drift flux model to calculate separation of the phases. So we've installed essentially an on-off switch into the code.

This switching criterion is based on what we would predict to be the net velocity of the vapor phase in the two-phased mixture in the downcomer. This is defined by the downward velocity of the mixture minus the upward drift velocity of the vapor. Once this net vapor velocity reaches zero, which means physically that the water is still flowing down but the vapor is essentially stopped, we would expect to see the phases begin to separate. At this time, we reapply our drift flux model in the downcomer only.

From this point on, we've got a drift flux model on the entire reactor vessel on the hot side and a homogeneous model in the rest of the system. But the rest of the system is voided, so we really don't need a two-phased model at all.

(Slide.)

There is one important effect of using a drift flux model for upward flow and a homogeneous model for downward flow. That is that such a model predicts a nonuniform distribution of voids in the primary system.

In other words, the upward flow regions generally remain at a lower void fraction than the downward flow regions.

To obtain some sort of experimental verification that this effect would actually exist, we've compared our prediction of PWR behavior for a hot leg break with the pumps running to the behavior that was observed in the Mod-3 semiscale demonstrations in the Three Mile Island transients.

There are admittedly many differences between a Three Mile Island transient at semiscale and hot leg break in a PWR, but both transients were characterized by continued RCP operation through a period when the void fraction in the system was increasing.

I'll see if I can adjust this so we can focus on what I'm talking about, this bottom curve compared to the void fraction in the loop, in this case at the pump suction, to the void fraction in the inner vessel mixture level that we calculate for our PWR analysis with the pumps running.

And as you can see, the average void fraction in

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the vessel remains significantly below the void fraction in the loop throughout the period of time th , we're looking at here.

DR. PLESSET: Is this more than the pressurizing effect of the pump itself?

MR. KESSLER: This is simply due to the fact that if you've got co-current upflow.

DR. PLESSET: I'm saying that the pressure rises through the pump, so you'd expect some collapse of voids as a result of the rise in pressure.

MR. KESSLER: That is an effect. It's more predominantly due to the fact that with unequal velocities in upward flow the residence time of the bubbles in the vessels, since the bubbles are rising faster than the mixture, are lower. So you predict a lower average void fraction in that case.

DR. ZUDANS: Is that a steady state situation or a transient?

MR. KESSLER: It's essentially a quasi-steady situation. It is transient.

DR. ZUDANS: How would that show up?

DR. PLESSET: I don't quite follow.

DR. ZUDANS: I don't know how the velocity differential would affect it.

DR. PLESSET: I think more it's a pressure effect.

You don't think so, Carl?

MR. MICHELSON: I assume that essentially here it's the core area void fraction versus the hot leg void fraction.

MR. KESSLER: That's not what I'm showing here. I'm showing the core area void fraction versus the void fraction of the pump inlet.

MR. MICHELSON: All right, not at the pump discharge.

MR. KESSLER: Right.

MR. MICHELSON: I also don't see why that void fraction should be -- wait a minute.

MR. KESSLER: If you've got a homogeneous system, the void fraction everywhere will be the same. If you've got slip in the system, the void fraction will be higher, where the flow is downward because the bubbles will simply be flowing slower than the mixture.

DR. PLESSET: That supposes that the pressure throughout the system doesn't change.

MR. KESSLER: Yes, that's true. There is additional effect.

DR. PLESSET: Okay. I wondered which is more important.

MR. KESSLER: I guess I'd be speculating on that answer.

DR. PLESSET: It's in there anyway.

MR. KESSLER: It's there.

The top curve here shows the same sort of data as measured in the semiscale TMI simulation. The solid curve here is a measured void fraction. I believe this is a gamma densitometer relation at the pump suction.

As you can see, over the period of time here it increases at a relatively steady level. In this test, the void friction in itself was not measured in the inner vessel. However, there were delta P measurements made there from which one can deduce a collapse level and therefore a void fraction.

In making a delta P measurement in a flowing system at high pressure, the instruments tend to get a little noisy. In fact, the data shown here was really represented by a rather broad band of hash.

What we've shown is the cross-hatched area here, the upper and lower bounds of this hash. From that you certainly can't tell what the exact void fraction was in the inner vessel.

It's clearly evident that the void fraction in the inner vessel region remained lower than it did in the loop, which qualitatively agrees.

DR. PLESSET: We'll believe that, I guess.

(Slide.)

MR. KESSLER: I'd like to move on now to the second item, which is the behavior of our pumps during the two-phased flow period.

To begin with, I'd first like to show you the head degradation curve that was used in all of the CE analyses with the pumps running.

As you can see, the curve, based on ANC data for the semiscale pump, is quite symmetrical. It shows no degradation for single-phase water flow; complete recover, again, for single-phase steam flow; and considerable degradation throughout the two-phased region, with a maximum degradation of about 75 percent at 50 percent void.

DR. PLESSET: Go ahead. They're having a conference.

MR. KESSLER: This data was obtained several years ago and has been around for quite awhile. Since that time CE has been involved in a cooperative effort with EPRI to obtain similar degradation data.

(Slide.)

For a one-fifth scale model of a typical PWR pump, this effort is not completed, and the data production is still going on, but there is sufficient preliminary data available to construct a similar curve to the one that you just saw, based on the data obtained in the CE pretest.

And this particular curve was derived from data at rated pumps B at near rated pump flow.

But the information that I've been able to see shows that it's probably not too bad an approximation for lower than rated flow. And, of course, we're talking rated speed here, since the pumps were running.

DR. ZUDANS: Could you define this multiplier more accurately if it's possible?

MR. KESSLER: The multiplier is simply a multiplier on a single-phased pump head in whatever fluid happens to be flowing through the pump.

DR. PLESSET: I think, Zenons, that it helps if you think of the head in dimensionless units; in other words, say, divided by rho U squared. They're taking that into account.

MR. KESSLER: Right now that rho is not taken into account. In my next slide it will be.

DR. PLESSET: The multiplier is not, but in the absence of pressure, it is taken into account.

MR. KESSLER: I will be getting into that in a moment.

DR. ZUDANS: I understand, but if now takes a single phase void in the pumps with this, a certain number of feet, then this is the multiplier that applies to that number.

MR. KESSLER: To the number of feet.

DR. ZUDANS: And not density or anything of that nature. There's an efficiency involved in the process as well. It could be very, very low, because there's a backflow through the blades.

DR. PLESSET: That's true.

I gather it's not as much lower as one might suspect from these data. I don't know how this would apply to all the different pumps in your installation. They're all centrifugal pumps with reasonable tip speed.

DR. CATTON: Isn't that multiplier measured? Didn't you just take delta P and divide it by the density of the fluid at the outset?

MR. KESSLER: I would imagine that that's the way it was done. I'm not personally familiar with the test procedure. I'm not sure if anyone sitting in the audience is more familiar with it than I am. I getting a lot of shaking of heads, no.

DR. CATTON: My understanding was that this first diagram by ANC was measurements for the semiscale pump.

DR. PLESSET: In dimensionless units.

DR. CATTON: Not with U squared, just delta P over rho.

DR. PLESSET: You might be tip speed or axial flow speed, either one, but the rho is in there. I think it has to be.

MR. KESSLER: In backing this particular multiplier out, the rho has to be taken into account if you're taking this from a delta P measurement.

DR. CATTON: It's just delta P over rho.

DR. ZUDANS: Let us give you a chance on the next slide.

MR. KESSLER: Maybe I'll move on to the next slide. I did want to mention that the two models show quite a bit of disagreement as to the amount of degradation in the low void fraction region, but they are pretty much converged at high void.

DR. ZUDANS: That would be expected.

MR. KESSLER: Now, as we've been discussing, that particular parameter is not very useful in defining pump performance.

(Slide.)

What we're really looking for here is differential pressure across the pump, which includes the density term. What I've done here is converted the curves that you've seen in the previous slide into a normalized differential factor by factoring in density.

Ror void fractions below about .5 there is considerable difference between the delta P predicted using the ANC degradation curve and what we would predice using the CE degradation curve.

But beyond the 50 percent void point, the two curves are essentially identical. The dash-dot line here is simply the change in density of void fraction, used as a point of reference.

And, as you can see, single-phase steam, ever if you had no degradation model at all, you would predict the same result as either of these two curves.

DR. YAO: Are those curves depending on the velocity?

MR. KESSLER: Yes, these happen to be derived for rated flow and rated speed.

DR. YAO: During a small break accident?

MR. KESSLER: There is some decrease in the velocity of flow, that is true, so that you couldn't look this curve and then figure out what the delta P was in the transient.

However, I was really trying to show here that in the range of interest for our calculations, the two degradation models would predict similar results so that any difference between what we might calculate for pump performance and what someone else might would not be due to the degradation model.

DR. ZUDANS: How do I read this curve, if I may dwell on it just a minute? I want to find out what kind of a delta P can I produce if you were just pumping pure staem.

MR. KESSLER: There's a point of reference, pumping pure liquid, the delta P here is about 80 psi. So when we get down to the pure steam region here, we're down about 5 percent of that, which is about 4 psi.

DR. ZUDANS: That much, would it amay that much.

MR. KESSLER: This is at 1000 pounds per square inch pressure, so that we're pumping reasonably dense steeam here.

DR. PLESSET: That's pretty heave steam.

MR. KESSLER: This is representative of the situation in the reactor coolant system.

DR. PLESSET: There is fair degradation though.

DR. ZUDANS: But the proportion of desity would be the minimal I would expect.

DR. PLESSET: That's a good question that Dr. Zudans brings up. What's the denisty ratio of steam at 1000 psi to the water density.

MR. KESSLER: Precisely 5 percent, right there.

DR. ZUDANS: So it has the same efficiency for water as it has for steam.

MR. KESSLER: That is the result that we obtained from the date.

MR. MICHELSON: Once you get out of the slug flow regime you're all right.

DR. PLESSET: This might not be quite so good for lower pressure steam.

DR. ZUDANS: Your density will just be inversely proportional.

MR. KESSLER: This particular curve is representative of 1000 pounds per square inch pressure. That is about the system pressure that we would calculate when the level finally drops below the hot leg and you begin to vent steam out the break.

Beyond that point the system depressurized relatively quickly and the pump differential pressure just falls off. And I think that's going to be an important point in the analysis results that Fred Carpentino shows you as to just why we don't see a benefit from continuing to run the pumps beyond that time.

(Slide.)

To relate that last picture to a PWR analysis, I have provided here a plot of the calculated void fraction at the pump inlet as a function of time -- calculated one foot square break at the bottom of the hot leg. This is what we calculate to be our limiting break size and location for running pumps.

As you can see, that 50 percent point, where the ANC model and the CE EPRI model converge, is reached about 480 seconds after the break. The pump's suction leg is completely voided at 750 seconds after the break.

Now, the effective of this sort of behavior on the really important parameter in the calculation, the core level --

(Slide.)

-- is shown in this slide.

What we're comparing here is the dark line, which is what we calculate for 1/10th of a square food hot leg break with the pumps running.

And the corresponding result from the same calculation, where we assumed the pumps are tripped, concurrent with reactor trip.

Now, if we move to this 480-second point, when the two degradation curves no longer disagree, we see that whether the pumps are running or not, the two-phased mixture level in the vessel is above the location of the break, which you'll remember is the bottom of the hog leg, which is right here.

This means that at this point the pumps are not contributing significantly to the depletion of mass from the primary system, because you have two-phase flow out the break, whether they were running or not.

Now, beyond this point, you see a significant effect of continued pump operation. The pumps are effectively holding this level up here for a longer period of time.

During this period, you're continuing to pump low quality, two-phase flow out the break. The flow rate out the break is an order of magnitude higher than the makeup flow from the safety injection system, so you're depleting mass from the primary system at something approaching 400 pounds per second.

As you can see, over this period of time, that's a considerable amount of mass depletion.

DR. PLESSET: That may be a conservative description.

Just suppose that you get low quality flow out through the break, but quality might go up and be higher than what you have in the hot leg.

DR. CATTON: I guess it gets back to G, more mass out the break is taken to be a conservative assumption, but that leads you to wanting to turn off the pumps, which may or may not be conservative.

MR. KESSLER: I think in this particular case it's clearly conservative to turn off the pumps from a LOCA standpoint, and we're talking here about LOCA.

DR. CATTON: But you've also made the assumption that the break will not be acting a steam separator.

MR. KESSLER: It is possible. I'm still not completely convinced that there is going to be much steam separation when you've got a system where you've got essentially a quiet pool of low quality, two-phased fluid sitting over a hole.

DR. CATTON: I'm not sure. What if the hole is at the top of the pipe?

MR. KESSLER: Okay, we're not considering that situation. We find that we get a more limiting result if the hole happens to be at the bottom; and there's no way you can really pick a location for the hole, so we've chosen the worst one.

DR. PLESSET: You're taking it as stratifying a hot leg, but still, as the water goes through the break it becomes supersaturated very quickly. That's what these diagrams were showing.

DR. CATTON: There is still going to be a higher mass flow to the bottom.

DR. PLESSET: That's right.

MR. KESSLER: We're simply concerned that we may have overpredicted the mass flow rate through this particular size break.

The question I would return to you is we don't really know whether we've got a 1/10th square foot break or not. We may have an 800 square foot break, in which case it might act like 1/10th square foot break where it were acting as a vapor separator.

For this reason, we've analyzed the spectrum of break sizes. This just happens to be the largest break with the highest break flow, for which we show a problem for operating RCPs.

There is a spectrum of sizes smaller than this, for which ws also show a problem, and they will be covered in the next presentation.

MR. MICHELSON: This was a four-reactor coolant pump?

MR. KESSLER: This was with all four running.

MR. MICHELSON: What difference would it make if you were voted back to your two-and-two proposition?

MR. KESSLER: I'm going to defer that to Fred. I'm simply showing this, running the pumps, for a model.

DR. ZUDANS: I'd like to ask another question, still on the subject of pumping steam. Do you believe that the pumps will be able to clear the entire cold leg from the top of the outlet to the reactor inlet of water? Or will this water just stay there and be pushed partially out and then bounce back into the pum discharge?

MR. KESSLER: You mean just sort of bounce back and forth?

DR. ZUDANS: What's the reason for being able to pump the water out of that veritcal pipe, that you had to pump it out in order to get --

MR. KESSLER: I'm not sure which end of the cold leg you're talking about. Are you talking about the pump suction?

DR. ZUDANS: Is the pump discharge exactly on the same level as the reactor vessel?

MR. KESSLER: Yes, it is.

DR. ZUDANS: Then my argument is not correct.

MR. MICHELSON: You got a good arument started though I think, because you have to ask now about the injection water on the cold legs.

DR. ZUDANS: It would come back.

MR. MICHELSON: It's setting up some kind of a strange reaction in condensing steam flow and so forth. Could you just elucidate slightly?

MR. KESSLER: If you're asking how we model injection in the cold legs, we model injection directly into the downcomer.

MR. MICHELSON: In reality, it's coming into the cold leg, and how does that affect pump behavior when the pump is running as a steam blower.

MR. KESSLER: Well, in reality, it is being injected into cold legs at an angle of 65 -- 60 or 75 degrees, inclined toward the vessel, which means that it is not like to flowing backward toward the pump.

MR. MICHELSON: In reality it's flash-condensing steam.

DR. PLESSET: It'll raise the pressure there.

MR. MICHELSON: Really, I'm not sure if it raises or lowers it.

MR. KESSLER: It will lower the pressure at that point probably.

MR. MICHELSON: It flash condenses a lot of steam locally, therefore it is not fluent toward the vessel necessarily. It could also be flashing fluid, and it could literally be carried back to the pump itself. This is a rather violent process.

MR. KESSLER: I don't see any possibility of getting that through the pump though as long as the pump is pumping forward.

MR. MICHELSON: But I can see interesting possibilities for pump behavior when you're condensing steam under those conditions.

I was just simply asking and extending the question.

MR. KESSLER: I would certainly agree that we have not covered all the possible conditions of pump behavior in this analysis, but I don't think that any such --

DR. PLESSET: You'd lower the pressure on the discharge size.

DR. ZUDANS: I guess, regardless, you would pump the steam.

MR. MICHELSON: It is not at all clear what happens when we inject cold water into a steam-filled system as to how the pump will continue to behave and which way the flow will continue to be and so forth.

It's not very clear.

MR. KESSLER: I have just about reached my conclusions now. I would simply make the closing statement that the local effects in the cold leg we don't feel would affect our overall conclusion, that is, that we're in worse shape if we have a break in the hot leg because the pumps keep two-phased flow above that location longer than they do for cold leg breaks; and that we do not see any benefit from continuing to run the pumps.

MR. MICHELSON: Just to be sure we understand each other, the whole reason for even mentioning the injection was one of the concernes that's been expressed repeatedly in these meetings has been how about hydraulic instability in this system, not from the point of view of your calculations at all, but simply the mechanical effects of hydraulic instability. That's the only reason I threw it in.

MR. KESSLER: I would agree with your point on that.

Before turning the presentation over to Fred Carpentino, I'd like to first ask if there are still any questions as to why we predict the hot leg to be the worst location.

DR. PLESSET: I think you've made the point.

DR. ZUDANS: He didn't make the point to me because I didn't see anything about the cold leg.

DR. PLESSET: I thought you did this in a qualitative way.

MR. KESSLER: I'm going to use a slide here which I prepared for a different purpose, so if you'll just completely ignore any label and just look at the pictures, maybe I can show you.

(Slide.)

The situation here is what the situation looks like while we've got approximately 70 or 80 percent void in the cold side of the system and a somewhat lower void fraction on the hot side.

This cross-hatched area is not solid water. It's just two-phased mixture. What the pumps are trying to do here is try to support the two-phased mixture all the way to the top of the U-bend in the steam generators. This is about 60 feet above the bottom of the downcomer, which means that the pumps have to supply a big pressure drop just to hold that level there, let alone push fluid over the top. Once the pumps can't push any more fluid over the top, you've lost your supply of water to a cold leg break.

The only water left is what happens to be remaining over on the cold side of the system. This means that whatever water is still here is going to stay here.

Now, in a hot leg break all this water is just going to drain right out the hole. This means that whatever water level is contained in this mixture up here is simply going to be lost to the system through the break, while it would be retained in the system in a cold leg break. This is why we predict that the hot leg break will be more limiting when we complete the system.

DR. ZUDANS: With pumps running.

MR. KESSLER: With pumps running, because we deplete the system significantly more for hot leg break.

MR. MICHELSON: Well, it's not clear how the pumps were running. You're saying that the water column is supported right up to the top of the U-tube, but there's no flow, I guess.

MR. KESSLER: The pumps are not necessarily constant flow devices.

MR. MICHELSON: I understand.

MR. KESSLER: They can deadhead. There is some leakage flow continuing between the downcomer and --

MR. MICHELSON: They behave a lot differently if the flow ceases. They soon form their own steam void within the pump, with all the energy going into the fluid that isn't moving any more. That's what minimum flow is all about. So you've got zero flow and are yet running the pumps.

MR. KESSLER: There is in fact not precisely zero flow in this case. There is leakage between the downcomer and the upper plenum and there is also steam being condensed in the cold leg.

MR. MICHELSON: There's also bypass around to any pumps that aren't running. I'm assuming all four are running.

MR. KESSLER: In this case all four are.

MR. MICHELSON: And the bypasses you were talking about are almost trivial compared to the minimum flow required to take heat out of those pumps. Otherwise, they start to flash steam within their casings, and that's another whole physical instability question.

I didn't realize you really thought you were going through a transition wherein flow ceased for a period of time. I guess it ceases until it can start to move steam through somehow. In other words, how did you get from this to where you're running it like a steam blower?

MR. KESSLER: If I can put the picture back up.

DR. ZUDANS: It's blocked.

MR. MICHELSON: It isn't blocked forever. Eventually, he doesn't have that much mass left in the system.

MR. KESSLER: Once we've depleted down to this point, we're now putting steam out the break. If you could ignore this column of water in the downcomer, which wouldn't be there if the pumps were running, you've now got a situation where you can blow some steam through the core.

MR. MICHELSON: How long does it take to get from there to where you first start blocking any further circulation?

MR. KESSLER: It's on the order of a minute or so.

I would hasten to add that this steam flow period doesn't last very long, either.

MR. MICHELSON: You say it only takes a minute to get rid of all the water in the upper regions of the U-tubes right on down to the middle of the vessel?

MR. KESSLER: Maybe I've overstated that a bit. It's something on the order of 200 seconds from the previous plot.

MR. MICHELSON: So for that period of time this pump sits there in some transition phase?

MR. KESSLER: Moving not much, but some flow forward. And it continues to do that, and we do see a brief recovery in flow when we reach this situation here.

MR. MICHELSON: The power input is rather large in these pumps. They don't take the heat out or move the water out of the casing and form steam very quickly and pump steam by them. Then they intermittently start to slug flow, and that's the end of the game, as I understand it. Maybe the rest --

MR. KESSLER: I'm stepping a little beyond my bound of expertise to handle that.

MR. CALLAGHAN: You know, the concept of the pump imparting energy to the fluid system is basically correct, but these pumps are driven by large induction motors and the pump itself can only extract from the induction motor whatever energy it needs to drive the fluid and then to account for some percentage of inefficiency.

If you have, say, a four megawatt pump, which these typically are, 80 percent of that would be going into the fluid when the fluid is being moved through the system during normal operation. But if you cease to pump that fluid, you don't continue to draw four megawatts out of the induction mode. In fact, the energy you extract from the motor decreases dramatically.

Then you slip into two-phased and finally steam, and you'll find the induction motor is being called upon to do very little.

MR. MICHELSON: I think that's exactly right, but it slips into this all-steam phase while there's still two-phased elsewhere in the loop.

MR. CALLAGHAN: Conceptually that's feasible.

MR. MICHELSON: That's so fast compared with the heat sink available in the case of water that it flashes to steam and yet the fluid at the suction is still two-phased. So what happens? It flashes to steam and then you get a flash condensation, and the pump tries to move the steam out and it gets hit with the slug two-phased. That's the slug flow that we're talking about, that we're not sure that you're able to handle.

I thought we were slipping into two-phased and never jumped into this situation. I just didn't realize that for a time there is no flow, and therefore you do indeed get into pulsation flow, which is caused by flashing to steam and then introducing the slug fluid from the suction side. And a pump doesn't run that way very long, I don't believe.

MR. KESSLER: My point is, once you've reached this point where you've spent a little bit of time in zero flow, whether the pumps continue to run and pump whatever low-density steam happens to be left in the system or just break, you don't really see any difference because the delta P that the pumps can produce as the system depressurizes falls off to nothing.

MR. MICHELSON: Let's make sure I made my point clear. I really am not concerned about the calculational answer. I'm concerned about the physical pressure boundary now, that can convert a small break into a big break because we busted up something in the process of trying to run the pumps in two-phased flow.

That's a new question, a new calculation which you haven't done, I don't believe.

MR. KESSLER: That is true.

MR. MICHELSON: I don't have any quarrel with what you've done. I just suddenly realized that it's not clear to me that you could leave the pumps running through this kind of situation unless you've got some real arguments on how the pump works under these conditions. And you are saying that you're going to run two of your pumps through these conditions.

But you are the only vendor, to my knowledge, that is proposing to do this.

MR. KESSLER: I guess that will be addressed.

I see Vince has more to say.

MR. CALLAGHN: There's a scheme that seems to be carrying through in these arguments. For purposes of bracketing the potential outcomes with the analytical effort, the assumption has been made in one set of cases that the pumps run. That does not mean that Combustion expects the pumps to run with steam. I think you understand what I'm saying. We're not saying that the pumps will run or that they are necessary to run. But for the purposes of understanding what one of the possible outcomes might be if they for some reason were capable of running, that has been considered in the analysis.

And as you can see from the presentation today, a great deal of effort has been made to model them accurately on a conservative fashion and measure the impact.

MR. MICHELSON: Maybe I missed your point. I thought you were trying to defend the proposition that you would like to have two pumps continue to operate. If you are saying that you always shut all four pumps off within ten minutes, then this is all immaterial. I thought you were going through this whole gyration because you're claiming it is acceptable to run two pumps through such a situation.

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MR. CALLAGHAN: We are claiming it's acceptable.

MR. MICHELSON: Then I think you have to answer the questions about pump stability and so forth while going through these conditions. And I'm not sure I've heard the basis yet for saying that's okay.

MR. GASPER: I'm a little confused slightly. I think we're saying that we can show, through Appendix K, that it's acceptable to run two pumps. We are not saying that it is necessarily desirable, if you are indeed in a small break situation, to be running the pumps. As a matter of fact, our procedures would say, shut down the pumps if you see pump instability.

DR. ZUDANS: That's another cause that eliminates the operation of the pumps. But in your analysis, where you said you can run two pumps, what kind of fluid did you pump from this analysis? Did you pump a fluid that has a very high flow?

MR. KESSLER: That will be covered in Fred's presentation.

DR. PLESSET: Why don't we go on to the next presentation.

MR. KESSLER: I think, before I completely leave the podium here, I would like to reiterate two points that I hope I've gotten across.

The first is that our fluid model does predict void formation in the primary system, which agrees qualitatively at least with observed results in semiscale.

The second, during the two-phased flow period, the effective RCP operation on primary system mass depletion is not sensitive to the particular degradation model that we use.

If there are no further questions, I'll turn the presentation over to Fred Carpentino, who will discuss the results of some of our calculations that we performed.

DR. PLESSET: You didn't make entirely clear to everybody, I'm afraid, why for a given sized break the mass loss is greater on the hot leg than the cold leg. Now could you do that in one sentence?

MR. KESSLER: The mass loss at a given time is going to be essentially the same, regardless of where the break is. It's just that for the hot leg break you continue to supply two-phased flow to the break for a longer period of time, so that the integral mass loss --

DR. PLESSET: That's with pumps running?

MR. KESSLER: That's with pumps running.

DR. PLESSET: But if the pumps aren't running?

MR. KESSLER: If the pumps aren't running, the difference between hot leg breaks and cold leg breaks is not as significant and is more than made up for by the fact that with a hot leg break there isn't a path for spillage of

ECC water. So you have more injection flow available to the system in a hot leg break.

DR. PLESSET: So then the cold leg break --

MR. KESSLER: The cold leg break is limiting with the pumps running.

DR. PLESSET: That's what I wanted to hear. Thank you for that good sentence.

MR. MICHELSON: That's just like Westinghouse.

DR. PLESSET: Well.

MR. CARPENTINO: Good afternoon, good evening, or whatever. It's getting fairly late.

My name is Fred Carpentino and I'm section manager in Combustion's ECCS Analysis Group in charge of licensing calculations typically. I've been involved with some of the other gentlemen who have spoken here today to a certain degree in the calculations, trying to predict the effect of continued pump operation on the small LOCA.

What I'd like to do for you, in brief terms, if I can, is spend a little bit of time just quickly summarizing the results of the calculations we have performed.

(Slide.)

Now, I'd like to separate the results I have to present to you into two parts: part one being a sequence of calculations we've performed with a model that we can essentially think of as our Appendix K or EN model, with only essentially the EN model -- with only those changes required to represent the pump operation. These were described to you this afternoon; not including some of the assumptions we chose to make for the part two calculations to do a little more realistic evaluation. That is, we did not introduce the better estimate on leak flow and the better estimate on decay heat.

The part one study encompassed a study of the effect of pump operation as a function of the break size, break location, and the time chosen to assume the pumps are shut off.

Part two, the more realistic evaluation, went into a study of, first, quantitative evaluation of the effect of the differences in the model to give us a reference point, a study of some potential allowable operating conditions with regard to the reactor coolant pumps, and a brief study to earmark the special effects of certain distinct differences we have in several of the units in terms of the ECCS design.

The plant we've chosen to use to perform these studies is basically a 2700 megawatt operating type of unit. It's characterized as a system with approximately 11,000 cubic feet of fluid inventory. It has four cold legs. They're 30-inch IDs and two hot legs, which are 42-inch IDs. The ECCS design used in the typical study was a nominal head type HPSI pump, shutoff head being on the order of 1300 psi, and the accumulators or safety injection tanks are 200 psi.

(Slide.)

MR. MICHELSON: Could I interrupt just a minute and ask you a similar question that I asked this morning. Why are most of your safety injection pumps in the older plants at 200 pounds and in the newer plants at 600 pounds? What happened?

MR. CARPENTINO: In terms of ECCS evaluation, we do see distinct benefits in the higher pressure tanks for small LOCAs. We see a significant benefit prior to having done this reactor coolant pump evaluation, which I'll get into a little later, the significant benefit in this regard as well.

MR. MICHELSON: Are these benefits that make it worthwhile to go back and boost the pressure on operating plants to 600 pounds?

MR. CARPENTINO: As an analyst, that would be nice. I don't know what the incentive is for the operating units at this time.

MR. LONGO: I'd like to address that question. When you say we have benefits at 600 psi safety injection tanks, that's true, and it's done on a licensing analysis going to decay heat and so forth. I think that when you look at a realistic analysis, the benefits of going back and having higher safety injection tanks put into the older operating plants is somewhat questionable.

MR. MICHELSON: Is it a question of changing the tanks or were these tanks designed for a higher pressure to begin with?

MR. LONGO: These tanks were designed for 200 psi.

DR. PLESSET: Speaking of benefits, are you thinking of small breaks only?

MR. LONGO: Yes.

DR. PLESSET: And you say, from a best estimate point of view, it's not as great as the EN model would indicate?

MR. LONGO: Typically, when we do our small break anlysis, we present the peak clad temperature for an Appendix K type of analysis and a peak clad temperature for a realistic analysis at the worst location. For example, in System 80 the peak clad temperature--and I think the limiting break is a .05 square foot break in the small break regime. The peak clad temperature was something like 1600 degrees Fahrenheit. When we took off the 1.2 decay heat, the .05 square foot break did not even uncover.

DR. PLESSET: This was for what pressure on these accumulators?

MR. LONGO: System 80 was 600 psi.

DR. PLESSET: Suppose it were 200?

MR. LONGO: I think you would see something very similar, but I think the break size would be slightly larger.

MR. CARPENTINO: The break size would probably be about a tenth of a square foot.

MR. LONGO: The limiting break.

MR. CARPENTINO: Yes. The thing is, call the limiting break any number you like, the conservatism required by Appendix K, in essence, primarily decay heat, would indicate that that limiting break would incur a significant amount of core uncovery, while a realistic calculation would say that that's not true.

So you'd base the benefit you'd get from a higher pressure tank on Appendix K. You see a large improvement, where you can see nearly nothing in a more realistic calculation.

DR. PLESSET: Let's go on.

MR. CARPENTINO: Okay. Part 1, Appendix K type, I use that with a little caution, not exactly in compliance with the Appendix K requirements, but conservative enough. We studied break size, break location, and the time to shut off the pump. And on this matrix I've chosen some case numbers we've chosen to designate for various cases to indicate the break size we're studying. And unless otherwise indicated under break location, the break is located at the bottom of the hot leg.

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In this column I'm going to indicate the number of reactor coolant pumps I'm assuming are initially operating at the beginning of the event, and to the right-hand side of the slash the number of pumps that would be tripped at some time, shut off at some time.

In this column I'd indicate the time that shutoff is assumed to occur, and as you can see here, decay heat was assumed to be 1.2.

(Slide.)

Now, the results for the cases in this part of the matrix, part one, indicate that break size has a significant influence on the depth of core uncovery. When the reactor coolant pumps, as you recall from the preceding matrix, which I believe you're going to need to track this better, that the reactor coolant pumps, all four of them, are operating continuously. They never shut off.

So for a tenth of a square foot break we predict about 7.6 feet of uncovery. We predict a minimum inventory to occur at this particular time of 61,000 pounds. And for the .05 we see a lesser amount of uncovery and a greater amount of minimum inventory. And for the smallest, the .02, we predict no uncovery at all and a minimum inventory predicted of 102,000 pounds.

DR. CATTON: Which one of these cases was run with the steam generator area cut in half?

MR. CARPENTINO: None of these cases address that directly. That was a study we performed.

DR. CATTON: I understand. But which one of these cases would be closest to it, and could you give me a rough idea?

MR. CARPENTINO: The steam generator heat transfer, we had concluded from previous studies, is significant and necessary for breaks above .02 and smaller. That's approximately a two-inch diameter hole.

DR. CATTON: What did cutting the area in half in the steam generator, the heat transfer area in half, do to that 102,000 pounds?

MR. CARPENTINO: The case they studied the effect of the heat transfer area on was a case where the reactor coolant pumps were not operating. They were assumed to have stopped when we had the reactor trip.

DR. CATTON: So based on the ones that you have here, I have no way of picking a comparison, because the only ones that you run without pumps off were part of the last set.

MR. CARPENTINO: P-4.

DR. CATTON: Ad P-4 had an area of?

MR. CARPENTINO: A tenth of a square foot.

DR. CATTON: So there's no way I could make the same conclusion you did, that the steam generator heat transfer is not important?

MR. LONGO: Dr. Catton, when I send you the energy versus time curve, I will send you the other curve also.

DR. CATTON: I would appreciate that. I'd like to be able to compare the two.

MR. MICHELSON: I'm not sure that I can fully appreciate when you say that the steam generator was not important. It is important even though it is not needed. It is important in that it maintains a lower pressure than would otherwise be experienced if you were removing no heat. So the only real comparison is to show us the difference between using the steam generator heat removal capability and not using it, or using it to half the number.

MR. CARPENTINO: I appreciate that. You're right.

MR. MICHELSON: So it's always important, unless it it's a very large break, when it becomes then insignificant compared with other effects.

MR. CARPENTINO: I had not planned to discuss the subsequent role of the steam generator composite on top of this. I prepared the presentation to address the reactor coolant pumps directly, isolating that individual effect. We have addressed that. It's documented in some of the preceding reports we issued earlier in the summer, and we had concluded at that time that steam generator heat transfer would have to be retained for something like NO-2. It could just progress to a fairly adverse condition if we did not have it. If the break were larger than that, you'd get to the point where you're going to be able to remove significant amounts of energy, or that all of the required energy through the leak at an early enough time; not too much after, you might dry the steam generator out at about that break size.

All right, one thing we can conclude from the subset of the effect on break size here is that, one, if you have a minimum inventory of 102,000 pounds plus or minus some small amount, you keep the core covered. So that's not a core cooling problem situation.

And two, that the larger break in this range results in the minimum inventory at the earliest time, and the corresponding maximum amount of uncovery.

One thing we noted that's not shown very clearly in the information in this table, but I think you'll see it on a slide that comes up later, that this break size happens to correspond to the condition that would be a break just small enough to avoid activating our accumulators. The accumulators play no significant role in recovering this event. This shows that the adverse effect of operating the pumps is limited to a narrow range of break sizes. .02 and smaller would not sense the difference between whether the pumps are operating or not.

Breaks larger than .1, the accumulators would come into play and remove some of the sensitivity to pump operation.

The center part of the slide is just a summary of the effect of break location. Now this cold leg is the pump discharge leg. The second case is the hot leg and the third is the suction leg or the suction to the reactor coolant pump at the bottom of what's sometimes called the loop seal. In all cases, the leak was located at the bottom of these pipes. In all cases, the break size is a tenth of a square foot, which we've defined as the limiting condition from the preceding study.

And as you can see, the hot leg results in significant uncovery compared to any of those other locations, and the minimum amount of mass inventory. So we've concluded that that is indeed the limiting location with regard to pump effects.

Having isolated break size and break location, combining those, we do a study on shutoff time for that limiting combination, the .1 square foot hot leg break. We've run cases. Some of these are repeats of cases you see up above, assuming that pumps are shut off coincident with a reactor trip on low pressure; assuming that pumps are shut off at six minutes, ten minutes; and the last one, the pumps are never shut off.

And as you can see, there's a monotonic effect on the depth of uncovery, getting worse as the pumps stay on longer. All four pumps were assumed to be running in these cases.

DR. ZUDANS: Do you have a similar declaration for cold leg breaks with pumps shut off at different times?

MR. CARPENTINO: No. From this selection of data, we conclude that we had to focus on the hot leg.

DR. ZUDANS: But you don't have information on the cold leg with pumps shut down, not on this tabulation.

MR. CARPENTINO: We have information here on the cold leg with all four pumps operating indefinitely, and normally for SARS we would assume the pumps are shut off essentially at time zero. In comparing the two, there's not a significant difference between them. So from that you can conclude that the time for tripping the pump for cold leg is a second order concern.

MR. LONGO: If I remember the case now, when the pumps were shut off on the cold leg, the depth of uncovery which is reported as 3.1 with the pumps running, was slightly higher, something like 3.4 feet of uncovery with the pumps off.

DR. ZUDANS: So that would indicate that the cold leg with pumps shut off is more controlling than hot leg with pumps shut off.

MR. LONGO: Yes. But to us it's pretty much of a wash.

DR. ZUDANS: One more question. On these cases, the pumps shut off at six minutes. What is the void fraction of the pump at that time?

MR. CARPENTINO: I might be guessing. I don't recall at the moment.

DR. ZUDANS: Are they pumping steam or essentially water with some steam in it?

MR. CARPENTINO: At that time they're pumping a two-phased mixture. It's not pure steam. I don't know what the void fraction is, however.

MR. MICHELSON: I guess another way of asking the same question is, at what point in time do we get into what might be an unstable pump flow condition? Is this like six minutes, ten minutes, 30 minutes? You may not know the answer. Fine.

MR. CARPENTINO: I don't.

MR. MICHELSON: Another question. Since you're dealing with hot leg breaks here, how would the pressurizer vapor space break compare performance-wise with these other postulated breaks, which I assume are in the reactor coolant pump itself?

MR. CARPENTINO: There would be much less effect on pump operation under that condition.

MR. MICHELSON: Why would you say that?

MR. CARPENTINO: That's a very defined break.

MR. MICHELSON: These are all well-defined breaks now.

MR. CARPENTINO: A well-defined break size.

MR. MICHELSON: For the same given break size.

MR. CARPENTINO: There's a ceiling on it, which I believe comes out about equal to this .02 value.

MR. MICHELSON: Wait a minute now. I've got an .05 break at the top of the pressurizer.

MR. CARPENTINO: An .05?

MR. MICHELSON: You're saying that's theoretically impossible.

MR. CARPENTINO: Unless you want to say the pressurizer dome has cracked.

MR. MICHELSON: Okay, the biggest break you can have is an .02.

MR. CARPENTINO: If all the PORVs opened up.

MR. MICHELSON: But not the safeties.

MR. CARPENTINO: The safeties wouldn't make it.

MR. MICHELSON: So the largest postulated break is .02. Okay. Now, for that break, then, have you actually run the calculation?

MR. CARPENTINO: No, sir.

MR. MICHELSON: What I'm wondering about is the part that the water that's up in the pressurizer plays in the final answers here. As I understand it, that water in the pressurizer may not ever leave the pressurizer for a break at the top, and therefore is unavailable to covering the core at the minimum point in your calculation, and by several hundred cubic feet there's that much less water available for covering the core.

Therefore, isn't the core now uncovered partially? So I think you have to run the calculation to be sure the answer is yes, that still was severe.

MR. CARPENTINO: My feeling is that, one, because of the size, it makes it fairly clear it shouldn't be limiting; two, because of its elevation, the pumps would have to be more effective in delivering liquid to the pressurizer.

MR. MICHELSON: Keep in mind, now, it's my understanding from various sources, and I think including you people, that there is sufficient steam flow through the surge line to essentially levitate the water in the pressurizer. Therefore, it can drain. Therefore, I can even have a completely empty hot leg, I can go through your entire scenario and extract from it 800 cubic feet of water, I think.

MR. CARPENTINO: Keep in mind that we're saying that the adverse effect of the pump continuing to operate is that it delivers the liquid from the cold side to the hot side, keeping the leak covered, with the liquid otherwise available to quiesce and keep the core covered.

MR. MICHELSON: From that viewpoint, then, maybe you are a little bit better off, okay. Yes.

Another question. Have you looked at the letdown line breaks? I believe your letdown line is probably off a cold leg, or is it off the hot leg?

MR. CARPENTINO: Cold leg. That would be on the order of .02. In fact, I think it's very close.

MR. MICHELSON: Then we aren't talking cold leg here, I guess.

Now, the one final question is, have you looked at steam tube ruptures and with the concurrent single failure being a stuck open atmospheric dump valve on the secondary side?

DR. PLESSET: That's the next presentation.

MR. MICHELSON: You'll get into that later? Okay.

DR. PLESSET: Have you got the high points of your presentation over?

RM. CARPENTINO: Part one, I can just summarize.

DR. PLESSET: Not to rush you, but.

MR. CARPENTINO: I'll try to step it up a bit.

The largest break in the hot leg is limiting, and from the results here we did some estimates of hot rod temperatures. If the pumps were tripped off in the event of this break size in the hot leg at six minutes, acceptable core cooling should be preserved. Now, that was done with more or less conservative models. I do have a slide that shows the variation in core level for the various locations, because I thought that might have been of some interest.

(Slide.)

I'll flash it. If you have no need to study it --

DR. CATTON: This is with pump running?

MR. CARPENTINO: This is with all four pumps running. The lower curve is the hot leg break, a tenth of a square foot. The center one is the pump discharge leg, and the uppermost would be the pump suction leg.

DR. CATTON: Do you have similar curves for pumps not running?

MR. CARPENTINO: Yes. Not available. I'm sorry. But they would be in 114.

DR. CATTON: Fine, I have 114.

Gee, and I thought I'd read it.

(Laughter.)

MR. CARPENTINO: There's another slide that's a repetition of the conclusion I think I've stated. I think I'll skip it.

DR. PLESSET: We'd appreciate it.

MR. CARPENTINO: All right. Part 2 of our studies gets us into the more realistic assessment we tried to make with regard to the pump.

(Slide.)

These we decided we ought to do primarily to factor the conclusions into the guidelines, or to aid in the development of guidelines. We first ran a few cases comparing to some available current marks on P-10 and P-11, comparable cases P-14 and H respectively, with the better estimate model, to conclude the quantitative influence in making these model changes. You can see the major things to keep in mind with regard to the two models are decay heat and leak flow, HEM for better estimate, Moody for the Appendix K type, 1.0 and 1.2.

In all cases the typical plant was used in terms of the ECCS design, SIT pressure, and the type of high-pressure pump, except when we get down here to study the separate effect of the 600-pound tank and the high-head HPSI.

Let me just flip to the results matrix, and we can use this as a guide going through the results.

MR. MICHELSON: Before you flip, let me ask you a question instead of searching all the numbers. The thing I'm a little wondering about is, what happens if you follow the instruction wherein you keep two pumps running, but you lose them at the most optimum time relative to maximizing core damage? Have you looked to see when that optimum time would be and what, if any, core damage would occur?

MR. CARPENTINO: Well, we've investigated this case in which we assumed two pumps would have been shut off at five minutes.

MR. MICHELSON: Now, when do the other two pumps shut off?

MR. CARPENTINO: If we were to lose the remaining two at some subsequent time, whether we could still retain an

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continues

adequate cooling situation? Our conclusion is yes.

MR. MICHELSON: You did a sensitivity study and varied the time and found at no time you had a problem?

MR. CARPENTINO: Well, we find that when, first of all, the concept of studying or tripping off only two pumps is sort of non-LOCA consideration.

First, we wanted to see whether if you kept two running, is that okay for the LOCA? It made an avenue for further considerations for non-LOCA sequences.

MR. LONGO: I think I can answer you question directly. When we shut two pumps off in five minutes, we kept two pumps continuing to run and determined the time at which we got a minimum inventory at that time -- and I think it will come up on the next slide. It's something like 86,000 pounds of mass minimum inventory.

And with that minimum inventory, if the pumps were to stop at that time, there would be no problem.

MR. MICHELSON: Okay.

(Slide.)

MR. CARPENTINO: Okay. P-19, P-14 are cases where we have assumed all four pumps continued to run indefinitely, P-10 being the conservative, or Appendix K, P-14, the realistic.

In addition, in both cases, it was assumed that two high pressure pumps were injecting. We eliminated that single failure assumption in both cases. And, as you can see, both cases result in -- the conservative case results in a little bit of uncovery, while the better estimate case results in no uncovery.

And you can see the major quantifying difference in terms of the minimum water inventory predicted. Conservatively, that's 72; while more realistically, that's 87,000 pounds.

It must so happens that in both cases we predict that there'll probably be adequate core cooling.

Another way to measure the effect of the best estimate approach was in terms of the time you have available to shut the pumps off. P-11 ws a case which was taken from the Part 1 slide, where we assumed we shut the pumps at six minutes and that resulted in adequate cooling.

And you can see the depth of uncovery and the minimal inventory predicted.

Case H was the more realistic one; but in this case now, assuming that we shut the pumps off at 10 minutes, a four-minute differential, you can see a significant improvement in the amount of uncovery, minimum inventory, and estimated coolability.

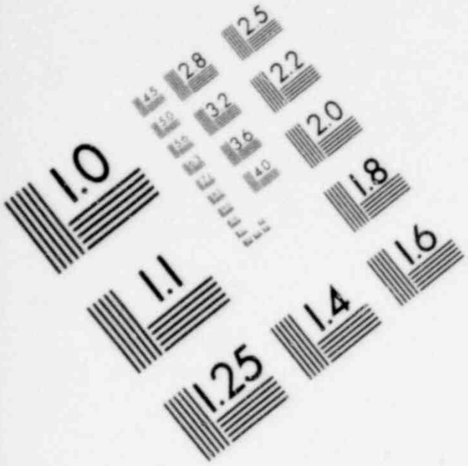
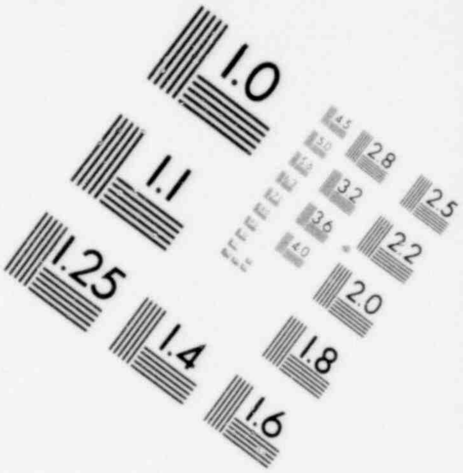
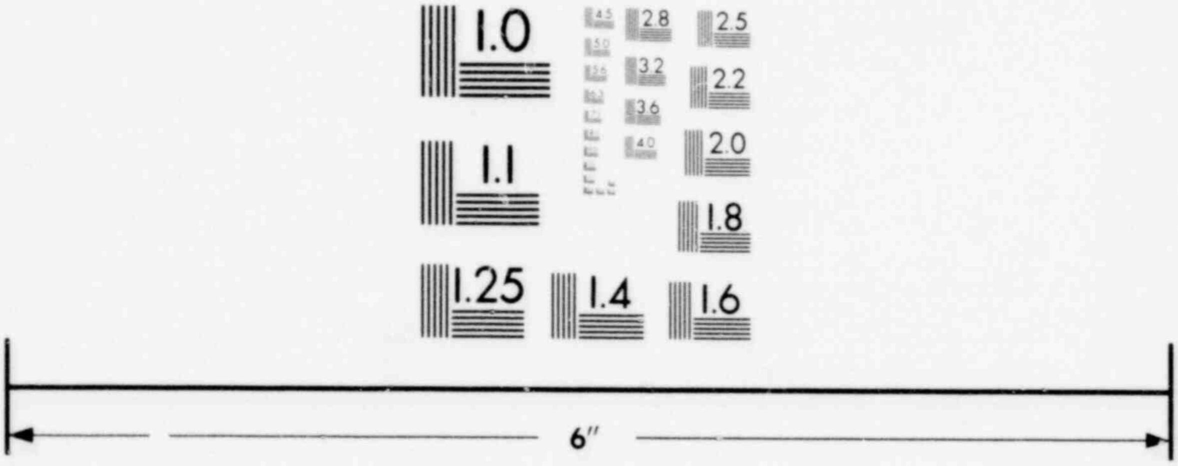
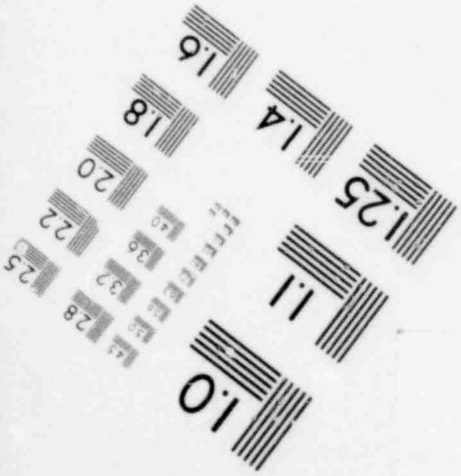
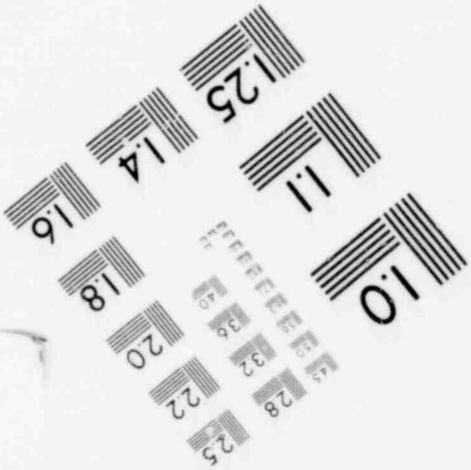
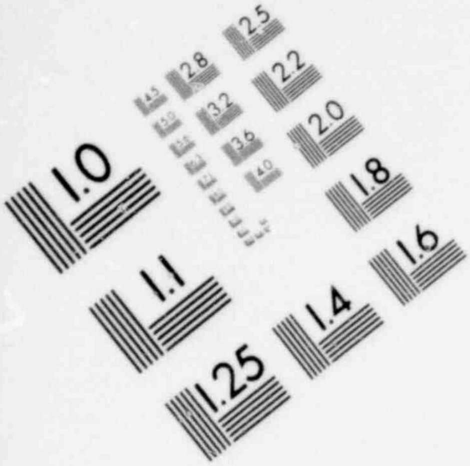
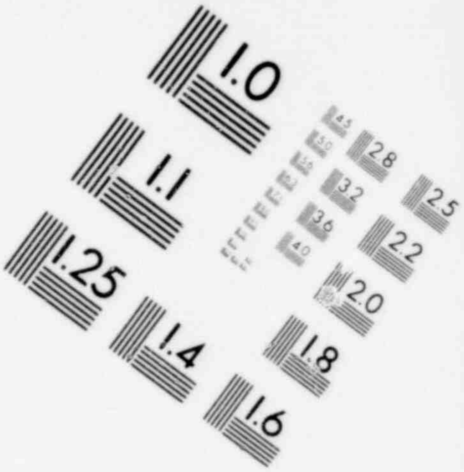



IMAGE EVALUATION TEST TARGET (MT-3)







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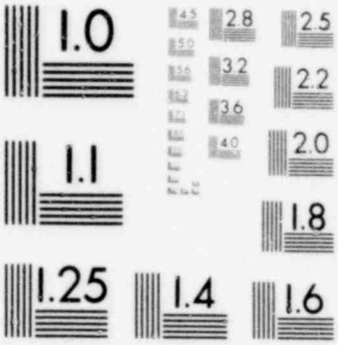

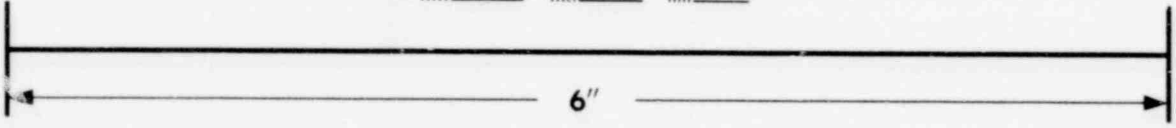

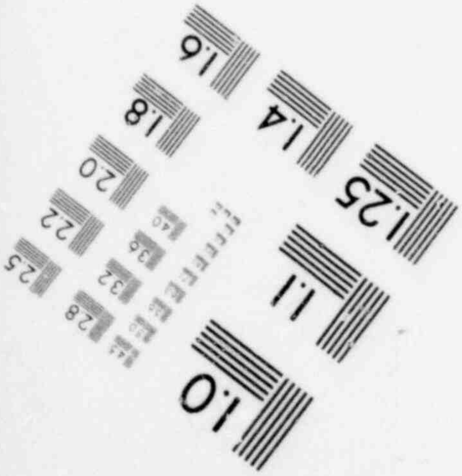

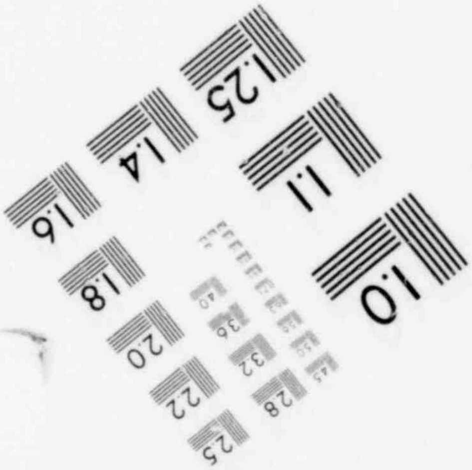

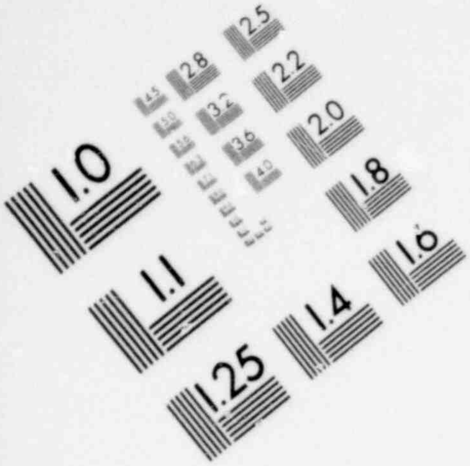

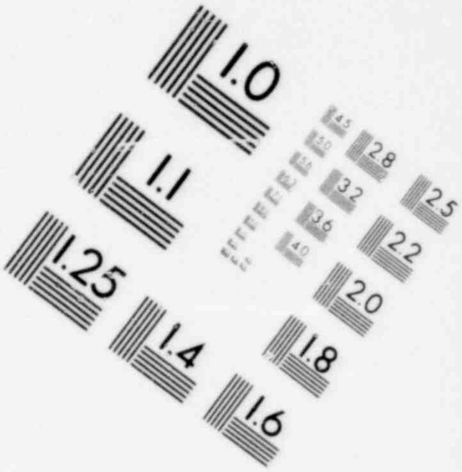

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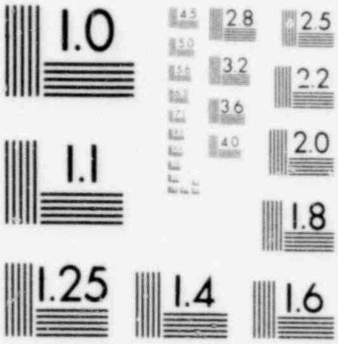
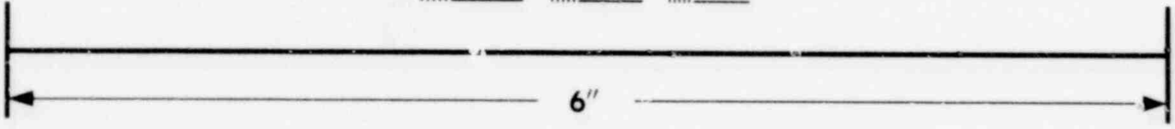
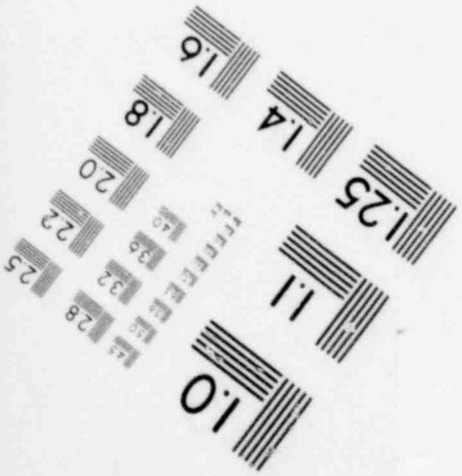
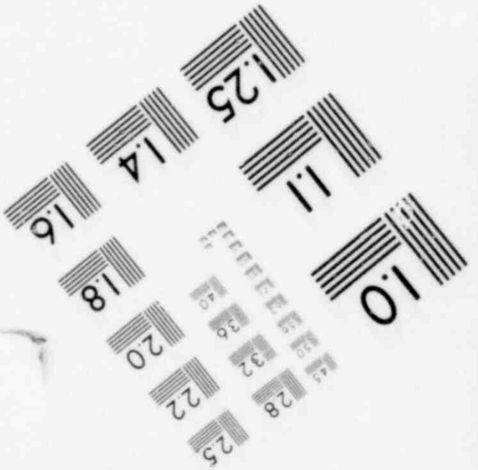








MR. CARPENTINO: So it has two effects, it leads to a higher prediction minimum inventory, a lesser amount of inventory and an extended amount of time to do something about the pumps.

DR. ZUDANS: You also had different decay heat according to the previous one.

MR. CARPENTINO: Yes, decay heat was different.

DR. ZUDANS: Wasn't that the dominating one, whether the pumps shut down four minutes later?

MR. CARPENTINO: A dominant part of the difference between the two model approaches is decay heat.

DR. ZUDANS: It has really very little to do with whether you shut down the pumps at six or 10 minutes.

MR. CARPENTINO: I'm just saying the difference is in the analysis assumptions or models would allow you to wait longer.

DR. PLESSET: That refers to the leeway he has.

MR. CARPENTINO: It's a measure of the benefit of using a more realistic model, the extra time you have available.

DR. ZUDANS: The first round of comments, I thought you assigned this benefit due to the fact that you shut the pump down earlier. But, as I see, you have different decays heats between H and P-11. Maybe decay heat difference was the only reason why you got more time.

DR. PLESSET: That's right.

DR. ZUDANS: The 10 or six minutes made no real difference.

MR. LONGO: You can take the benefits of going with the best estimate, over that of going with Appendix K, in either of two ways: One, lower peak clad temperature, where you trip the pumps at the same time; or extending the time at which you can trip the pumps.

DR. PLESSET: The only changes really are the models of rate flow, what he thinks are more realistic, and it cuts down the decay heat to the the true value, or what we think is the true value; right?

That's what he said.

MR. MICHELSON: I'm having a little difficulty here with your condition G.

MR. CARPENTINO: You're way ahead of me.

MR. MICHELSON: Let me ask it anyhow. You're predicting here temperatures in excess of 2200 for that particular case. That was a case when tthe pumps were running throughout. That's the way I read it at least.

MR. CARPENTINO: That is right.

MR. MICHELSON: Some explanation on why you get so hot with the four pumps running all the time?

MR. CARPENTINO: Yes.

MR. MICHELSON: And you'll get to that?

MR. CARPENTINO: Let me just develop this. In exploring possible operating conditions, let's repeat the results of the P-14 from above. As you recall, that assumes you have four pumps running continuously, and that two high pressure pumps are injecting the water. And that didn't result in any uncovery.

Case B was an exploration into the possibility that if that were true; but at some time perhaps, whatever the mechanism is, you lose power to all four pumps and get cut back to one HPSI, presumably you lose normal AC power and half to go on emergency power. Maybe that's the end result, and that occurring at the worst possible time, when we predicted the minimum mass inventory for Case P-14, 900 seconds, and see what would happen.

Well, we did, and it turned out that for that case, primarily due to the effect of cutting back on the heat injection rate, cutting it in half, there was some uncovery now, when previously you would not have. And you can see the minimum inventory somewhat reduced.

And we went ahead and estimated some quiet temperatures for that condition, and it's kind of high, but acceptable by licensing standards.

Case C was a study of the possibility of losing two pumps at reactor trip, but continuing the other two operating indefinitely. So that was the basic assumption.

Here we're taking credit for only one high pressure pump, and the results are shown here, resulting in about two and a half feet of uncovery. Here's the minimum inventory. Note that most of these numbers are well below the 102,000 pounds estimated to keep the core completely covered at all times.

And the temperature for C would be on the order of 1200 degrees, so that looked like a possibility.

DR. ZUDANS: Could I ask a question on the correlation between core uncovery other than zero and the clad temperature?

How can you -- what do you do to get the clad tempereratures, say, for feet of uncovery at 1680 degrees?

MR. CARPENTINO: If you see a number like 1683, that was detailed calculation. When you see two zeros at the end of the number, that's deinitely one of our estimates. And the say we estimate it was based on the similarily of the depth of uncovery that we might have had for some previous analyses at the same power density or a similar power density.

DR. ZUDANS: Is this number comleted on an actual heat transfer with steam being in contact with the fuel elements?

MR. CARPENTINO: Yes, we're in a steam-cooling mode.

DR. ZUDANS: And that's all you're getting is that temperature?

MR. CARPENTINO: Yes. It's strictly steam cooling.

DR. PLESSET: Gentlemen, for reasons beyond my control, we have a half hour more, so I'll leave it up to you, or the speaker, and Mr. Longo; what do you want to do in another half hour?

MR. LONGO: I think I'd like to have the non-LOCA presentation summarized, and then come in with a summary of our presentation today.

DR. PLESSET: All right. Is that agreeable with you?

I think we've got a pretty good view of what we had to say.

Mr. Carpentino, if you will forgive us, we will move on to the rest of the program

MR. CARPENTINO: There's one question unanswered.

MR. MICHELSON: Dr. Plesset, there's quite a few questions associated with guidelines, as to the proper operating procedures, both as it relats to would it shut pumps off? and does it relate, in general, to how operating procedures are prepared.

You had already indicated I guess that Westinghouse will have to come back to discuss that subject.

Maybe CE will come back and discuss the general ect of operations, including whether to shut pumps off, and so forth.

We could just forget the questions that we're -- about whether we trip pumps or not.

MR. LONGO: If you invite us we'll come.

DR. PLESSET: Carl, it might be better to do it right.

MR. MICHELSON: Otherwise there's quite a few questions that really have to acked.

DR. PLESSET: If that's agreeable, then, we'll plan it that way.

MR. KLING: I have a feeling that's right.

DR. PLESSET: We have a little more than that. We want a summary from someone from CE.

MR. KLING: Well, good evening, my name is Charles Kling, and I'm the Manager of Safety Transients at Combustion Engineering. I'm essentially respnsible for non-LOCA transients.

As the people back there can tell you, I've been sort of anxiously waiting for this moment for almost 12 hours now, and I guess the only other thing I can say when I start is that if you intend to ask me anything difficult I might have to defer to the next speaker.

(Laughter.)

MR. KLING: My interest is that I may have seemed to have been blamed for a few times for wanting to keep a couple of pumps on if an operator is told to start turning them off. And I hope to explain in some detail why I have that interest in mind.

(Slide.)

What I'm interested in talking about then this evening is what the impact of reactor coolant pump trip is on the non-LOCA transients. And I'd like to discuss this in several parts:

First, to identify those non-LOCA transients which we had evaluated which might have to have pump trip;

Then to discuss the impact of the trip on two separate areas -- first, on the specified, acceptable fuel design limits or those limits which are associated with relatively high frequency events; then the impact of pump trip on the non-LOCA accident consequences or events of low probability;

And then the conclusions of what the impact of this pump trip is.

(Slide.)

First, to look at those non-LOCA events which can depressurized the reactor coolant systems to the SIAS set point, going though a low RCS pressure trip in the process of getting to the SIAS set point and therefore meeting the conditions that the operator would have to say he would have to consider tripping some reactor coolant pumps.

The type of events are in three areas: Increased heat removal by the secondary system, which for high frequency types of events or excess load, say due to a steam valve malfunction on the secondary side, where you would have a high flow rate, higher than expected flow rate from the steam generator; and this would go on up into the accident range, where you'd be talking about steam breaks, where you can get an extremely large increase in the heat removal rate.

The heat removal rate, in excess of what the RCS is generating, would depressurize the RCS and could depressurize it to the point of low trip, pressure trip and SIAS.

There is a potential for events that decrease RCS inventory. The ones I'll be talking about are for high frequency events, the pressurizer local control system malfunction, where, say, the letdown comes on inadvertently and lowers the pressurizer level, and it would have to wait for the operator to take some action to stop that increase in level.

And in the accident region we're talking about steam generator tube rupture, and of course you could go on to LOCA, but that's been the subject of essentially all the foregoing discussions, so I'm not going to be discussing it here.

Finally, we can talk about reactor coolant system pressure control malfunctions. In this, we're talking about the potential for the pressurizer spray to come on inadvertently and depressurize the reactor coolant system simply by having the spray on for a long period of time.

(Slide.)

The first type of impact I'd like to talk about would that be that associated with the specified acceptable fuel design limits. This is associated for that case where we can talk about a simultaneous low prssure trip and SIAS.

It happens that on some of our plants that this set point is essentially the same set point. You get a low pressurizer pressure trip and a safety injection actuation signal essentially simultaneously.

You could also have a situation where you have a high rate of depressurization which would -- even though these set points might be separated by a little bit, would be very close in time. And if an operator was seeing this type of thing he would meet the condition with having to trip the pump and would do so quite rapidly in response to an SIAS.

This immediate trip can rsult in a flow decrease due to the operator turning off the pumps before the heat flux decays due to the control rod insertion after the trip.

Because of this, there's the possible short-term violation of the specified acceptable fuel design limit on DNBR.

Now, this is really more of a licensing concern than, say, an actual concern, a short-term violation of the SAFDL has a potential for saying that you could have a critical heat flux event for a short time in the reactor. In reality there's usually more margin associated with these conditions than we would show in a licensing analysis.

So, in reality, we would probably not violate the SAFDL.

In order to prevent this, in a licensing sense, it would be advisable to wait at least five seconds following the reactor trip before tripping the pumps.

DR. CATTON: What does "SAFDL" stand for?

MR. KLING: Excuse me, that was "Specified Acceptable Fuel Design Limits," just abbreviated.

When you talk about acceptance criteria for these events, you talk about meeting the specified acceptable fuel design limit.

(Slide.)

This is just giving a pictorial outline of the sequence I went through there, an event starting here at initial DNBR over here, because of initial depressurization, the DNBR decreases, you get to the point of reactor trip on low pressurizer pressure and SIAS.

If the operator would trip the pumps at this time, you would get a characteristic decrease in DNBR that would be a flow coastdown, a decrease in the DNBR. And then as the heat flux decreased, this would turn around and start back up.

This is essentially going on over a period of time. We're talking about this period of time of about three seconds. It goes on over the period of time that the control rods are being inserted in the core.

And if we waited just a few seconds beyond full rod insertion, we would be high enough up on the NDBR curve so that any potential decrease in DNBR would have no capability of violating the specified acceptable fuel design limits.

This type of a delay, five seconds of course, would have no impact on the LOCA analyses that we have been talking about.

Again, I want to stress that we're really talking about this being a result of a licensing type of analysis. Whereas if we were to do best estimate, we'd generally have more margin in the plant than we do in the licensing sense and wouldn't really expect to violate the SAFDL in any case.

MR. MICHELSON: It's not clear to me what argument you're trying to develop here. Are you trying to argue that the operator may be too fast? Are you trying to argue that you shouldn't have automatic pump trip? Or just what's -- I mean, these are all extremely short times, hardly within operator response times generally.

So what's the purpose of the development?

MR. KLING: The purpose of the development is that the bulletin says, "When you meet the conditions of reactor trips and SIAS, immediately trip the pumps."

MR. MICHELSON: But you haven't correlated any of this to SIAS safety injection, and until you do, nothing happens.

MR. KLING: Here's the signal. This is the SIAS signal.

MR. MICHELSON: You're going to get that condition in your plants, a fraction of a second apart?

MR. KLING: Yes, with the events I'm talking about, they can be simultaneous in some of our plants, because the low pressurizer pressure trip set point and the SIAS set point can be identical.

MR. MICHELSON: That can in your plants?

MR. KLING: In some of our plants, they can be.

MR. MICHELSON: So you're arguing that you don't want to be too fast after that?

MR. KLING: That's the argument.

MR. MICHELSON: Okay.

(Slide.)

MR. KLING: It might be too fast, okay.

The other impact I'm going to be talking about is associated with accidents. We first talk about the margin to fuel failure during a steam line break. The teem line break, as we analyze it and as it shows up in the safety analysis reports, we have the break, you get usually a short-term reactor trip.

The cooldown in the transient is enough so that the positive reactivity feedback associated with that cooldown will overcome the amount of rods that you've inserted and can bring the reactor back to power. This is on the order of a couple of minutes into the transient. That return-to-power condition is the result of a licensing assumption that we make that one of the control rods is stuck out of the core.

We have the expected condition of no rods being stuck out of the core after the trip. Then on the CE reactors there's enough reactivity inserted so that we don't expect to have a return to power.

So, again, this is something on the order of what occurs when you use the licensing analysis. This return to power then is something that happens a couple of minutes into the transient.

If we have a flow coastdown prior to or during this post-trip return to power, there's a potential to having a loss of flow in addition to power generation and somewhat of a margin reduction to the potential for fuel failure.

Now, not particularly for the operating plants, but on recent dockets, we have had to show what the impact of having a concurrent reactor coolant pump trip with steam line break, essentially having to assume a loss of AC power on steam line break.

These analyses have shown that we don't expect any fuel failure for the steam line break for the reactor coolant pump trip essentially. There is sufficient margin in this post-trip, return-to-power phase so that the impact of having the pumps coast down is not enough to result in a fuel failure. All it does is reduce the margin a little bit.

For this reason, we would say it is preferable to continue operation of at least one reactor coolant pump in each steam generator loop, preferable to tripping all of them, so that you help keep a larger margin to the potential for fuel damage.

(Slide.)

The final impact with respect to the accidents is one on radiological releases. If the reactor coolant pumps are tripped in the course of an accident, from that point on we sort of increase the time it takes for that accident to reach a conclusion.

We talk about taking them all the way to cooldown. And without reactor coolant pump flow, we're going to increase the time it takes to cooldown. There are some cases where this increased cooldown time can have an impact on radiological releases.

The case I have as an example here is the steam generator tube rupture, where reducing the reactor coolant system flow will increase the time that the mainstream safety valves may open for a steam generator tube rupture and increase the amount of release you would get of the safety valves and therefore impact the site-boundary dose.

This happens to be an incremental impact on the total site-boundary dose for the steam generator tube rupture.

Again, on recent dockets, we have analyzed steam generator tube rupture with concurrent loss-of-reactor-coolant pumps, and the dominant impact on the site-boundary dose is really having to cool down the plant once the pumps are off.

So the fact that we turn the pumps off very early and leave the steam safety valves open for a short period of time has an incremental impact on the licensing analysis.

I think one of the possible things we've learned recently is that if these pumps are turned off and the other things in the plant are normal, such as being able to cooldown through the condensor, that you do increase the potential for opening the steam safety valves and having some release.

Whereas, if the pumps were left on, you may not have opened the safety valves at all. Because this is just another incremental effect, we don't expect to exceed dose limits due to it. It's just another somewhat more adverse consequence of turning the pumps.

jlLAV

Therefore, again, continued operation of at least one pump in each loop is preferable to turning off the pumps.

(Slide.)

My last slide just summarizes all these conclusions by saying that, in general, tripping the pumps for non-LOCA transients makes them incrementally more adverse. Several of the aspects of what makes them more adverse are due to the approach that we have of analyzing events and some of the licensing assumptions that we make, and adding a reactor coolant pump trip to those licensing assumptions makes the consequences a little bit more adverse.

However, we do not expect to violate any of the acceptance criteria, particularly if we weight five seconds following full rod insertion before tripping the reactor coolant pumps; and we would have continued increased margin to potential fuel failure and incremental reduction in the calculated site boundary dose if we continued operation of at least one reactor coolant pump in each steam generator loop.

Questions?

MR. MICHELSON: What I think you said is that there are no unacceptable consequences, but that the situation are a little more severe.

Now, on the other side of the coin, one has to prove that there are no significantly more serious consequences of running those last two pumps and having them get in trouble later.

You've already made a statement -- or the other gentleman did -- that indeed you can trip the two pumps at the worst case, at the worst time, and still be all right.

My question is: Has that case been documented, where I could look at it?

MR. LONGO: Yes.

MR. MICHELSON: Which document?

MR. LONGO: It's in CEN 115.

MR. MICHELSON: Then it's just simply a question of looking at the disadvantages on both sides.

MR. KLING: I think if I could state it, I am happier if two pumps are left on for the non-LOCA events. That would result in a situation where the operator is told that he has to turn some pumps off, things are better.

And what you're being told from the LOCA side is that leaving two pumps on doesn't make things any worse.

MR. LONGO: I'd like to put it another way.

MR. MICHELSON: I'm not sure I agree with the last part of your statement. I don't think he said that; he said it was still acceptable. He didn't say it wasn't worse. I think it has to be a little worse.

MR. LONGO: It is a litttle worse.

What I would like to summarize in saying is that we would like to keep two pumps on for a non-LOCA event. If we had a LOCA and the operator knew it was a LOCA, then we'd say, "Shut off all four pumps."

Now, there was a concern raised earlier about the effect of keeping those two pumps on when you did have a LOCA and you could get into the slug flow perhaps in the pumps. That would be, in my mind, a good indication that you did have a LOCA to the operator and he should shut off those pumps.

MR. MICHELSON: Providing it didn't catch up with him before he had a chance to shut them off.

MR. LONGO: Yes. I think that what we're really saying is that you have an option, you can keep two pumps on, and this can buy you the operator some time to determine whether he does have a LOCA or not.

DR. PLESSET: Well, thank you. You were very succinct.

(Laughter.)

MR. MICHELSON: I had one question I didn't get a chance to ask before that still puzzles me a little bit, and probably a real quick answer to it -- it's an analytical question. That is, when only two pumps are running, how do you handle the two dead loops in the analysis? You know, the one pump is running backwards, and the other pumps and so forth, and what does that do in terms of the analysis and so forth?

How is that handled? And what effect, if any, does that have? It's just an inquiry.

MR. CARPENTINO: The two operating pumps would push some fluid towards the annulus, and the dead pumps in each of the loops would be directly connected to the annulus.

What you'd have at that point is a recirculation through the active and back in.

MR. MICHELSON: I just have a gut feeling about -- you know, we talk about levels going up and down and fluids moving around, and we never talked about that in a case where there was a dead loop along with a live pump.

MR. LONGO: That would help you a little bit.

MR. MICHELSON: Is that discussed somewhere in your report?

MR. CARPENTINO: I don't think it's explicitly discussed.

MR. MICHELSON: But it is the real world.

MR. LONGO: It probably would help, because you wouldn't keep the core flow up to that level.

MR. MICHELSON: I don't know if it helps or hurts; I'm just asking the question. I think that if you really believe that you want to run this way, it would be necessary to take care of that point as well.

DR. PLESSET: Well, we are aware, Mr. Longo, that we owe you a little more time, and we'll keep it in mind. And we would like to hear about the guidelines in detail, and you can be sure we'll ask for that.

And I think that most likely the loss-of-feedwater events is another item we'd like to hear about. And you may have some reaction to the Staff's comments tomorrow.

So, all in all, it looks like we need to get together again as soon as reaonable.

MR. LONGO: Fine.

DR. PLESSET: We thank you for being cooperative with our compressing you, and look forward to seeing you again.

MR. LONGO: Thank you very much.

(Whereupon, at 7:35 p.m. the hearing was adjourned, to reconvene at 8:30 a.m., Thursday, October 18, 1979.)

OTHER S.G. RELATED TESTS

I LEVEL SWELL, ENTRAINMENT AND HEAT TRANSFER ON SECONDARY SIDE

a) PARTIALLY SUBMERGED TUBE BUNDLE

TO VERIFY ANALYTICAL MODELS IT MAY BE POSSIBLE TO UTILIZE RESULTS OF

- FUEL BUNDLE BOIL-OFF TESTS
- FLECHT LOW RATE BOTTOM FLOODING TESTS

b) FULLY SUBMERGED BUNDLE

- THTF TESTS

c) FEEDWATER SPRAYED ON BUNDLE FROM TOP (AS FOR AUX. FEED IN OTSG)

- BWR FLECHT TESTS

II CONDENSATION INDUCED HYDRAULICS & HEAT TRANSFER WITHIN PRIMARY SIDE OF UTSG

PLANNED FLECHT-SEASET TESTS

SECONDARY SIDE: i) TUBES FULLY IMMERSED
($T_{SEC} < T_{PRIM}$) ii) TUBES PARTIALLY "

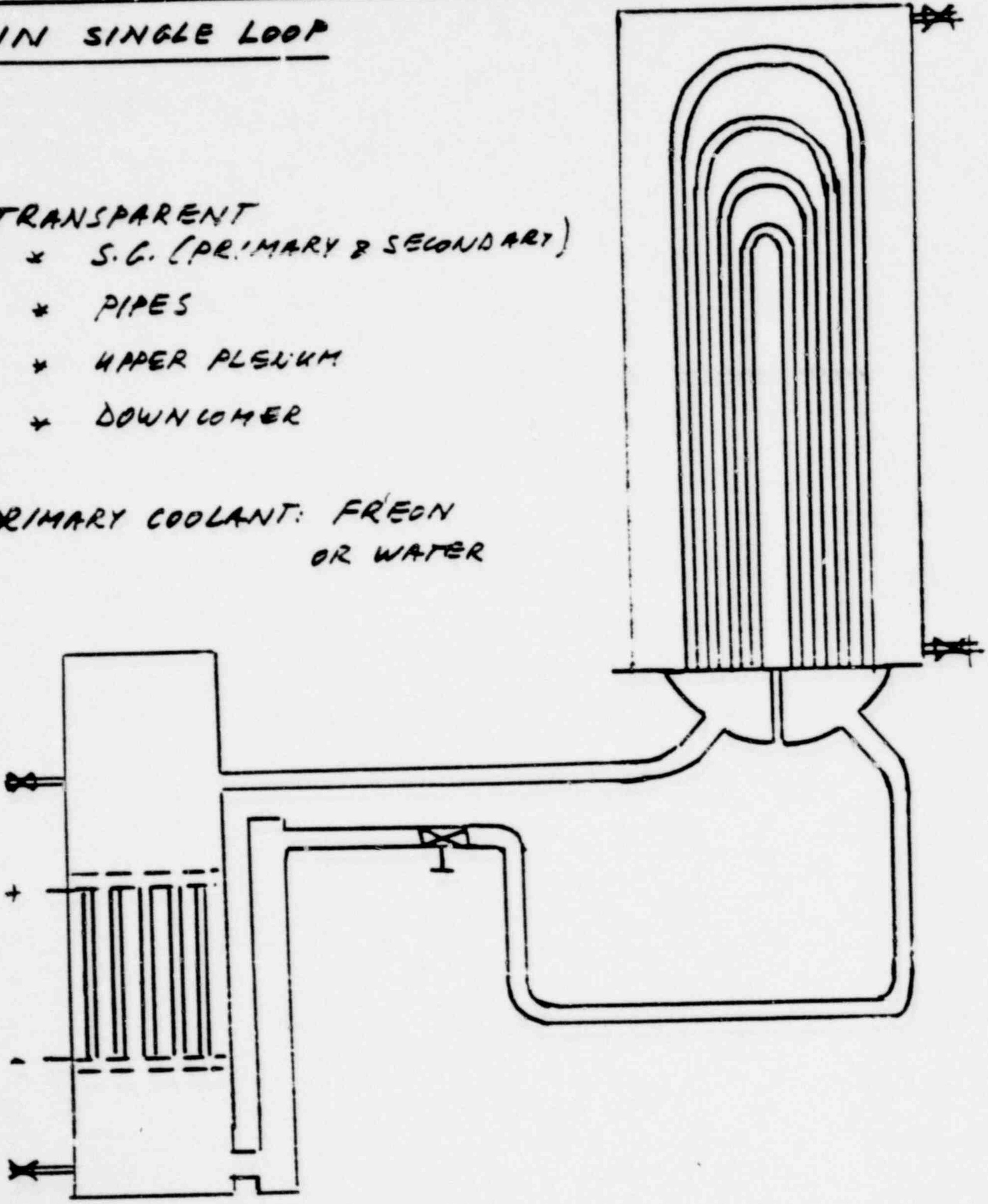
PRIMARY SIDE: i) DRY STEAM INFLOW
ii) 2-ϕ INFLOW, AT LOW AND HIGH RATES
iii) EFFECTS OF NON-CONDENS... GAS

/

MIT PROPOSED TEST FOR VISUALIZATION OF FLOW REGIMES DURING 2-ϕ NAT. CIRCULATION IN SINGLE LOOP

TRANSPARENT
- S.G. (PRIMARY & SECONDARY)
- PIPES
- UPPER PLENUM
- DOWNCOMER

PRIMARY COOLANT: FREON
OR WATER



OCTOBER 17, 1979 ACRS MEETING

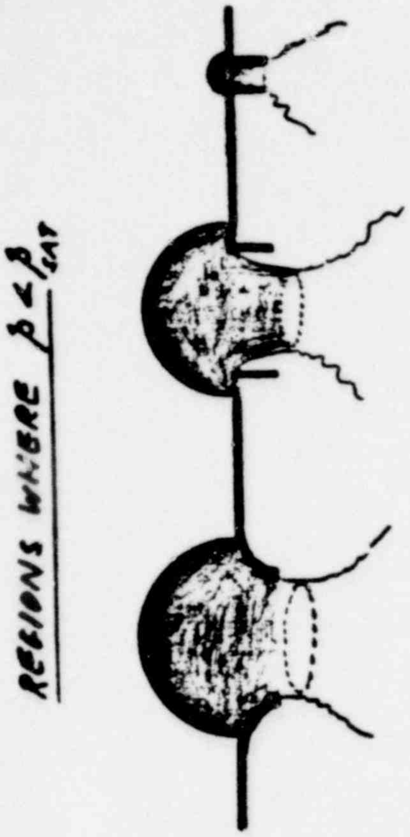
TOPICS DISCUSSED BY S. FABIC, NRC/RES

1. CRITICAL FLOW THRU SMALL BREAKS
   - EFFECTS OF GEOMETRY
   - MODELING ISSUES
   - INFLUENCE OF PHASE SEPARATION

2. FLOW & HEAT TRANSFER IN STEAM GENERATORS
   - TEST DATA BASE FOR UTSG
   - TEST DATA BASE FOR OTSG
   - STABILITY ISSUES DURING 2-ϕ N.C.

CHOKED FLOW THRU SMALL BREAKS

1. VERY SHORT TUBES (L < D)



OBSERVATIONS

a) PATH LENGTH IN SUPERHEATED LIQUID REGION:

INCREASES AS DIAMETER INCREASES

DECREASES AS TANK SUBCOOLING INCREASES

THE LONGER THE PATH LENGTH THE MORE PRONOUNCED THE CHOKING.

(b) ENTRANCE GEOMETRY EFFECTS:

SHARP ENTRANCE LEADS TO FLOW CONTRACTION, SMALLER EFFECTIVE FLOW AREA

ROUNDED ENTRANCE GIVES LESS CONTRACTION, HIGHER FLOW SOMEWHAT COMPENSATED BY LONGER PATH IN LIQUID SUPERHEAT REGION

(c) THERMAL NON-EQUILIBRIUM IMPORTANT

(d) 1-D MECHANISTIC ANALYSES NEED TO EMPLOY EMPIRICAL FLOW COEFFICIENT TO ACCOUNT FOR MULTI-D PHENOMENA.

(e) IN LUMPED PARAMETER ANALYSES HENRY-FAUSKE AND BURNELL MODELS CAN BE USED, IN CONJUCTION WITH EMPIRICAL DISCHARGE COEFFICIENT, WHEN "TANK" FLUID IS SUBCOOLED OR SATURATED LIQUID.

(f) WHEN "TANK" FLUID IS 2-φ MIXTURE OR VAPOR, HENRY-FAUSKE AND HEM MODELS APPLY, ALTHOUGH THE DISCHARGE COEFFICIENTS ARE LIKELY TO BE DIFFERENT.

2. SHORT PIPES $(2 < \frac{L}{D} < 10)$

(a) ENTRANCE GEOMETRY, DIAMETER, AND THERMAL NON-EQUILIBRIUM EFFECTS NOT SIGNIFICANT (EXCEPT FOR VERY SMALL DIA. PIPES WHEN $L/D \approx 2$)

(b) 1-D MECHANISTIC ANALYSES GIVE ACCEPTABLE RESULTS

(c) LUMPED PARAMETER ANALYSES CAN GIVE ACCEPTABLE RESULTS WITH HENRY-FAUSKE OR BURNELL MODELS FOR SUBCOOLED UPSTREAM CONDITIONS AND WITH HEM FOR VERY LOW SUBCOOLING OR SATURATED UPSTREAM CONDITIONS

HOWEVER, THESE UPSTREAM CONDITIONS ARE OFTEN NOT ADEQUATELY CALCULATED, RESULTING IN A VARIETY OF DISCHARGE COEFFICIENTS CHOSEN TO OBTAIN AGREEMENT WITH TEST DATA.

SMOOTH TRANSITION IS NEEDED, IN ANALYSES, WHEN SWITCHING MODELS.

3. LONG PIPES $(\frac{L}{D} \geq 40)$

(a) IF PIPE IS DISCRETIZED IN ANALYSIS THE COMMENTS MADE IN (2) ABOVE APPLY.

(b) CHECKS FOR "INTERNAL CHOKING" NEED TO BE MADE IF FLOW RESTRICTIONS ARE PRESENT WITHIN THE PIPE.

(c) IF THE (UNIFORM FLOW AREA) PIPE IS NOT DISCRETIZED THE BREAK FLOW MODEL MUST ACCOUNT FOR WALL FRICTION EFFECTS.

4. ORIFICES WITHOUT DOWNSTREAM CONFINEMENT

(a) NO CHOKED FLOW IS EXPECTED WHEN THE EXTENT OF SUPERHEATED LIQUID REGION UPSTREAM OF ORIFICE IS SMALL.

BERNOULLI EQ., COMBINED WITH A FLOW CONTRACTION COEFF. ADEQUATELY PREDICTS FLOW RATE IN SUCH CASES.

(b) IF THE UPSTREAM FLUID IS NOMINALLY SATURATED OR SUBCOOLED, THE EXTENT OF LIQUID SUPERHEAT REGION IN CLOSE VICINITY OF ORIFICE CANNOT BE DETERMINED IN "SYSTEM ANALYSIS". EMPIRICAL DISCHARGE COEFFICIENT USED TO ACCOUNT FOR SUCH MULTI-D EFFECTS.

(c) SEE OBSERVATION 1-f FOR DISCHARGE OF 2-ϕ MIXTURE

5. CONFINED ORIFICES

(a) IF THE FLUID IMMEDIATELY UPSTREAM OF THE ORIFICE IS SUBCOOLED OR SATURATED LIQUID (AND THE ORIFICE SMALL), CHOKING DOES NOT OCCUR AT THE ORIFICE BUT DOWNSTREAM WHERE EXPANDING JET MEETS THE PIPE WALL.

AT THAT LOCATION HEM GIVES ADEQUATE PREDICTION OF CRITICAL FLOW.

CURRENT ANALYSES DO NOT ADDRESS THIS ISSUE. CAN BE ENCOUNTERED IN TEST FACILITIES.

6. RELIEF VALVES

TEST DATA BASE IS LACKING AS OF NOW.

MECHANISTIC MULTI-D ANALYSES COULD BE USED TO CALIBRATE 1-D OR LUMPED PARAMETER MODELS, ACKNOWLEDGING AN UNCERTAINTY BAND.

7. EFFECTS OF NON-CONDENSIBLE GAS

CURRENT MECHANISTIC ANALYSES ADEQUATELY PREDICT 2-ϕ 2-COMPONENT CRITICAL FLOW. HAVE NOT, SO FAR, EXAMINED THEIR PERFORMANCE FOR FLOW OF VAPOR/LIQUID/AIR MIXTURES.

7. CRITICAL FLOW THRU CRACKS

IN ORDER TO PRESERVE FLOW AREA AND THE WETTED PERIMETER (WALL FRICTION AND HEAT TRANSFER), CRACK CAN BE REPRESENTED BY A PARALLEL ARRAY OF THICK WALL TUBES.

FOR A CRACK OF LENGTH a AND AVERAGE WIDTH b, AN EQUIVALENT ARRAY CONSISTS OF n TUBES OF DIAMETER D, WHERE

$$n = \frac{a}{b\pi} \quad , \quad D = 2b$$

LENGTH OF EACH TUBE EQUALS PIPE WALL THICKNESS L.

EXAMPLE:

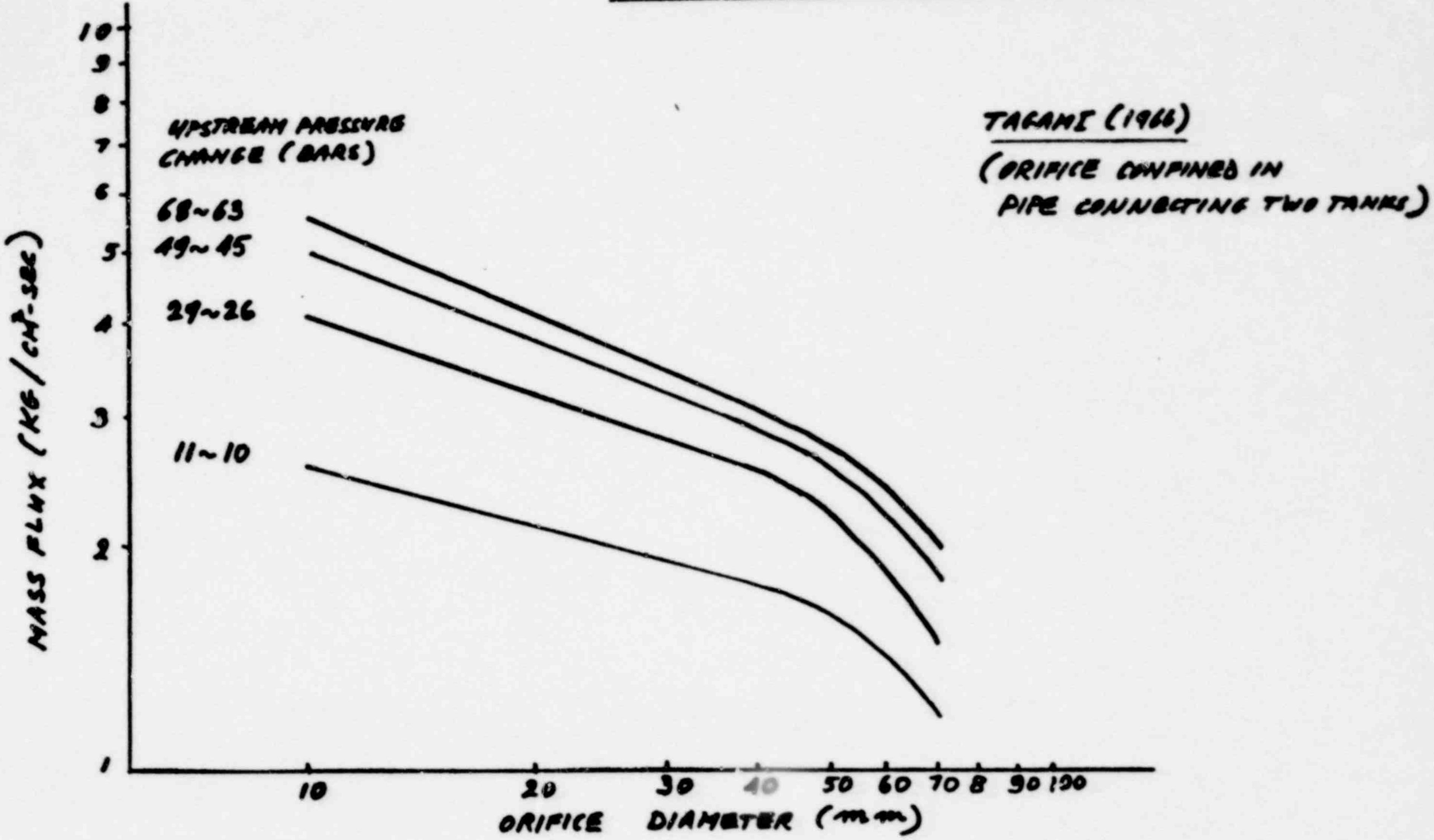
CRACK $a = 6$ inch , $b = 0.1305$ inch
(FLOW AREA EQUIVALENT TO THAT OF 1 INCH DIA PIPE)
WALL THICKNESS = $2\frac{1}{2}$ inch
EQUIVALENT TUBE ARRAY CONSISTS OF
$n = 14.6$ (15) TUBES, EACH OF $D = 0.2610$ in

NOTE: L/D FOR EACH TUBE = 9.5

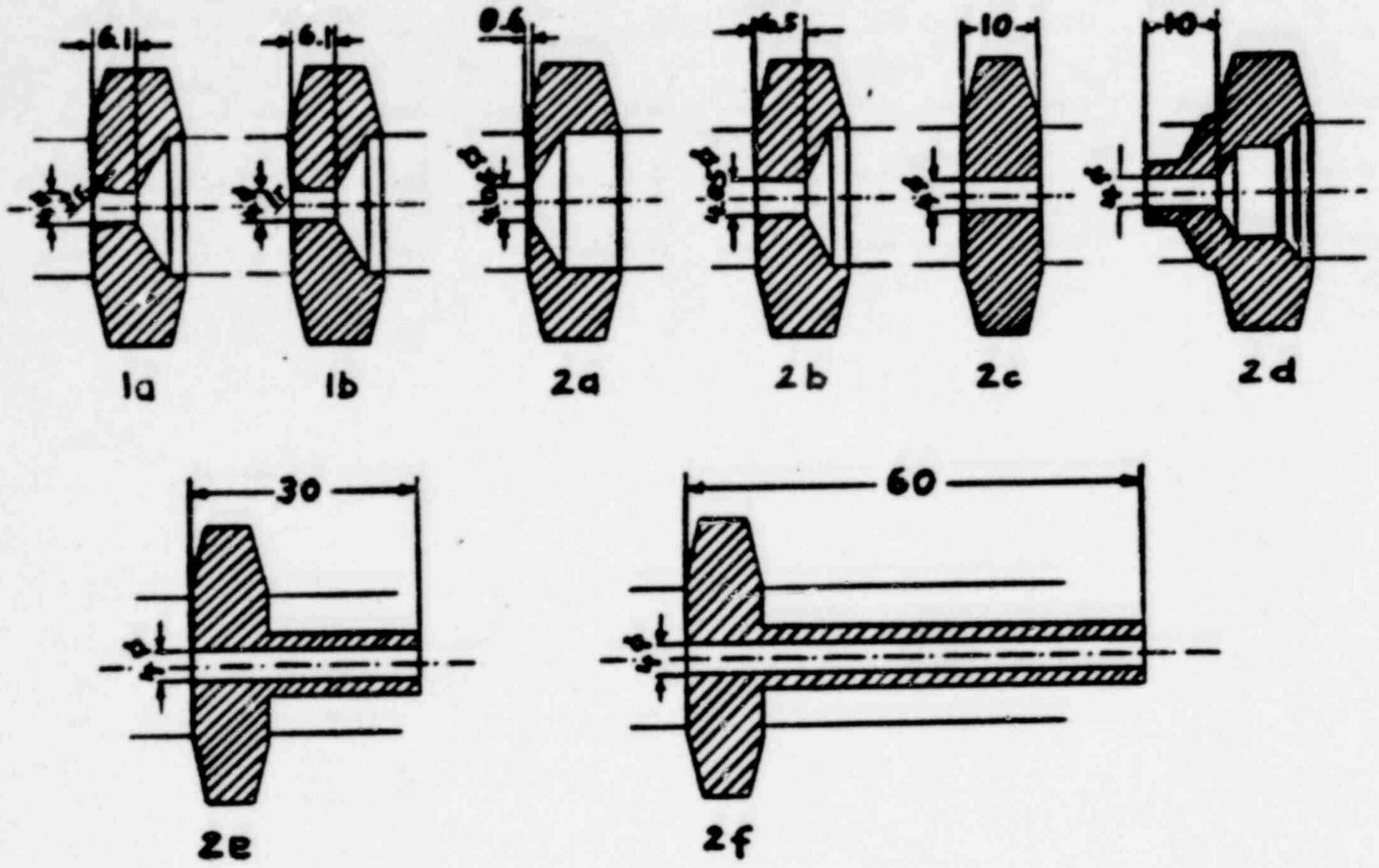
AMPLE TEST DATA BASE EXISTS FOR CRITICAL FLOW THROUGH SMALL TUBES

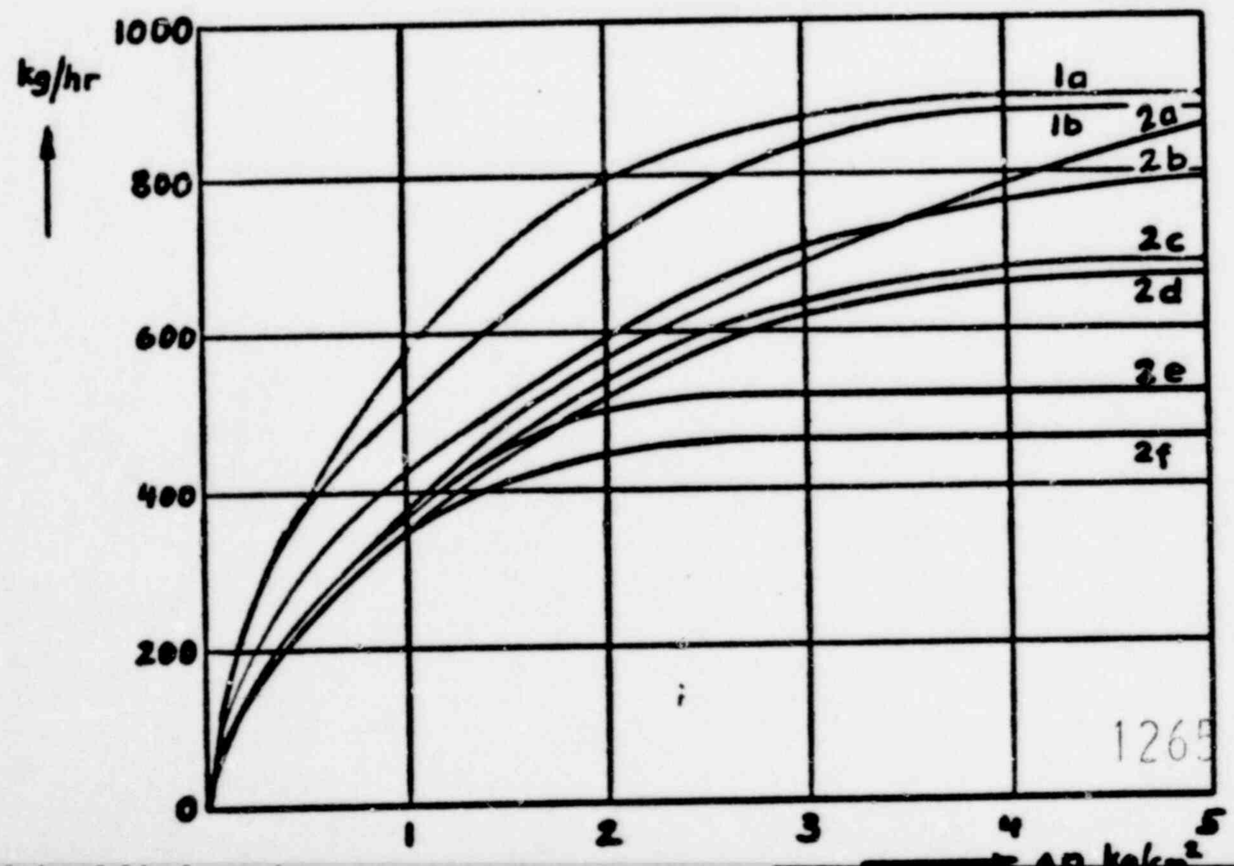
$$\left(G_{CRIT}\right) \approx \left(G_{CRIT}\right)_{TUBE}$$

BLOWDOWN OF SATURATED WATER THROUGH ORIFICES OF DIFFERENT SIZE



EFFECTS OF EXIT GEOMETRY ON BREAK FLOW





1265 030

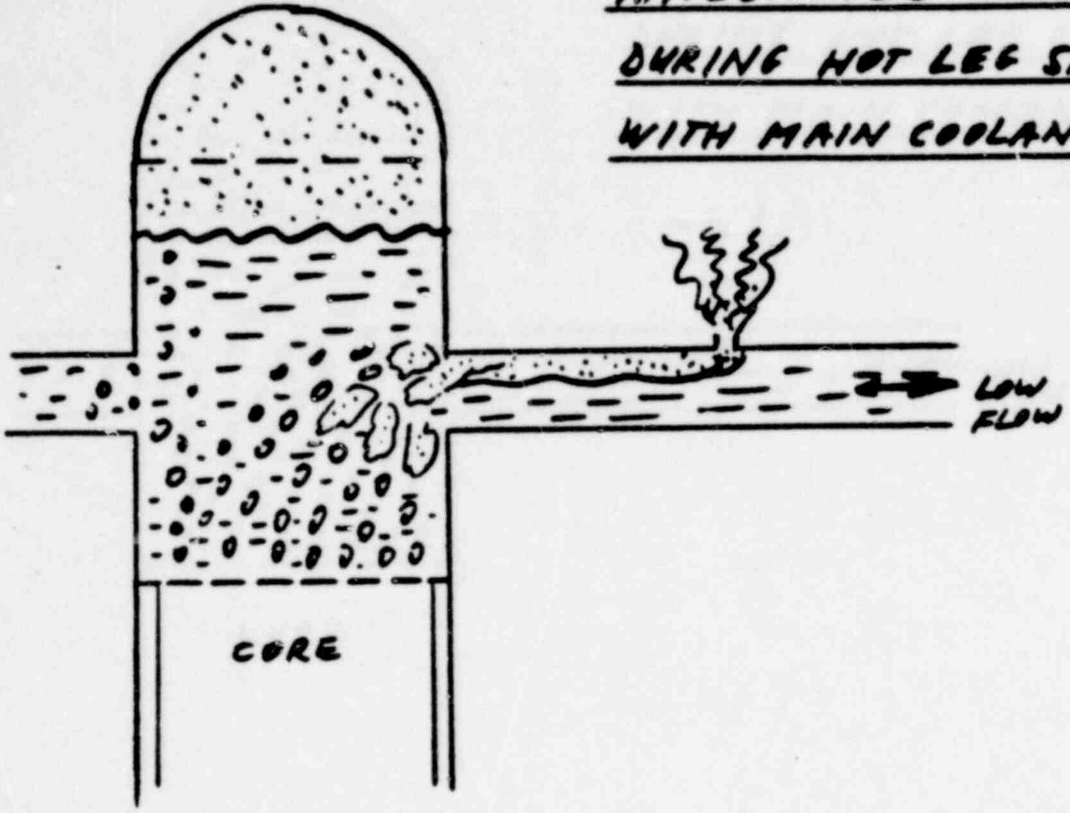
PSA, Sep. 17, 1979

MATRIX FOR ASSESSMENT OF B.E. SYSTEMS CODE

SEPARATE EFFECTS BREAK FLOW

FACILITY	Description	Throat Dia.	Max p [MPa]	Max ΔT [K]	Fluids	# of Tests
MOBY DI	Long pipe followed by diffusor	14 mm	0.7	145	s/w a/w	3 3
SUPER MOBY DICK	As above	20 mm	15	320	s/w	4
BNL nozzle	Convergent-divergent	25.4 mm	0.8	150	s/w	6
IRB nozzle	Long pipe followed by sudden expansion	16 mm	15 1	10 —	s/w a/w	6
MARVIKEN-CFT	"Demonstration" Tests Short and Long Nozzles	200, 300 and 500 mm	5	50	s/w	15

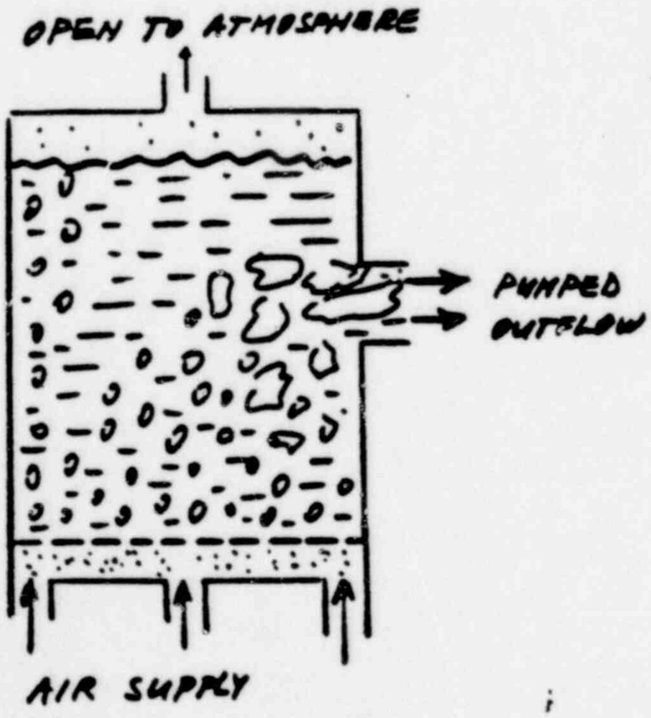
ANTECIPATED PHASE SEPARATION DURING HOT LEG SMALL BREAK WITH MAIN COOLANT PUMPS TRIPPED



CONTEMPLATED TESTS AT RPI

2-D (SLAB), TRANSPARENT UPPER PLENUM, WITH AND WITHOUT INTERNALS

AIR/WATER



UTSG TESTS

FLECHT-SEASET
TASK 3.2.6

SECONDARY-TO-PRIMARY SIDE HEAT TRANSFER
(as occurring during reflood stage of LOCA)

NUMBER OF TUBES = 32

TUBE BUNDLE HEIGHT = 11 m

TUBE O.D., THICKNESS, PITCH, MATERIAL } AS IN FULL SCALE

TEST CONDITIONS:

SECONDARY SIDE

$p = 1.72 - 5.86$ MPa
(250 – 850 psia)

$T = 204 - 274$ °C
(400 – 525 °F)

$H = 100\%, 25\%$

PRIMARY SIDE

$p = 0.138 - 0.414$ MPa
(20 – 60 psia)

$T = 109 - 145$ °C
(228 – 293 °F)

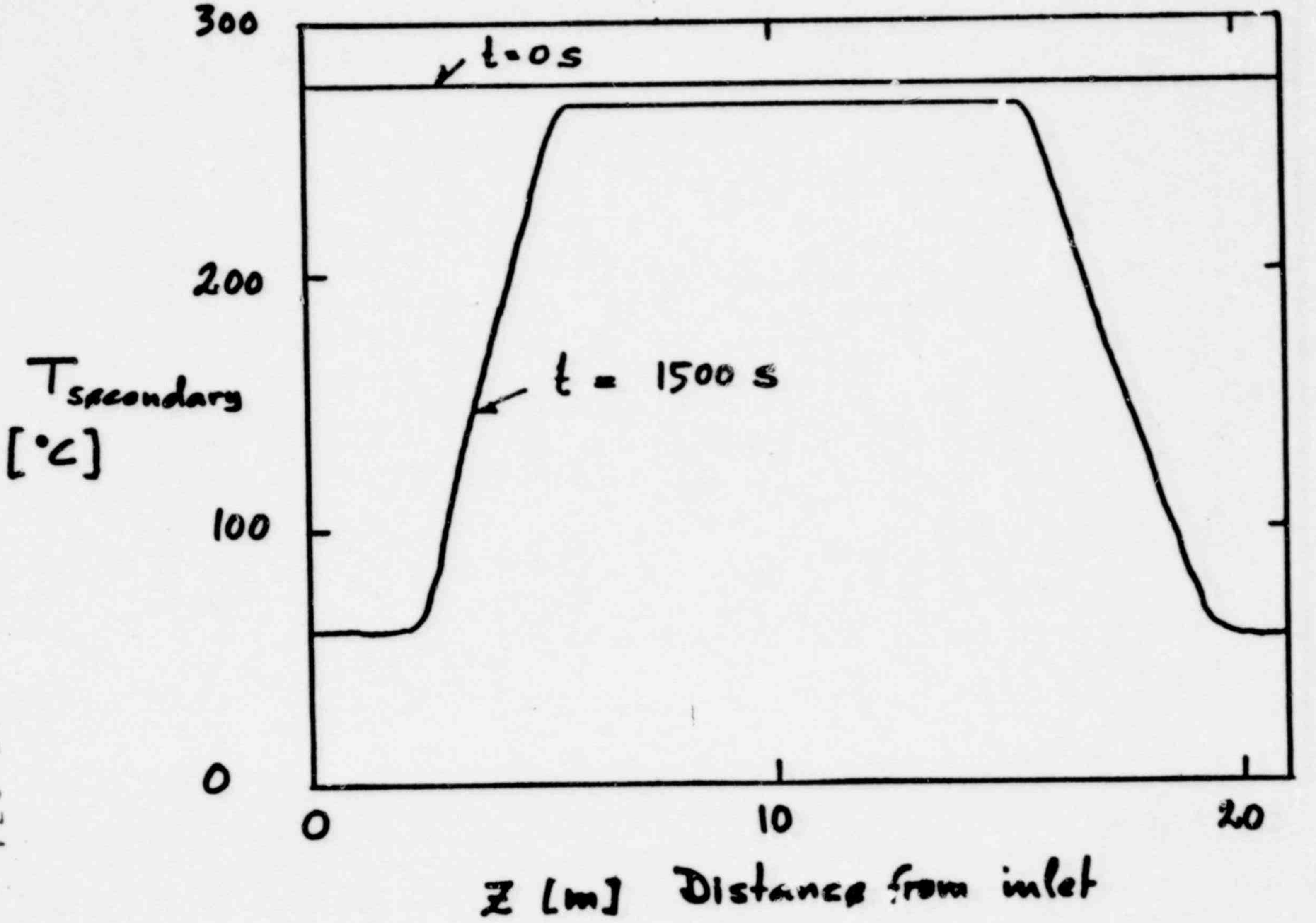
$G = 64.9 - 129.9$ Kg/sec/m²
(13.3 – 26.6 Lb/sec/ft²)

$x_{in} = 0.1 - 1.0$

20 TESTS

FLECHT - SEASET

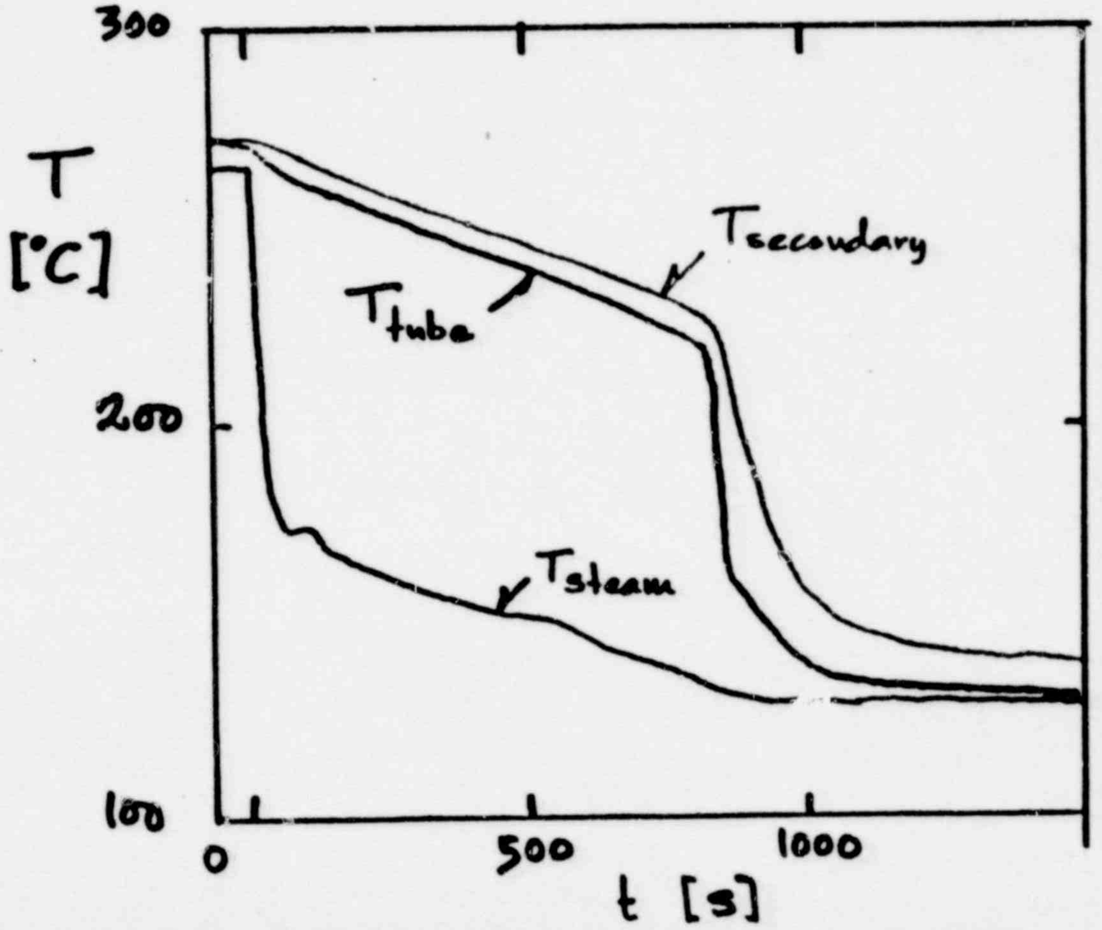
STEAM GENERATOR TEST 22701



FLECHT - SEASET

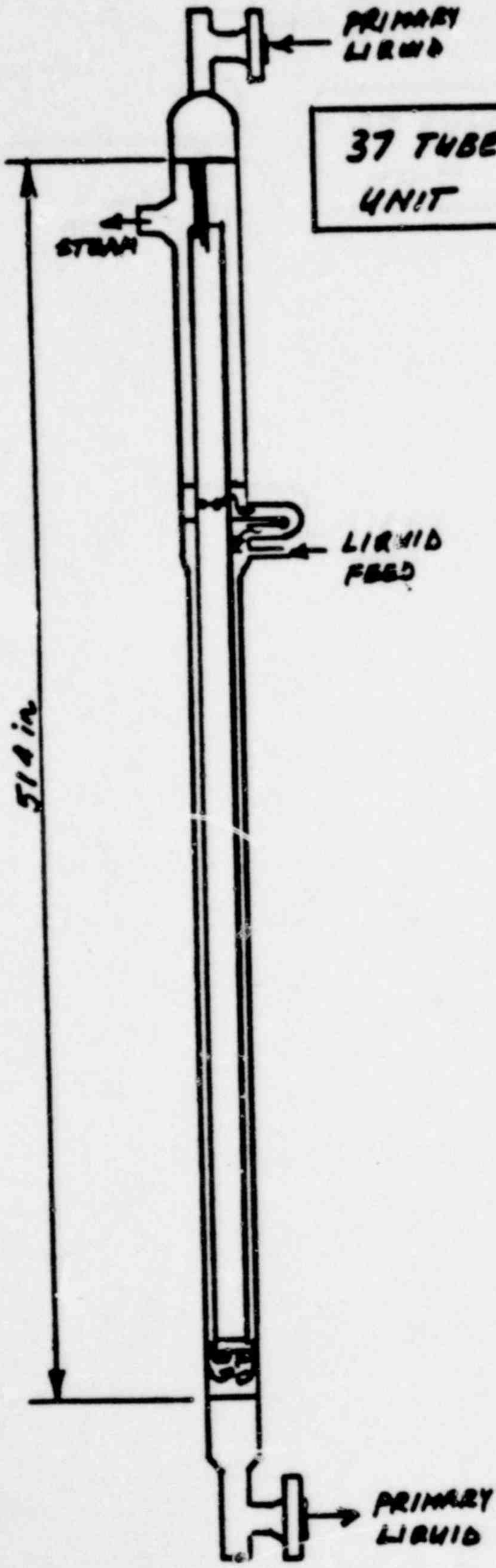
STEAM GENERATOR TEST 22701

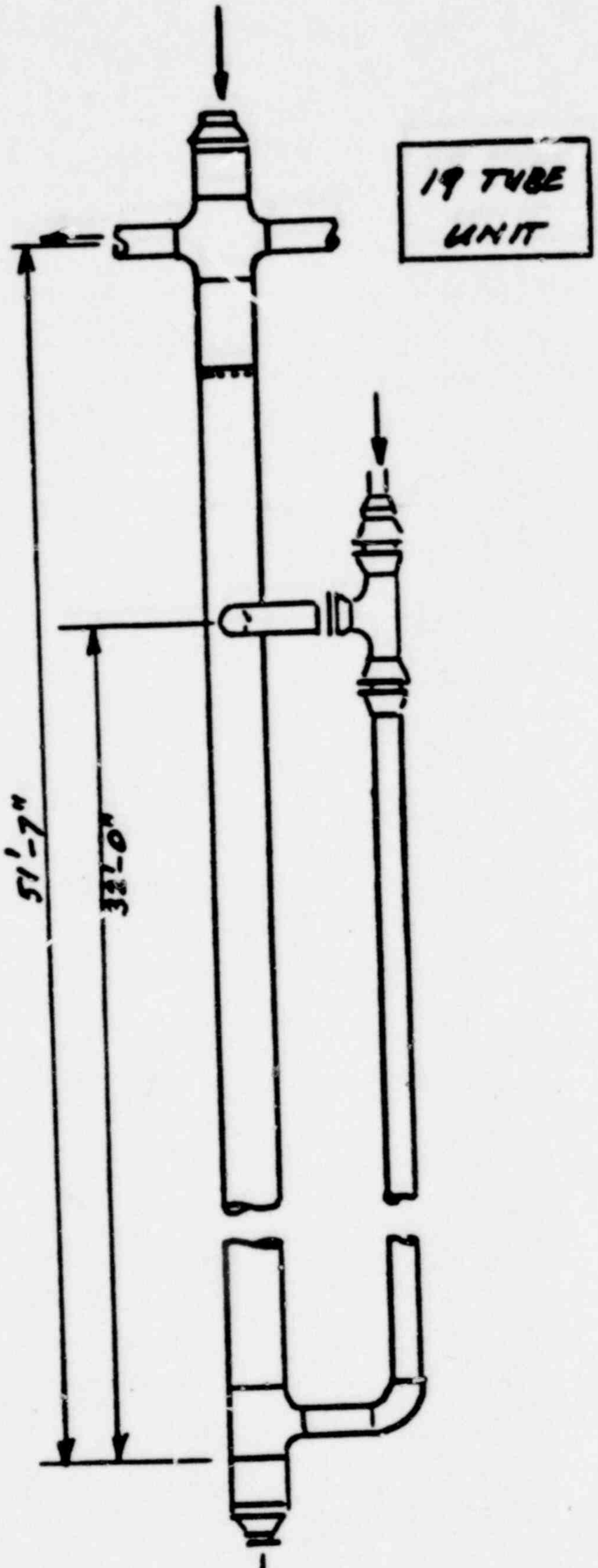
$Z = 1.22$ m



OTSG TESTS

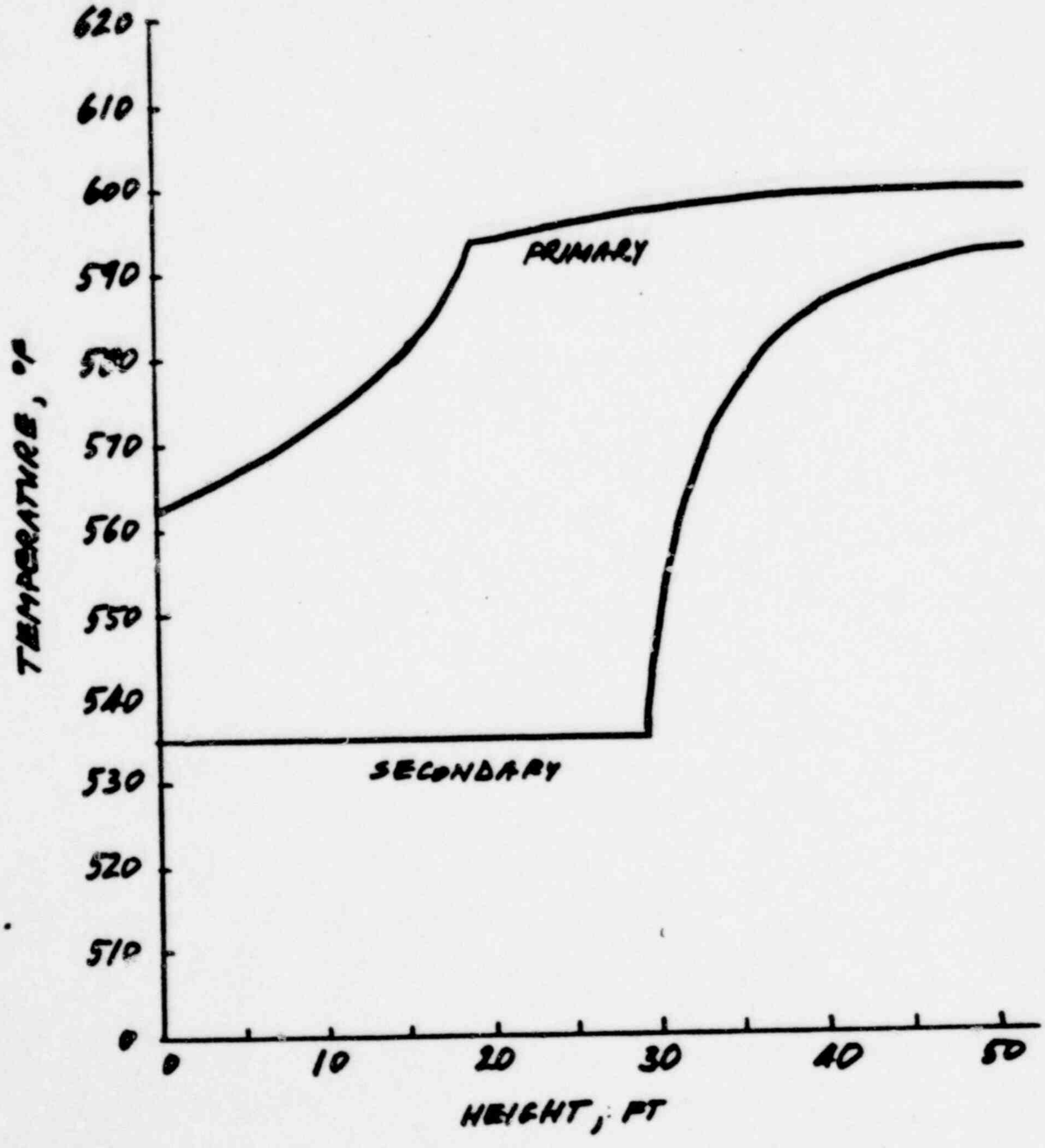
(B&W)





OTSG

MEASURED FLUID TEMPERATURE PROFILES
19-TUBE UNIT, 80% RATED POWER



TRANSIENT TESTS WITH 37-TUBE OTSG

L[illegible]UT TRANSIENT

STEAM PIPE FAILURE

LOSS OF STATION POWER

LOSS OF FEEDWATER FLOW

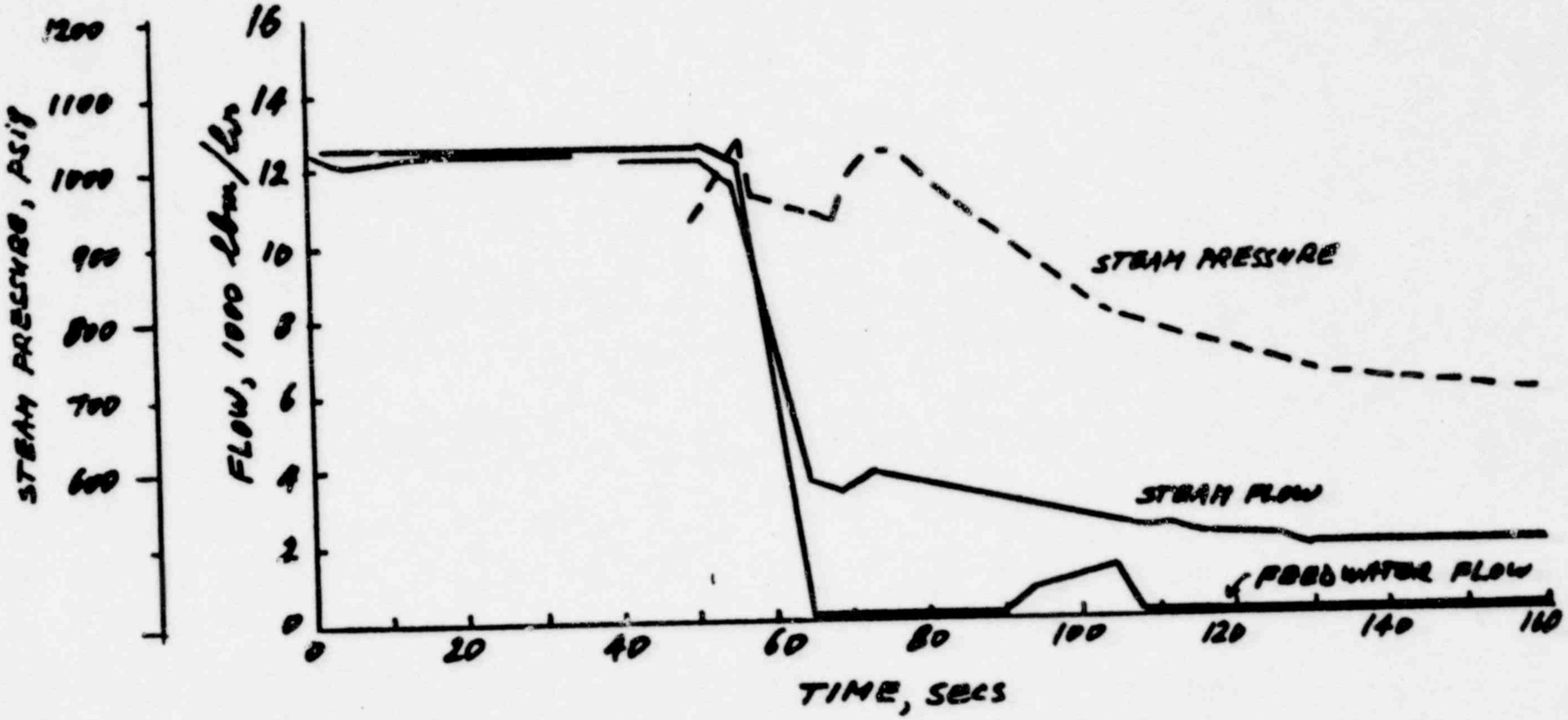
PRIMARY RUPTURE TESTS

$1\frac{3}{4}$" φ ORIFICE

$2\frac{1}{2}$" φ ORIFICE

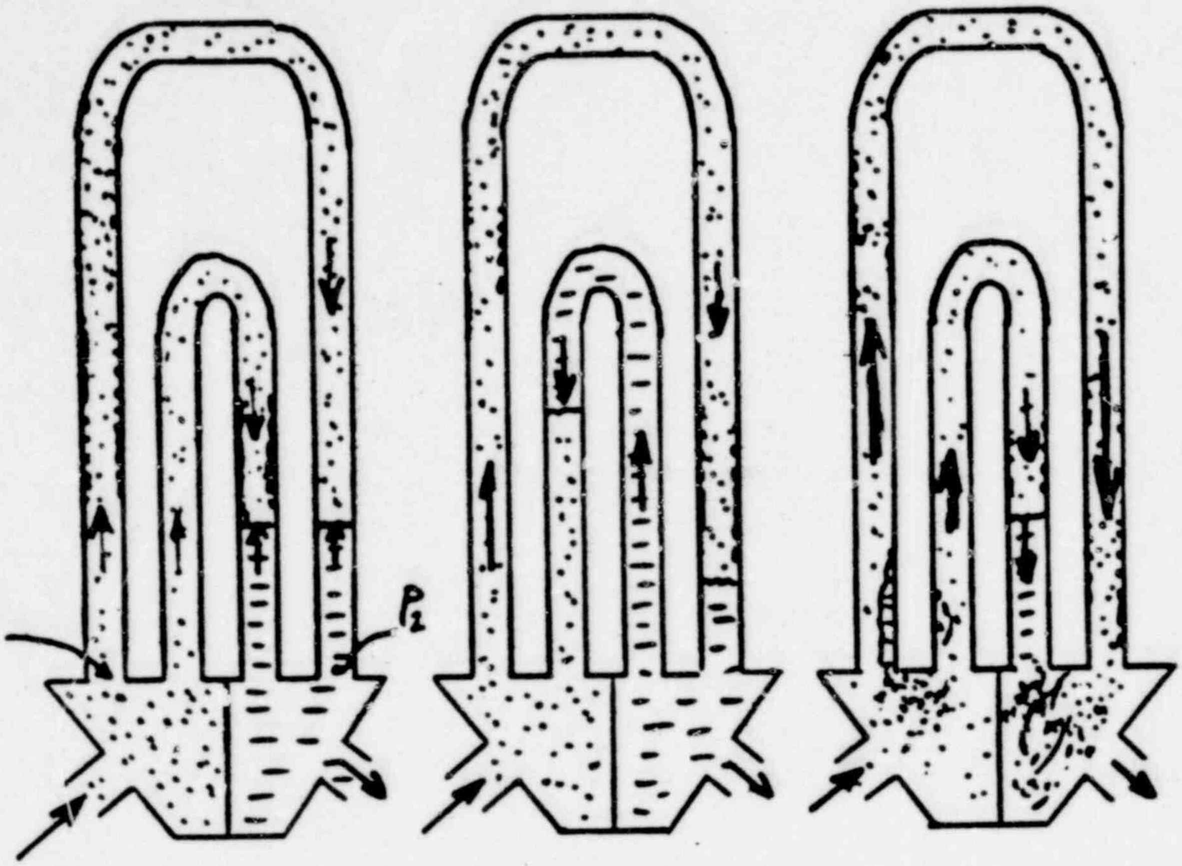
37-TUBE OTSG TEST

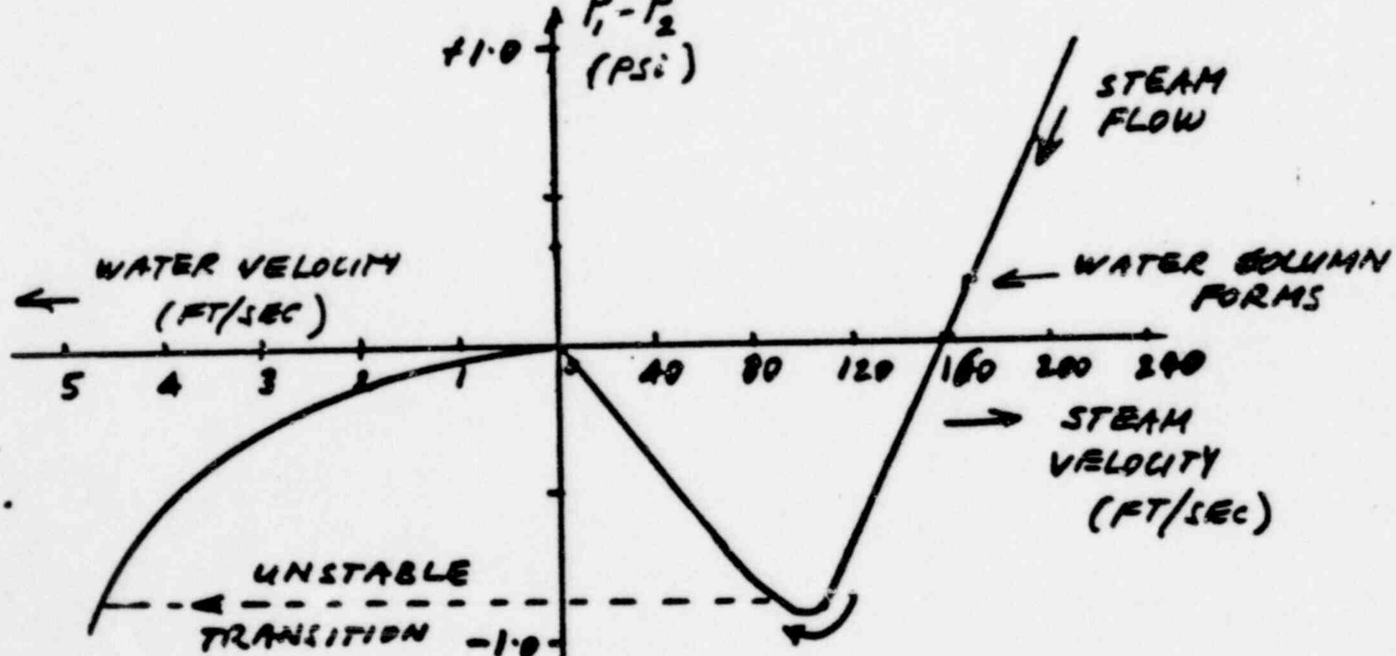
LOSS OF FEEDWATER FLOW



2-ϕ NATURAL CIRCULATION

POSTULATED INSTABILITIES IN UTSG





MATRIX FOR ASSESSMENT OF B.E. SYSTEMS CODE

PWR SEPARATE EFFECTS, STEAM GENERATOR

	FACILITY	TYPE	# of tubes height	# of Tests
	FLECHT-SEASET	UTSG	32 10.4 m	4
	B & W	OTSG	19 13.05m	4
Integral Tests	PKL	UTSG	60 8.43m	2
	CCTF	UTSG	158 20.5 m	4
	Semiscale/MOD3	UTSG	54 6.4 m	2

WESTINGHOUSE ACRS AGENDA - 10/17/79

1. SUMMARY OF SMALL BREAK STUDY (WCAP-9600)

2. SUMMARY OF REACTOR COOLANT PUMP BEHAVIOR (WCAP-9584)

   - RCP MODEL
   - EFFECT OF DELAYED TRIPPING
     - SMALL BREAKS
     - NON-LOCA EVENTS

3. SUMMARY OF PROCEDURAL ASPECTS

   - PHILOSOPHY
   - PROCESS
   - CRITERIA

4. SMALL BREAK MODEL/NATURAL CIRCULATION STUDIES

   - BREAK FLOW MODEL
   - UHI CONSIDERATIONS
   - NODALIZATION/FLUID MODELS/NAT'L CIRC.
   - STEAM GENERATOR HYDRAULIC WORK

5. WORK IN PROGRESS

SUMMARY OF ANALYSES PERFORMED SUBSEQUENT TO

THREE MILE ISLAND, UNIT #2

3/28 - THREE MILE ISLAND, UNIT #2

- TMI RECOVERY SUPPORT AND ANALYSES

4/7 - W CUSTOMERS WITH COINCIDENT SI LOGIC REMINDED TO MANUALLY TRIP SI ON LOW PRESSURIZER PRESSURE INDEPENDENT OF LEVEL

- REANALYSES OF PRESSURIZER VAPOR SPACE BREAKS
  - OPERATOR ACTION TIME > 30 MINUTES
  - NO CORE UNCOVERY WITH MINIMUM SAFEGUARDS
  - SENSITIVITY TO AFW
  - PRESSURIZER LEVEL WILL INCREASE IF ONE OR MORE PORV'S ARE OPEN

4/10 - W LETTER TO CUSTOMERS/MANUAL SI

4/11 - W/NRC MEETING ON SMALL BREAK

4/11 - IE BULLETIN 79-06/MANUAL SI

4/14 - IE BULLETIN 79-06A/NEW SI LOGIC/RCP OPERATION

- ANALYSES INDICATE A NEED FOR FURTHER STUDY OF DELAYED RCP TRIP DURING SMALL LOCA
- MANUAL TRIP OF ALL RCP's AT 1250 PSIA RECOMMENDED
- ANALYSIS OF TMI SCENARIO ON W NSSS

4/23 & 4/26 - NRC/W SMALL BREAK MEETINGS

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- ANALYSIS OF TMI SCENARIO ON W NSSS/PORV FUNCTIONS AS DESIGNED
- EVALUATION OF NON CONDENSIBLES

5/7 - NRC BULLETINS AND ORDERS/LESSONS LEARNED TASK FORCES FORMED

5/9 - NRC REQUEST FOR ADDITIONAL INFORMATION ON SMALL BREAK

5/10 - ACRS/W MEETING ON SMALL BREAK/NATURAL CIRCULATION

5/16 - RESPONSE TO NRC REQUEST FOR ADDITIONAL INFORMATION ON SMALL BREAK

5/23 & 5/30 - W/CUSTOMER SEMINARS

5/30 - WESTINGHOUSE OWNER'S GROUP, WOG, FORMED

SEQUENCE OF EVENTS

5/31 WOG, NRC, W

- Clarify NRC SB Needs
- Required Information

6/04 NRC LETTER REQUESTING ADDITIONAL INFO

- Methods
- Analysis
- Procedures

6/11 WOG$^{(ATT)}$, NRC, W

- Resolve Methods Concerns
- Conclusions
  - Proceed with Analysis Aspects
  - Additional Methods Info to be in Final Report

6/29 REPORT SUBMITTED TO NRC -- WCAP-9600

- 11.4 EMM
  3.5 TMM
  > 60 hrs. CDC-7600

OVERVIEW OF WCAP-9600

- METHODS
  - Pressurizer Noding and Surge Line
  - Steam Generator Noding
  - Non-Condensible Sources
  - Mixture Level Model
  - Break Flow Model
  - Two-Phase Natural Circulation

- GENERAL BEHAVIOR
  - Transient Characteristics/Long Term Stable Conditions
  - Pressurizer Vapor Space Breaks
  - HPI Termination

1265 046

- SPECIFIC SCENARIO ANALYSES
  - RCP's Tripped
  - Operator Action Time
    - Loss of FW w/o SB
    - Loss of FW w SB
  - Isolated Steam Generator
  - Isolating Break
  - Challeges to PORV

- NATURAL CIRCULATION
  - 15 Concerns of Michelson
  - Modes of Energy Removal

- GUIDELINES FOR REF. EMERGENCY OPERATING INSTRUCTIONS

1265 047

SUMMARY AND CONCLUSIONS

- REPORT CONTINUES TO SUPPORT THE SAFETY OF THE WESTINGHOUSE NSSS DESIGN
- MODELS AND METHODS USED TO EVALUATE THE SAFETY OF THE DESIGN ARE CONSERVATIVE BUT ACCEPTABLY REALISTIC
- COMPREHENSIVE REVIEW OF SB TRANSIENTS WITH SUPPORTING ANALYSES HAS BEEN PROVIDED
- PRELIMINARY ASSESSMENT OF SB ANALYSIS UNCERTAINTIES (+150°F)
- WESTINGHOUSE RECOMMENDED HPI TERMINATION CRITERIA AGREES CLOSELY WITH NRC CRITERIA
- PORV OPENING (1-3), NO CORE UNCOVERY

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SUMMARY AND CONCLUSIONS (CONT.)

- COMPLETE LOSS OF FW (INCLUDING AUX FW)
  - Continuous Operating of PORV'S
  - With Cold Leg SB Limiting Case

- Operator Actions Considered
  - Aux FW Initiation 60 Min Later - No Core Uncovery
  - PORV Manual Open 40 Min Later - No Core Damage

- 1 STEAM GENERATOR SUFFICIENT TO REMOVE DECAY HEAT

- NEW PROPOSED WESTINGHOUSE RCP TRIP CRITERIA RESULTS IN LOWER PCT THAN DESIGN ANALYSES IN SAR'S

1265 049

SUMMARY AND CONCLUSIONS (CONT.)

- MICHELSON'S CONCERNS REGARDING NATURAL CIRCULATION (MODES OF TRANSITION) ADDRESSED AND NO SERIOUS CONCERN FOR CORE COOLING RESULTS IN A WESTINGHOUSE PWR

- REVISED REFERENCE EMERGENCY OPERATING INSTRUCTIONS

OTHER ACTIVITY RELATIVE TO SMALL BREAK ANALYSIS

1. STUDY OF DELAYED RCP TRIPPING FOLLOWING A SMALL LOCA, WCAP-9584, 9/1/79
    - EXTENSION OF WCAP-9600
    - IE BULLETIN 79-06C, 7/29/79
2. ADVANCED ANALYTICAL STUDY OF TWO PHASE NATURAL CIRCULATION MODES INCLUDING TRANSITION BETWEEN MODES, WCAP 9586, 9/1/79
3. ADVANCED ANALYTICAL STUDY OF STEAM GENERATOR FLOW INSTABILITY DURING TRANSITION BETWEEN MODES OF TWO PHASE NATURAL CIRCULATION, 12/1/79
4. UHI CONSIDERATIONS
5. PRE-TEST PREDICTION OF SEMISCALE MOD-3 SMALL BREAK EXPERIMENT, 10/15/79
6. WORK IN PROGRESS

ANALYSIS OF INADEQUATE CORE COOLING, 10/31/79

PRE-TEST PREDICTION OF LOFT SMALL BREAK EXPERIMENT, 11/15/79

BETTER ESTIMATE ANALYSES FOR OPERATOR TRAINING

ANALYSES OF CHAPTER 15 TRANSIENTS AND ACCIDENTS, 12/31/79

30

ANALYSIS OF DELAYED REACTOR COOLANT PUMP TRIP DURING SMALL LOCAS FOR WESTINGHOUSE NSSS

WCAP-9584

SUBMITTED TO NRC ON 8/30/79

IN RESPONSE TO NRC BULLETIN 79-06C

1. ANALYTICAL METHODS ASPECTS OF MODELLING SMALL BREAKS WITH RCPS RUNNING.
2. ANALYSIS RESULTS AND EVALUATION OF SYSTEM BEHAVIOR ASSUMING RCP OPERATION FOR VARIOUS LENGTHS OF TIME.
3. DETERMINATION OF CRITICAL RCP TRIP TIME ASSURING PCTS WITHIN APPENDIX K LIMITS CONSIDERING SMALL BREAK SPECTRUM.
4. SUMMARY AND CONCLUSIONS.

1265 052

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ANALYTICAL METHODS ASPECTS OF MODELLING SMALL BREAKS WITH RCPS RUNNING

A. VERIFICATION OF WFLASH RCP MODEL FOR TWO PHASE AND ALL STEAM INLET CONDITIONS.

- CALCULATIONS INDICATE WFLASH PREDICTS EXPECTED DEGRADATION OF PUMP PERFORMANCE IN TWO PHASE REGION AND PERFORMANCE RECOVERY IN SINGLE PHASE.
- GOOD COMPARISON BETWEEN WFLASH RCP PERFORMANCE AND EVA 1/3 SCALE PUMP TEST RESULTS.

B. DETERMINATION OF APPROPRIATE CONTROL VOLUME STEAM-WATER MIXING ASSUMPTION DURING RCP OPERATION (HOMOGENEOUS VS HETEROGENEOUS).

- BREAK LOCATION CONTROL VOLUME
    1. EVA TEST RESULTS JUSTIFY HETEROGENEOUS ASSUMPTION
    2. COMPARATIVE WFLASH ANALYSIS INDICATES HETEROGENEOUS ASSUMPTION YIELDS CONSERVATIVE RESULTS.
- CORE CONTROL VOLUME AND DOWNCOMER CONTROL VOLUME
    1. COMPARATIVE WFLASH ANALYSIS INDICATES HETEROGENEOUS ASSUMPTION YIELDS CONSERVATIVE RESULTS

ANALYSIS RESULTS AND EVALUATION OF SYSTEM BEHAVIOR ASSUMING RCP OPERATION FOR VARIOUS LENGTHS OF TIME

A. RCPS TRIP PRIOR TO TIME OF RCS DRAIN TO BREAK ELEVATION FOR FSAR CASE

1. RCS MINIMUM PRIMARY LIQUID MASS APPROXIMATELY THE SAME AS FSAR CASE.
2. PCTS APPROXIMATELY EQUAL TO OR LOWER THAN FSAR CASE.

B. RCPS TRIP AFTER THE TIME OF RCS DRAIN TO BREAK ELEVATION FOR FSAR CASE

1. PROLONGED PERIOD OF LIQUID BREAK DISCHARGE RESULTS IN REDUCED RCS MINIMUM PRIMARY LIQUID MASS:
    A. DEEPER CORE UNCOVERY (HIGHER CLAD HEATUP RATES)
    B. REDUCED TOTAL TIME OF CORE UNCOVERY
2. TWO CHARACTERISTICS HAVE OPPOSING EFFECTS ON PCT - MAXIMUM FUNCTION OF PCT VS RCP TRIP TIME RESULTS.
3. MAXIMUM PCT MAY BE GREATER THAN FSAR CASE AND 2200°F DEPENDING ON BREAK SIZE ASSUMED.

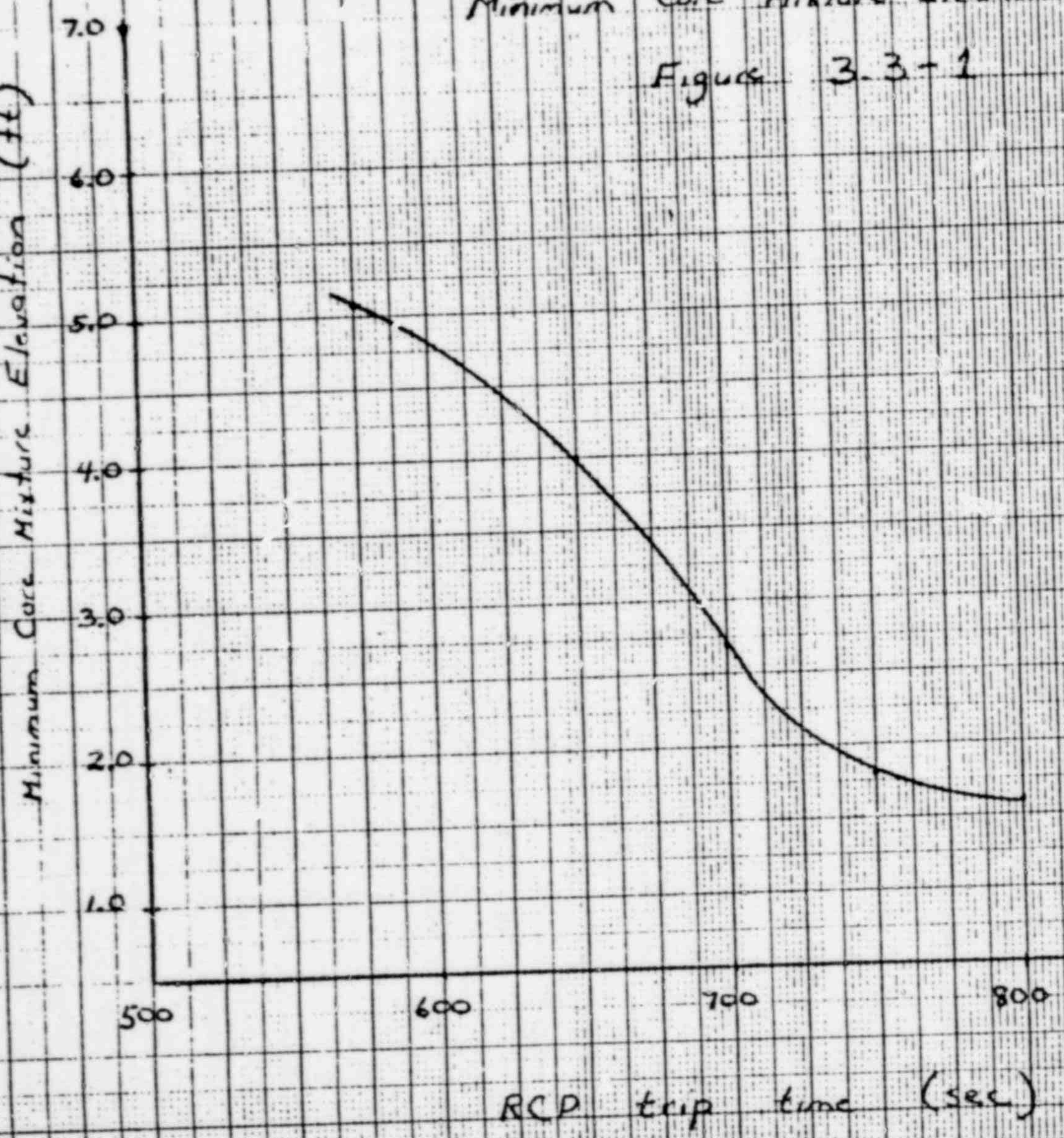
C. RCPS OPERATE THROUGHOUT ENTIRE TRANSIENT

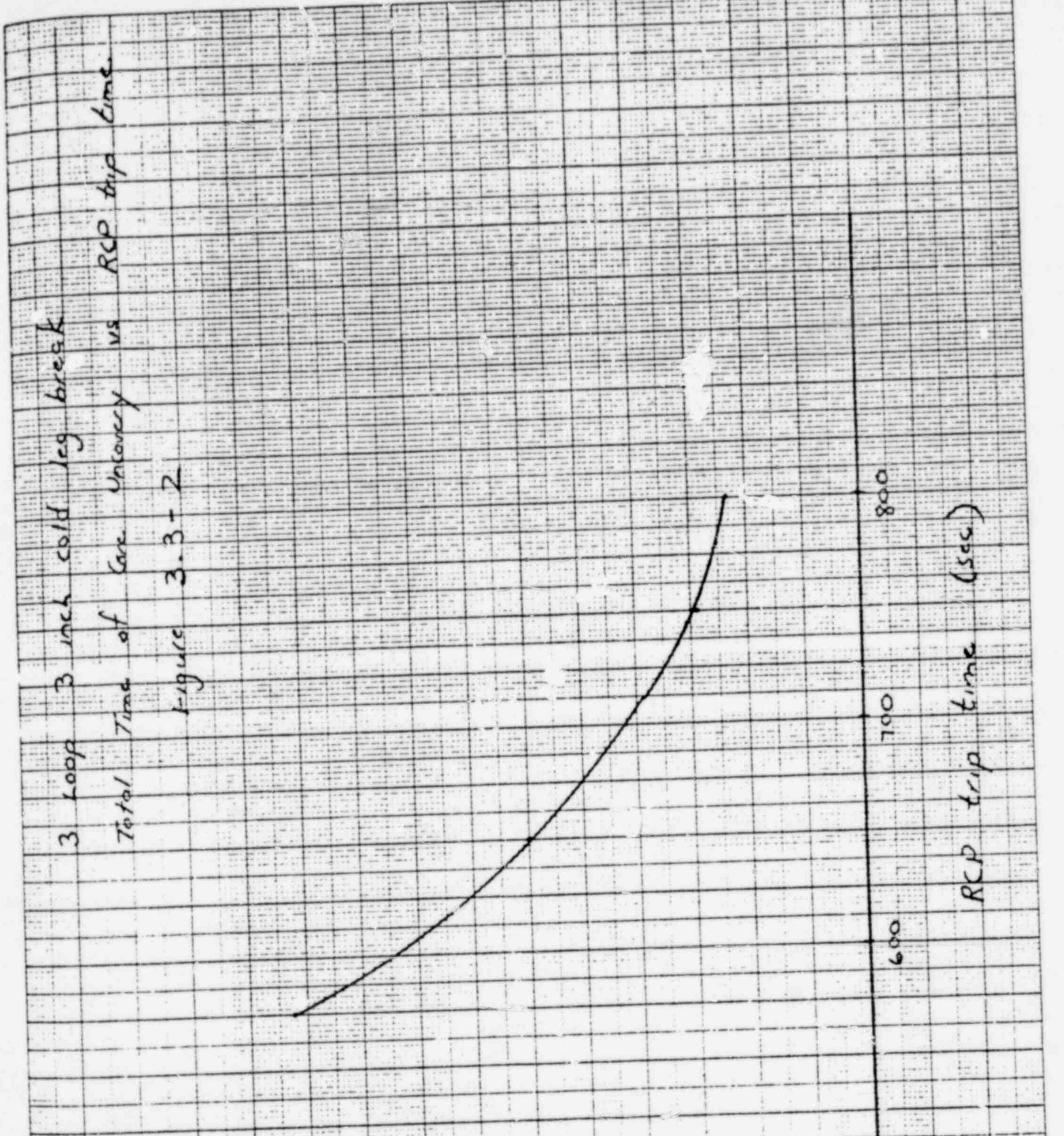
1. LIQUID MASS BREAK DISCHARGE PERIOD IS MAXIMIZED
2. PCTS REMAIN WELL BELOW FSAR CASE DUE TO ENHANCED STEAM COOLING.

3 Loop 3 inch cold leg break

Minimum Core Mixture Elevation vs RCP Trip Time

Figure 3.3-1





3 Loop 3 inch cold leg break

Total Time of Core Uncovery vs RCP trip time

Figure 3.3-2

EFFECT OF BREAK SIZE AND LOCATION ON
PCT PENALTY AND RCP TRIP TIME INTERVAL OF WORSE PCTS

1. BREAK SIZE AFFECTS MAGNITUDE OF WORST PCT PENALTY

   LARGER BREAK → REDUCED PCT PENALTY

   SMALLER BREAK → INCREASED PCT PENALTY

   VERY SMALL BREAK (< ∿ 1.0 DIAMETER) → NO PCT PENALTY
   (RCS DOES NOT DRAIN)

2. BREAK SIZE AFFECTS LENGTH OF RCP TRIP TIME INTERVAL OF WORST PCT RESULTS.

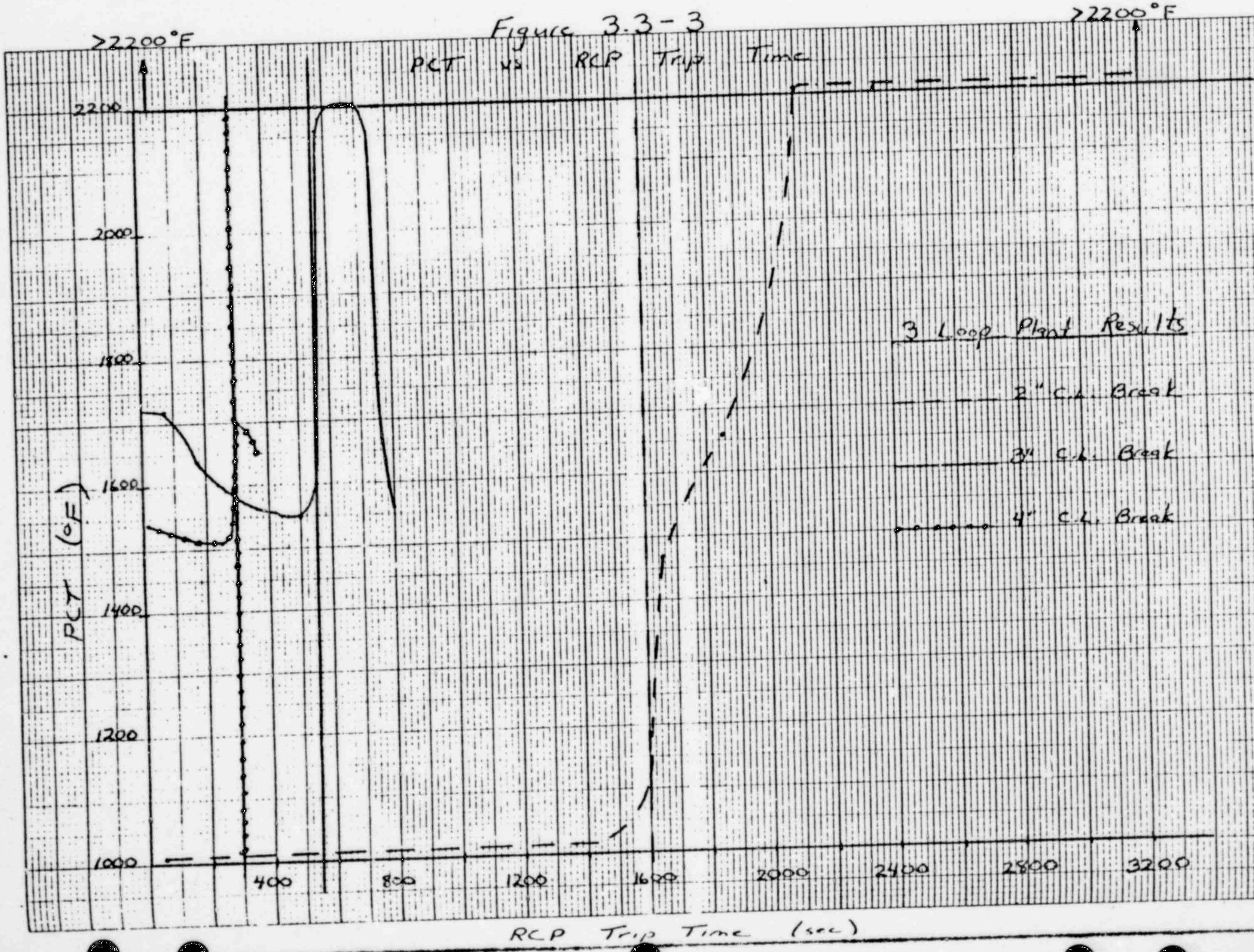
   LARGER BREAK → INTERVAL DECREASES OR VANISHES

   SMALLER BREAK → INTERVAL INCREASES

3. VERIFIED BY ANALYSIS THAT HOT LEG BREAK IS LESS LIMITING THAN COLD LEG BREAK.

Figure 3.3-3

PCT vs RCP Trip Time



POOR ORIGINAL

DETERMINATION OF CRITICAL RCP TRIP TIME ASSURING PCTS WITHIN APPENDIX K LIMITS CONSIDERING SMALL BREAK SPECTRUM

3 LOOP PLANT

1. LARGEST BREAK SIZE YIELDING PCTS GREATER THAN 2200°F APPROXIMATELY 3 INCH DIAMETER C.L.

2. RCS DRAINS TO BREAK ELEVATION AT APPROXIMATELY 10 MINUTES AFTER ACCIDENT INITIATION FOR 3 INCH C. L. BREAK.

∴ CRITICAL RCP TRIP TIME = 10 MINUTES

IF RCPS TRIP PRIOR TO 10 MINUTES, PCT < 2200°F REGARDLESS OF BREAK SIZE.

1265 059

2 LOOP AND 4 LOOP PLANTS

PCT IS A FUNCTION OF:

1. TIME OF FIRST UNCOVERY
2. DEPTH OF CORE UNCOVERY → DECAY HEAT, SI
3. TIME OF CORE RECOVERY (ACCUMULATOR INJECTION)

∴ TIME OF FIRST CORE UNCOVERY AND ACCUMULATOR INJECTION ARE MAJOR INFLUENCES ON WORST BREAK SIZE AND PCT.

THE TIMING OF THESE EVENTS A FUNCTION OF TOTAL RCS VOLUME AND BREAK SIZE.

RELATIONSHIP BETWEEN PLANT TYPES DETERMINED BY CONCEPT OF EQUIVALENT BREAK SIZE.

$$\left(\frac{\text{PLANT VOLUME}}{\text{BREAK DIAMETER}^2}\right)_1 = \left(\frac{\text{PLANT VOLUME}}{\text{BREAK DIAMETER}^2}\right)_2$$

3 INCH BREAK, 3 LOOP PLANT

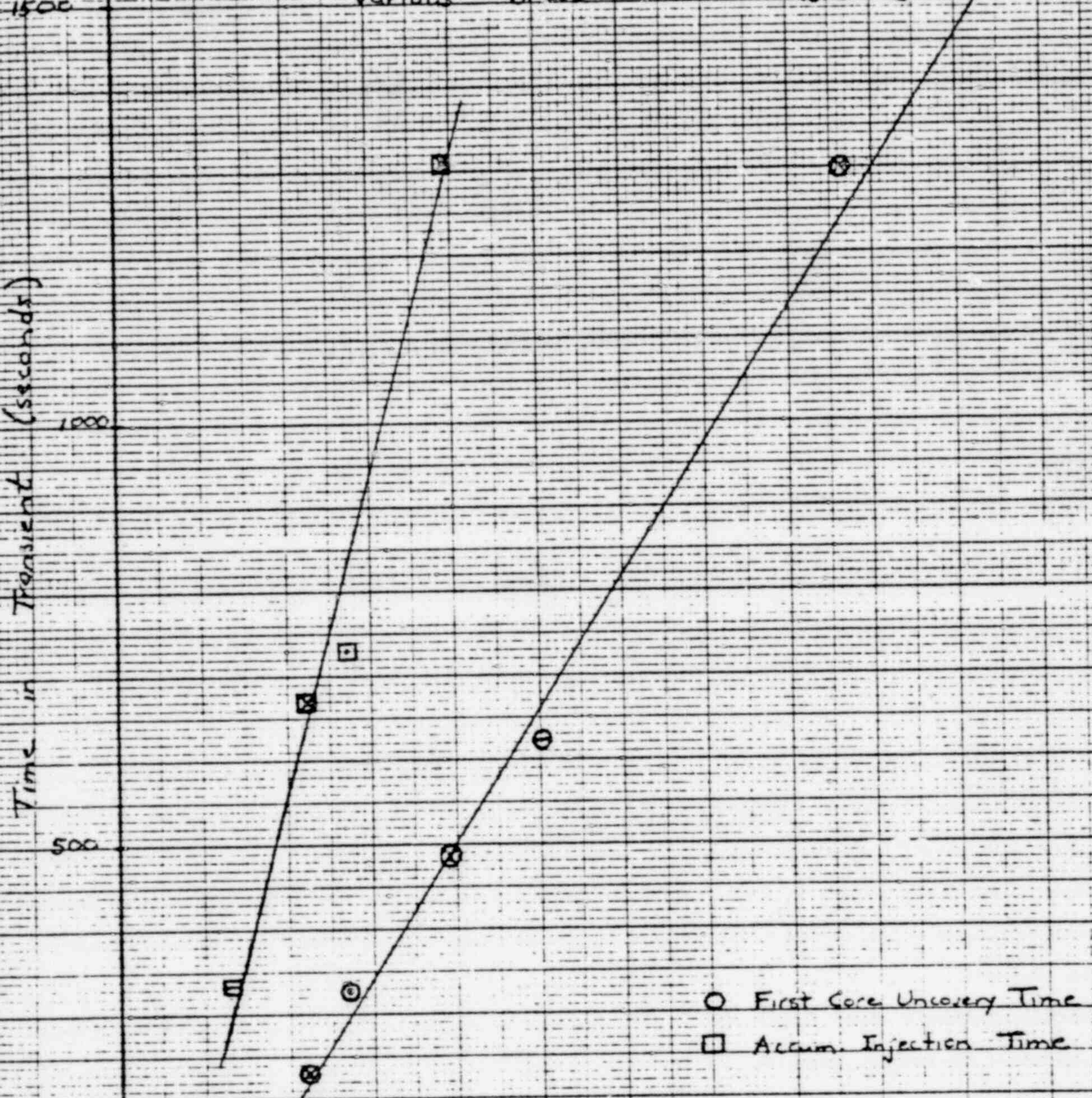
= ∿ 3.5 INCH BREAK, 4 LOOP PLANT

= ∿ 2.5 INCH BREAK, 2 LOOP PLANT

CRITICAL TIME OF RCP TRIP FOR THESE BREAKS IS ALSO APPROXIMATELY 10 MINUTES.

Figure 3.3-4

Time of 1st Core Uncovery and Accumulator Injection Time for 2-, 3-, 4- Loop Plants Various Break Sizes Considered



POOR ORIGINAL

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4.0 CONCLUSIONS

1. An evaluation of the present small break analytical methods applicability to analyses with the RCPs running for some period in the transient was performed. It was concluded that the existing modeling methods were appropriate for the study.

2. Additional verification of the capability of the WFLASH RCP model to calculate reasonable values of pump flow and pressure under high void fraction conditions was shown using applicable experimental data.

3. If the RCPs can be operational throughout the entire small break transient, significant benefits in PCT occurs due to enhanced steam cooling.

4. If the RCPs are tripped in conformance with the Westinghouse Emergency Operating Procedures Guidelines, the thermal-hydraulic system behavior and calculated PCT will be almost identical to the FSAR calculation assuming RCP trip at reactor trip time.

5. For any given break size, tripping the RCPs after the time in the FSAR calculation when break flow becomes all steam tends to prolong liquid break discharge which depletes more liquid mass out of the primary system resulting in two main effects, 1) deeper core uncovery, and 2) reduced total time of uncovery. These two characteristics have opposing effects on PCT giving rise to a maximum function and a worst time interval of RCP trip. PCTs become worse for RCP trip during this interval than FSAR type calculation PCTs and sometimes greater than 2200°F.

6. As small break size increases, the maximum PCT penalty resulting from delaying the RCP trip decreases or vanishes. As small break size decreases, the maximum PCT penalty increases.

7. When considering the spectrum of possible small break sizes, there exists a critical time such that, if RCPs are tripped no later than that time, PCTs will remain below 2200oF for that Plant type regardless of break size assumed to occur.

8. The critical RCP trip time has been determined to be approximately 10 minutes for all Westinghouse Plant types, including 2-, 3-, and 4-Loop designs. This was determined through extensive analysis performed for the 3-Loop Plant including many conservative analysis assumptions. The concept of an equivalent break size was utilized to conclude the 10 minute critical time for 2-Loop and 4-Loop Plants.

1265 063

EFFECTS OF TRIPPING RCP'S FOR NON-LOCA EVENTS

- BASES FOR TRIPPING THE PUMPS
- EVENTS AFFECTED
- HOW THE EVENTS ARE AFFECTED

BASES FOR TRIPPING RCP'S

- VERIFY HPI OPERATION

AND

- RCS PRESSURE BELOW 1250 PSI + INSTRUMENT UNCERTAINTY AND DECREASING

NON-LOCA EVENTS

EVENT	DEPRESSURIZATION BASIS SAR	 BETTER ESTIMATE
REACTOR TRIP (RT)	YES	YES
REACTIVITY EXCURSIONS		
1. ROD WITHDRAWAL FROM SUBCRITICAL	NO	NO
2. ROD WITHDRAWAL AT POWER	NO	NO
3. BORON DILUTION	NO	NO
4. SINGLE ROD WITHDRAWAL	NO	NO
5. ROD EJECTION	NO	NO
6. START-UP OF INACTIVE LOOP	NO	NO
7. ROD DROP	YES	YES

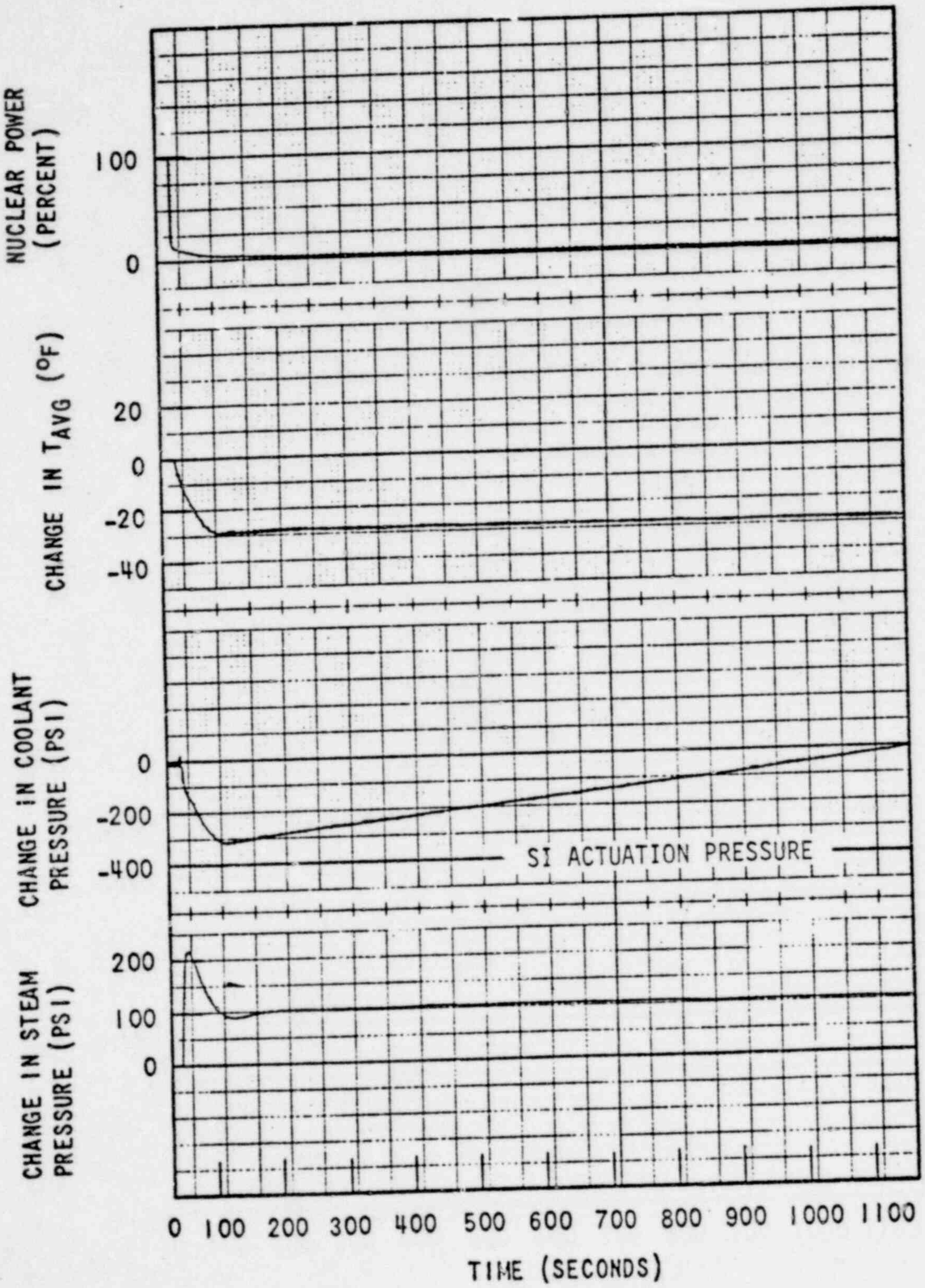
PRIMARY/SECONDARY SIDE MISMATCH

	DEPRESSURIZATION BASIS	
	SAR	BETTER ESTIMATE
1. LOAD REJECTION	NO	NO
2. LOSS OF PRIMARY FLOW	NO	NO
3. LOSS-OF-OFFSITE POWER	NO	YES
4. LOSS-OF-NORMAL FEEDWATER	NO	NO
5. EXCESSIVE FEEDWATER	YES	YES
6. EXCESSIVE LOAD INCREASE	YES	YES
7. FEEDLINE RUPTURE	NO	YES
8. STEAMLINE RUPTURE	YES	YES

SEVERITY OF DEPRESSURIZATION EVENTS

EVENT	CONSEQUENCE
REACTOR TRIP (RT)	DOES NOT RESULT IN SI
ROD DROP	SIMILAR TO RT
LOSS-OF-OFFSITE POWER	SIMILAR TO RT
EXCESSIVE FEEDWATER	BOUNDED BY STEAMLINE RUPTURE
EXCESSIVE LOAD INCREASE	DOES NOT RESULT IN SI
FEEDLINE RUPTURE	PRESSURE STAYS ABOVE 1700 PSI
STEAMLINE RUPTURE	MINIMUM PRESSURE DEPENDS ON 1) BREAK SIZE 2) CAPACITY OF SI PUMPS 3 OPERATOR ACTION TO ISOLATE BREAK

REACTOR TRIP



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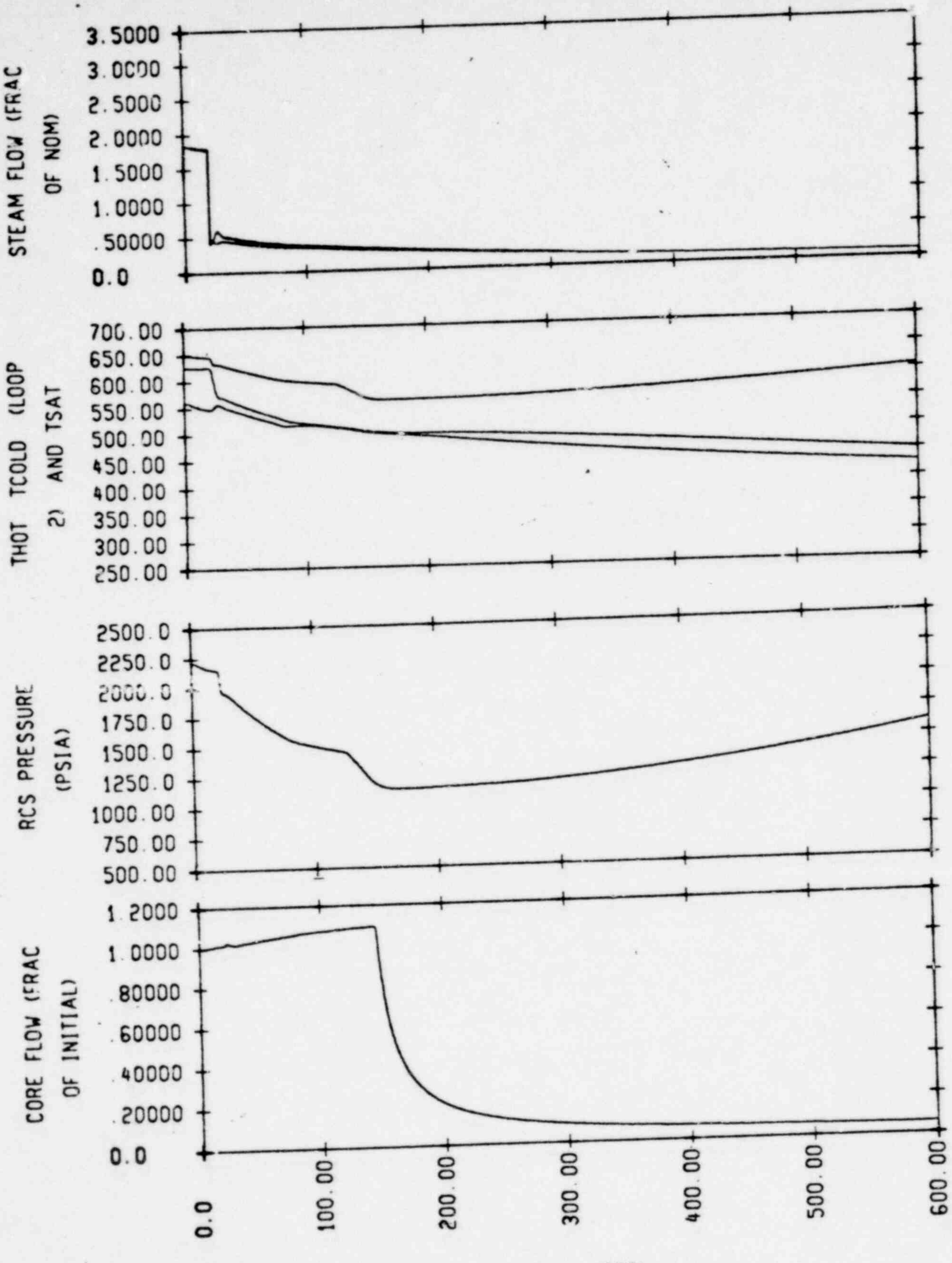
STEAMLINE RUPTURE

- UNCONTROLLED RELEASE OF STEAM FROM SECONDARY SIDE
- PRIMARY SIDE COOLS DOWN AND DEPRESSURIZES
- COOLDOWN AND DEPRESSURIZATION CONTINUES UNTIL BREAK IS ISOLATED, IF POSSIBLE
- ROLE OF RCP'S IS TO COUPLE SECONDARY SIDE FORCING FUNCTION TO PRIMARY SIDE COOLDOWN
- TRIPPING THE RCP'S DURING A STEAMBREAK TENDS TO DECOUPLE THE SECONDARY SIDE FROM PRIMARY SUCH THAT RATE OF COOLDOWN IS DECREASED
- FOLLOWING A STEAMBREAK THE RCS WILL REPRESSURIZE
    - TO SI PUMPS SHUT-OFF HEAD WITHOUT SPRAY WHICH MAY OPEN PORV'S AND SAFETIES
    - LIMITED REPRESSURIZATION WITH SPRAY



INTERMEDIATE STEAMLINE BREAK ($0.2\ FT^2$/LOOP)

UNISOLATABLE BREAK W/ RCP TRIP

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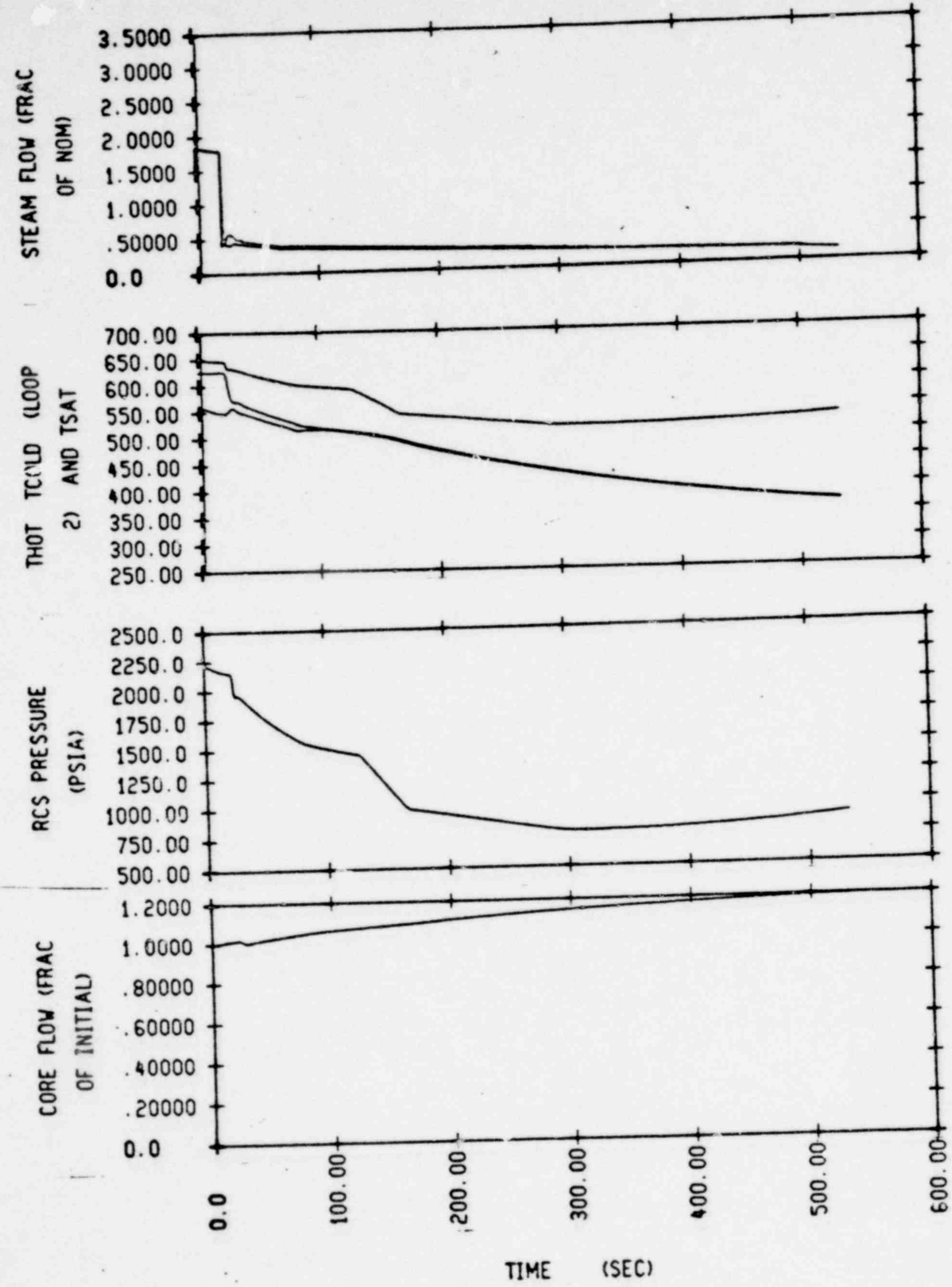

INTERMEDIATE STEAMLINE BREAK (0.2 FT^2/LOOP)
UNISOLATABLE BREAK W/O RCP TRIP

1265 072

STEADY STATE NATURAL CIRCULATION

- Flow is defined as:

$$W = \left[\frac{2 g_C \bar{\rho}^2 \; \beta \; Q \; \Delta Z}{C_\rho \; \Sigma (K / A^2)} \right]^{1/3}$$

With:

ΔZ - Height between heat generation and heat loss

Q - Decay heat generated

ρ - Average density

β - Volumetric coefficient of thermal expansion

K - Component flow resistance

A - Component flow area

CONCLUSIONS

1. ONLY SIGNIFICANT RCS DEPRESSURIZATION EVENTS LEAD TO CONCERN ABOUT RCP TRIP

2. THE STEAMBREAK EVENT BOUNDS ALL NON-LOCA EVENT IN TERMS OF DEPRESSURIZATION

3. TRIPPING THE RCP'S WILL
    a) RESULT IN MORE DIFFICULT PRESSURE CONTROL
    b) INCREASE POSSIBILITY OF OPENING PRESSURIZER PORV

4. TRIPPING THE RCP'S DURING A STEAMBREAK WILL DELAY/ MINIMIZE THE COOLDOWN

5. SUB-COOLED NATURAL CIRCULATION CAN BE EASILY ESTABLISHED FOLLOWING RCP TRIP

REVISED REFERENCE
EMERGENCY OPERATING
INSTRUCTIONS

THE NEED

THE OBJECTIVES

THE PHILOSOPHY

THE PROCESS

THE NEED

NRC IE BULLETIN 79-06A

SI TERMINATION

RCP STATUS

MULTI-INSTRUMENT ACTIONS

THE OBJECTIVES

- MULTI-INSTRUMENT BASIS FOR ACTIONS.
- COMPLETE IMMEDIATE ACTIONS PRIOR TO DIAGNOSIS.
- MINIMIZE DIFFERENCES IN OPERATOR ACTIONS UNTIL DIAGNOSIS IS COMPLETE AND RECOVERY IS IN PROGRESS.

THE PHILOSOPHY

- PROVIDE CONTINUING DIAGNOSIS.
- PROVIDE DETAILED INSTRUCTIONS AND NOTES. BELIEVED EASIER FOR UTILITY TO REMOVE MATERIAL RATHER THAN GENERATE ADDITIONAL DETAIL.
- AUTOMATIC SYSTEMS SHOULD STABILIZE PLANT PRIOR TO OPERATOR ACTIONS TO CONTROL RESPONSE.
- IF SI IS TERMINATED, THEN PLANT CONTROL MUST BE MAINTAINED BY THE OPERATOR.
- MINIMIZE REQUIRED OPERATOR ACTIONS AND DECISIONS
- MAXIMIZE PROCEDURE UNIFORMITY

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THE PROCESS

- 2 SMALL TASK TEAMS IN RESPONSE TO IE BULLETIN 79-06A.

- COMBINE TASK TEAMS.

- MULTIDISCIPLINARY

  CONTROL SYSTEMS

  PROTECTION SYSTEMS

  SYSTEMS DESIGNER

  SAFETY ANALYSIS

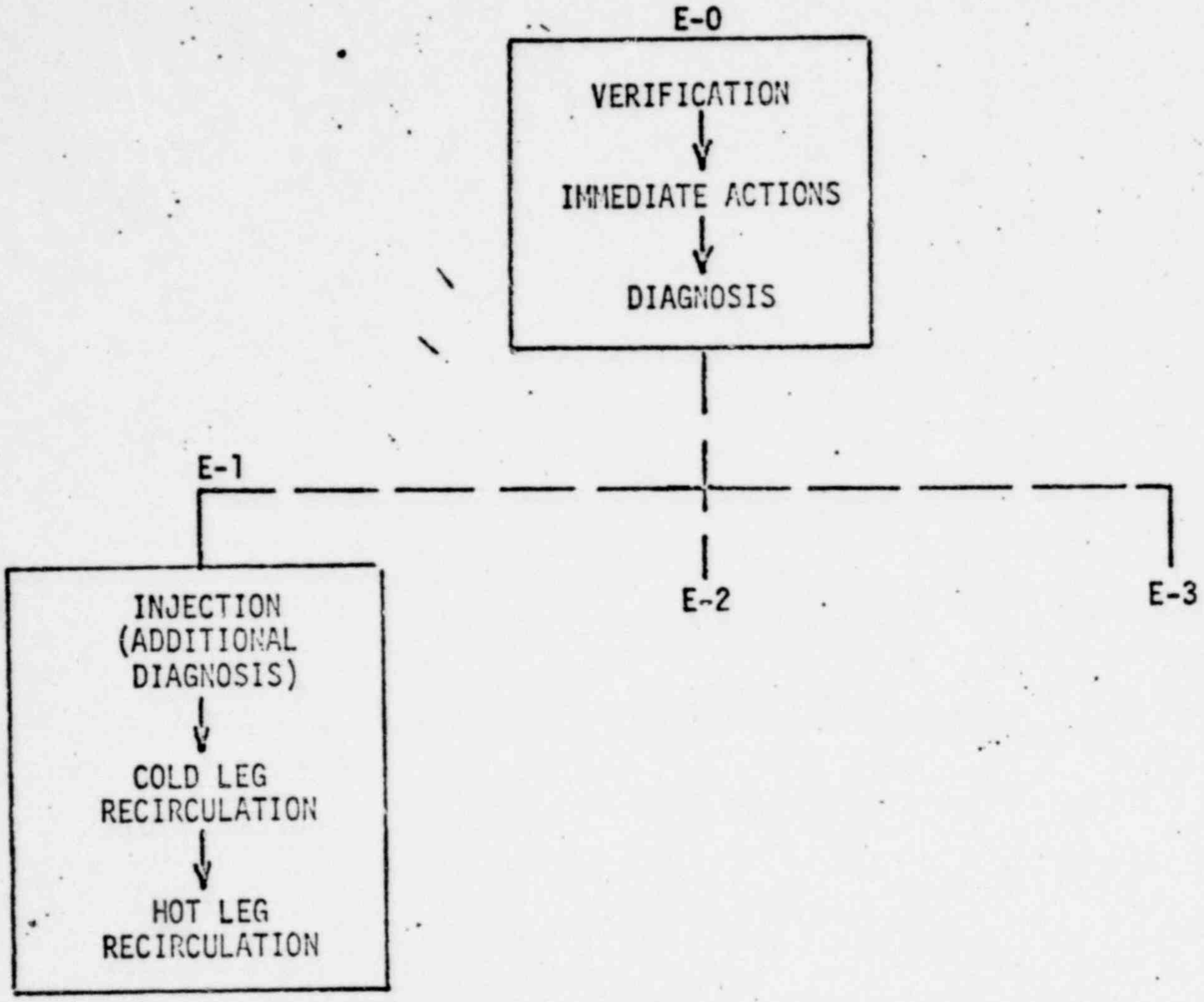
  PROCEDURE SPECIALISTS

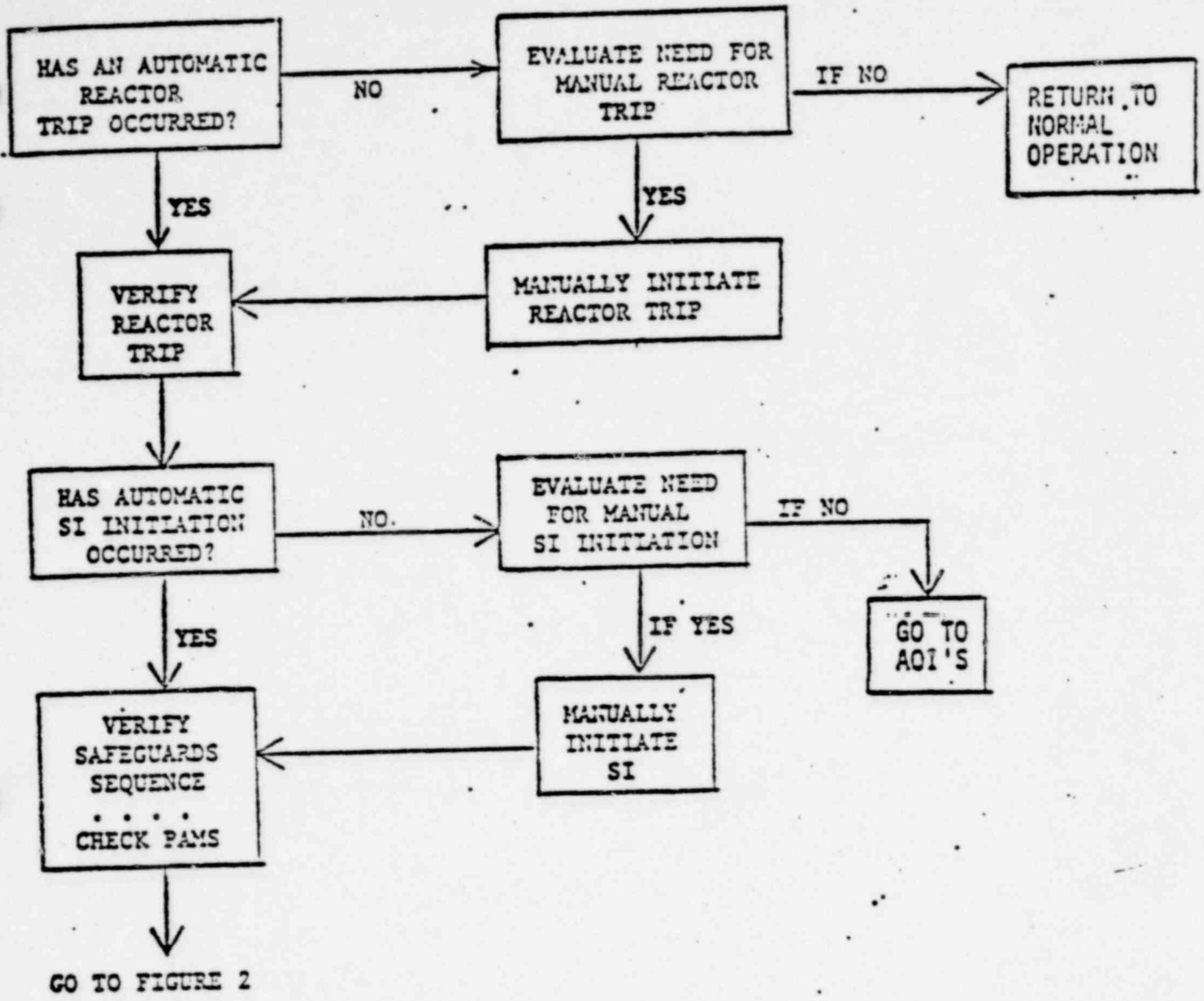
- INDEPENDENT REVIEW

  TRAINING SPECIALISTS

  SIMULATOR INSTRUCTORS

STRUCTURE


E-0
VERIFICATION
IMMEDIATE ACTIONS
DIAGNOSIS
E-1
INJECTION (ADDITIONAL DIAGNOSIS)
COLD LEG RECIRCULATION
HOT LEG RECIRCULATION
E-2
E-3



IMMEDIATE ACTIONS

FIGURE 1

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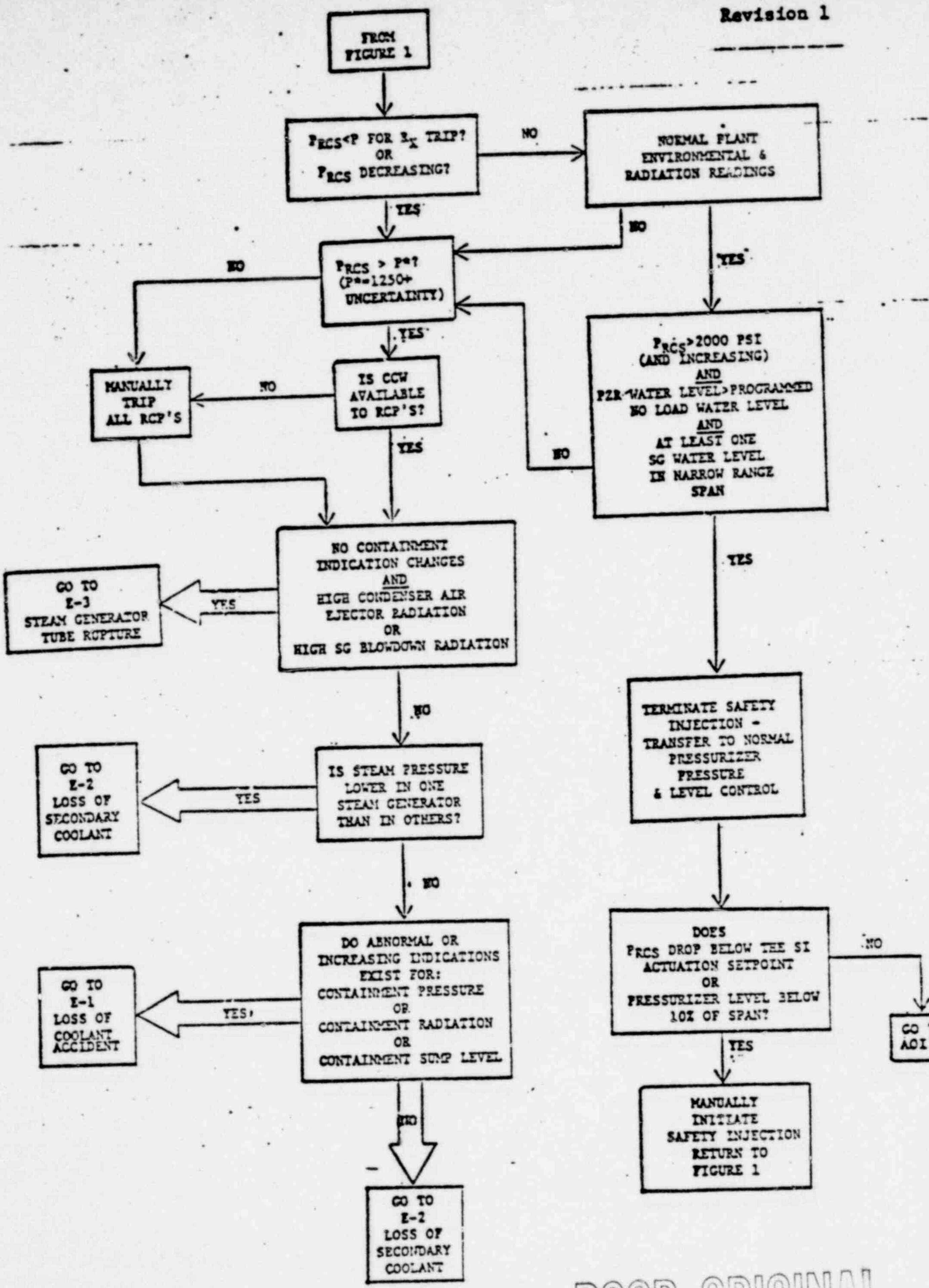
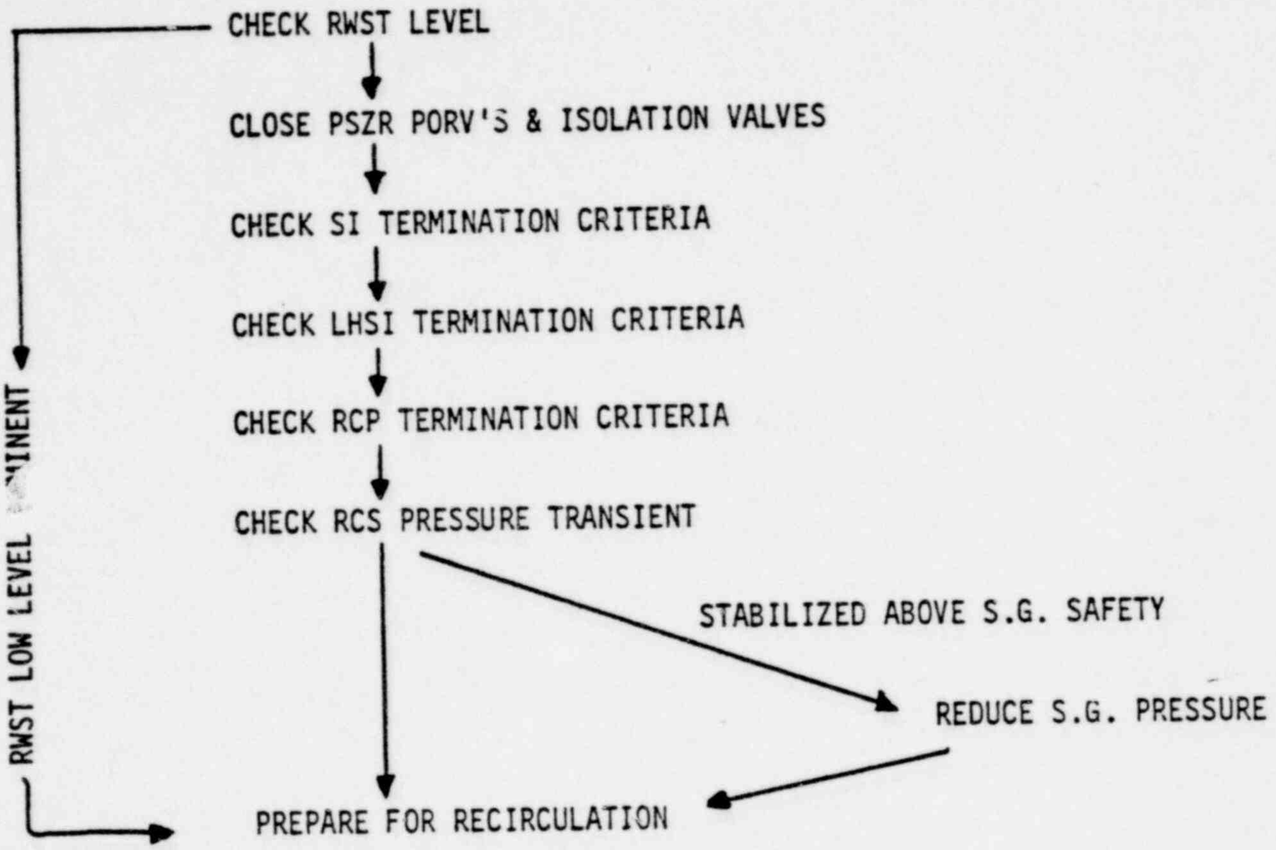


POOR ORIGINAL

FIGURE 2

E-1 LOSS OF REACTOR COOLANT



SI TERMINATION CRITERIA PARAMETERS

- EXISTING INSTRUMENTATION
- FAMILIAR INSTRUMENTATION
- MULTIPLE INDICATIONS
- CONSISTENT INDICATIONS

BASES FOR SI TERMINATION CRITERIA

- ASSURE SYSTEM INVENTORY
- RETURN TO NEAR NORMAL PLANT CONTROL CONDITIONS
- ASSURE CAPABILITY FOR DECAY HEAT REMOVAL FROM RCS
- PROVIDE CAPABILITY FOR NORMAL PLANT CONTROL
- MINIMIZE POTENTIAL FOR SUBSEQUENT RCS INVENTORY LOSS
- ACCOUNT FOR POSSIBLE INSTRUMENT UNCERTAINTIES

Safety Injection can be terminated IF:

(A) Reactor coolant pressure is greater than 2000 psig and increasing, AND

(B) Pressurizer water level is greater than 50% of span, AND

(C) Water level in at least one Steam Generator is in the narrow range span, or in the wide range span at a level sufficient to assure that the U-tubes are covered.

THEN:

(A) Reset safety injection and stop safety injection pumps not needed for normal charging and RCP seal injection flow.

(B) Place all non-operating safety injection pumps in standby mode and maintain operable safety injection flowpaths. (Do not lock valves).

(C) Isolate safety injection flow to RCS Cold Legs via Boron Injection Tank and establish normal charging flow.

CAUTION: If reactor coolant pressure decreases in excess of 200 psi or pressurizer water level drops below 20% of span following termination of safety injection flow, MANUALLY REINITIATE safety injection to establish reactor coolant pressure and pressurizer water level. The reactor coolant pressure will stabilize at a pressure greater than 2000 psig and less than the safety valve set pressure. Go to E-0 to reevaluate the event, unless this reevaluation has already been performed.

(D) Reestablish normal makeup and letdown (if letdown is unaffected) to maintain pressurizer water level in the normal operating range and to maintain reactor coolant pressure at values reached when safety injection is terminated. Ensure that water addition during this process does not result in dilution of the reactor coolant system boron concentration.

(E) Reestablish operation of the pressurizer heaters. When reactor coolant pressure can be controlled by pressurizer heaters alone, return makeup and letdown to pressurizer water level control only.

(F) Perform a controlled cooldown to cold shutdown conditions if required to affect repairs. Maintain subcooled conditions in the reactor coolant system. If subcooled conditions cannot be maintained, go to step 4.

EVENTS RESULTING IN SI TERMINATION

- SPURIOUS SI (E-0)
- ISOLATED LOCA (E-1)
- EXTREMELY SMALL LOCA (E-1)
- LOSS OF SECONDARY COOLANT (E-2)
- STEAM GENERATOR TUBE RUPTURE (E-3)
    - PROVISION FOR SI RE-INITIATION

1265 088

STATUS OF REVISED GUIDELINES

E-0 } COMPLETE, SUBMITTED TO NRC,
E-1 } NRC COMMENTS INCLUDED

E-2 } COMPLETE, SUBMITTED TO NRC, NRC COMMENTS ON
E-3 } E-0 AND E-1 BEING INCORPORATED

COMBUSTION ENGINEERING, INC.
PRESENTATION
BEFORE
ACRS SUBCOMMITTEE ON ECCS

October 17, 1979

1265 090

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AGENDA FOR ACRS SUBCOMMITTEE MEETING
ON SMALL BREAKS

10-17/18-79

1. Introduction	J. Longo	5 minutes
2. General Features of SB Model		
A. Fluid Models	J. H. Holderness	30 minutes
B. Break Flow Model C. SG Heat Transfer Model D. Pressurizer Model	G. Menzel	30 minutes
3. Special Model Features for Reactor Coolant Pump Operation	T. C. Kessler	30 minutes
A. Noding Differences		
B. Two-Phase Pump Model		
4. Results of Small Break Analyses with Reactor Coolant Pumps Running	F. L. Carpentino	30 minutes
5. Non-LOCA Events	C. Kling	30 minutes
6. Guidelines for RCP Operation	V. Callaghan	15 minutes
7. Loss of Feedwater Events	F. L. Carpentino	20 minutes

COMBUSTION ENGINEERING

SMALL BREAK LOCA
HYDRAULICS MODEL

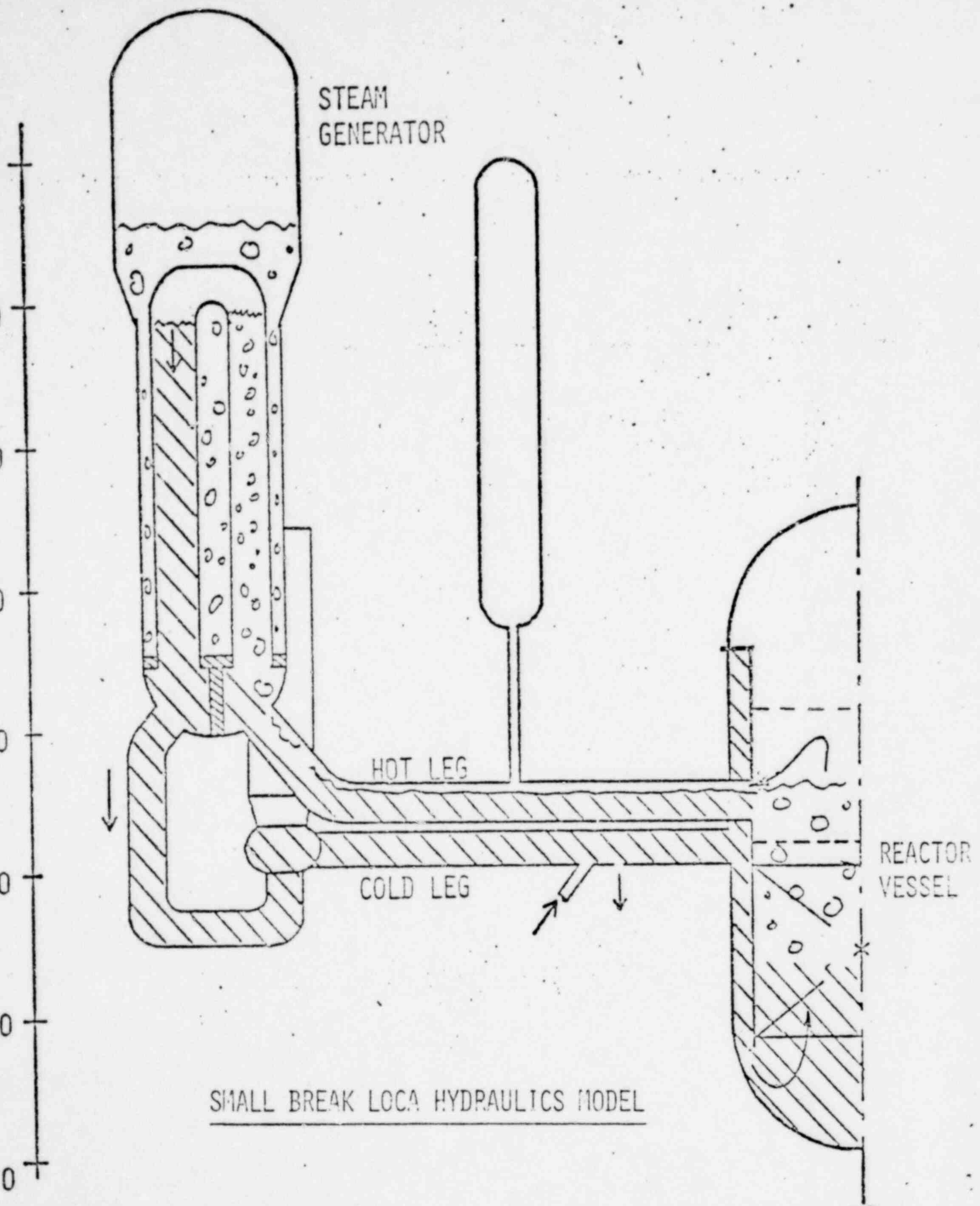
J. H. HOLDERNESS

REFERENCES:

CENPD-137-P, AUGUST, 1974

CENPD-137, SUPPLEMENT 1-P, JANUARY, 1977

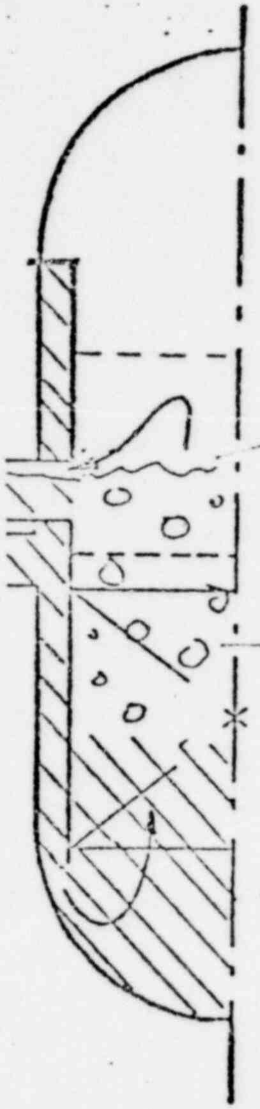
CEN-114-P, JULY, 1979



SMALL BREAK LOCA HYDRAULICS MODEL

POOR ORIGINAL

REACTOR VESSEL MODEL



DRIFT FLUX FORMULATION

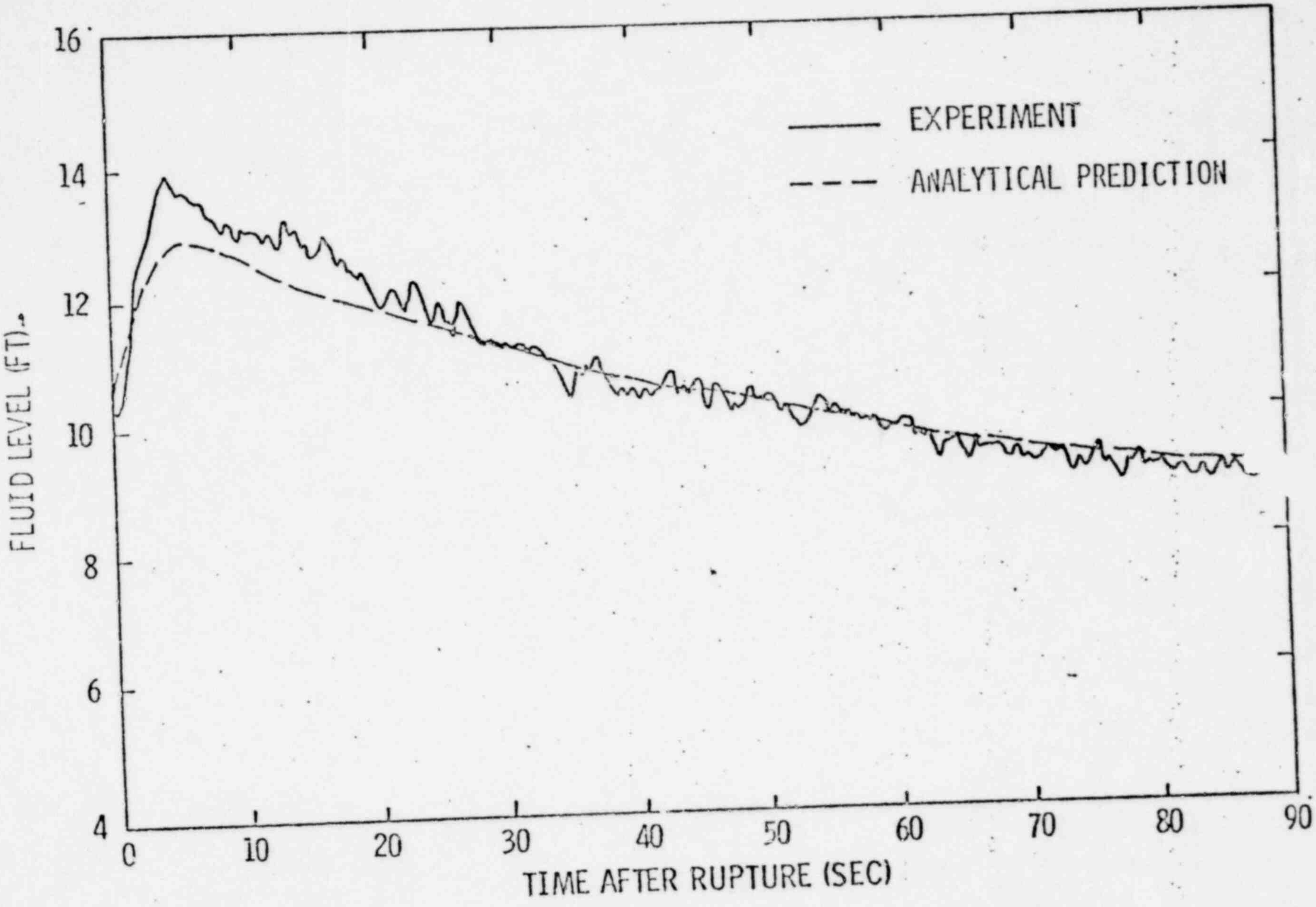
EMPIRICAL CORRELATION OF DRIFT VELOCITY

PHASE SEPARATION BASED ON SURFACE VOID FRACTION

AXIAL VOID PROFILE BASED ON DETAILED ENERGY BALANCE

SOURCES OF ENERGY:
- COOLANT INLET SUBCOOLING
- METAL WALL HEAT TRANSFER
- CORE HEAT TRANSFER
- FLASHING

CSE BLOWDOWN TEST FROM A TOP OUTLET
RUN B-53 BTN



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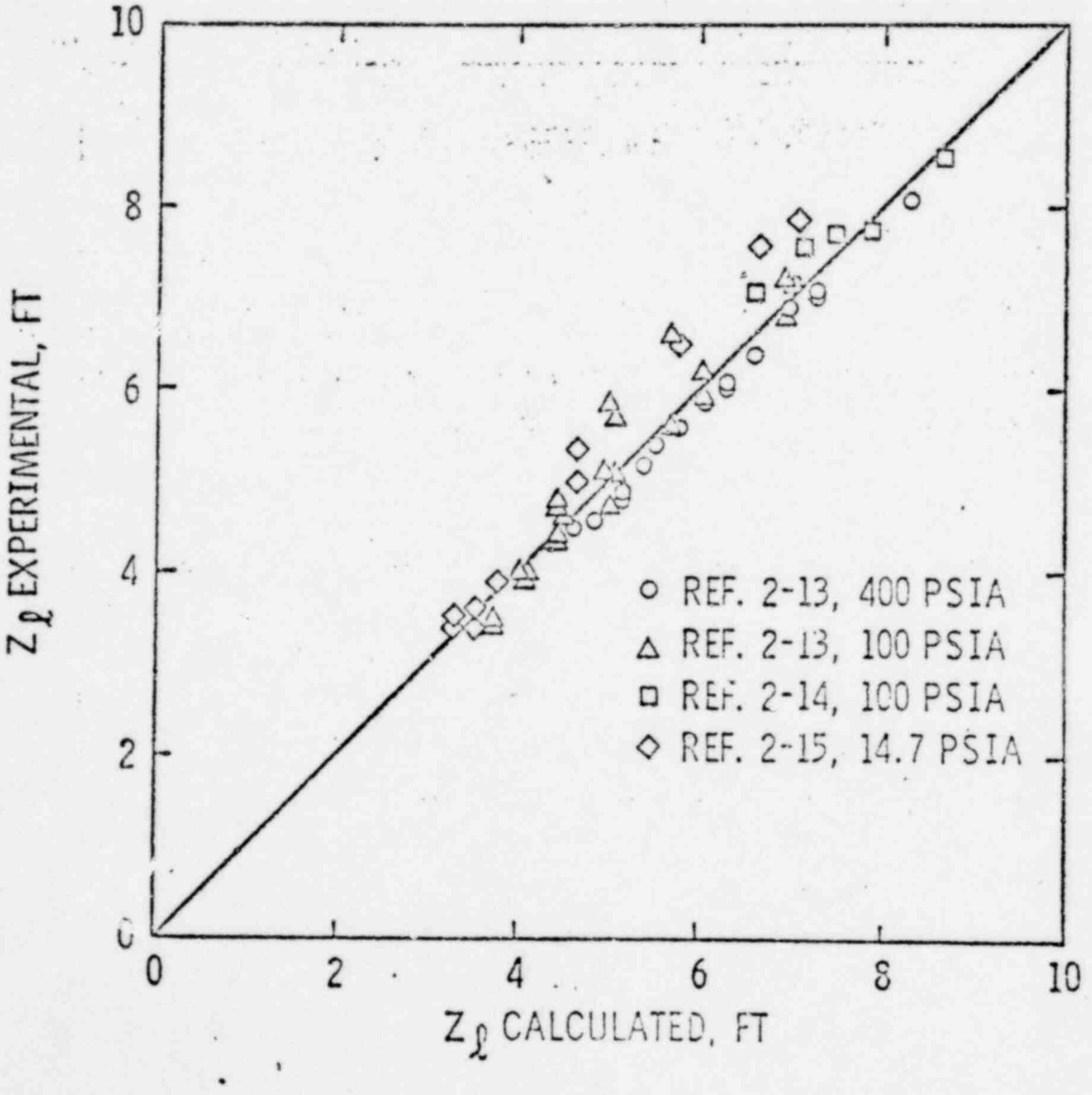
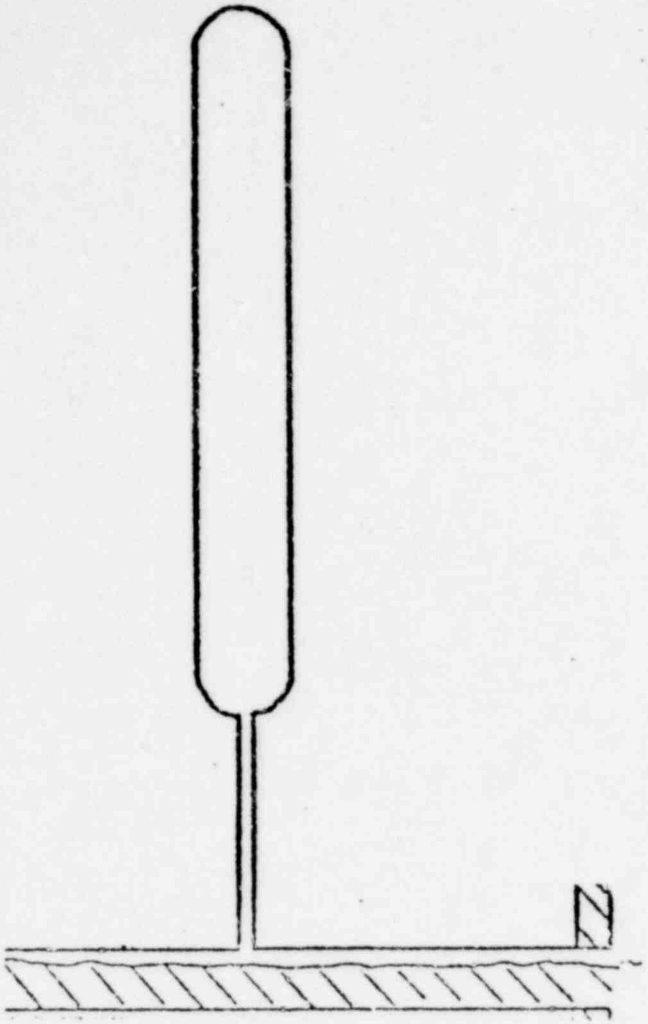
EXPERIMENTAL COMPARISON



POOR ORIGINAL

75

1265 096



HOT LEG MODEL

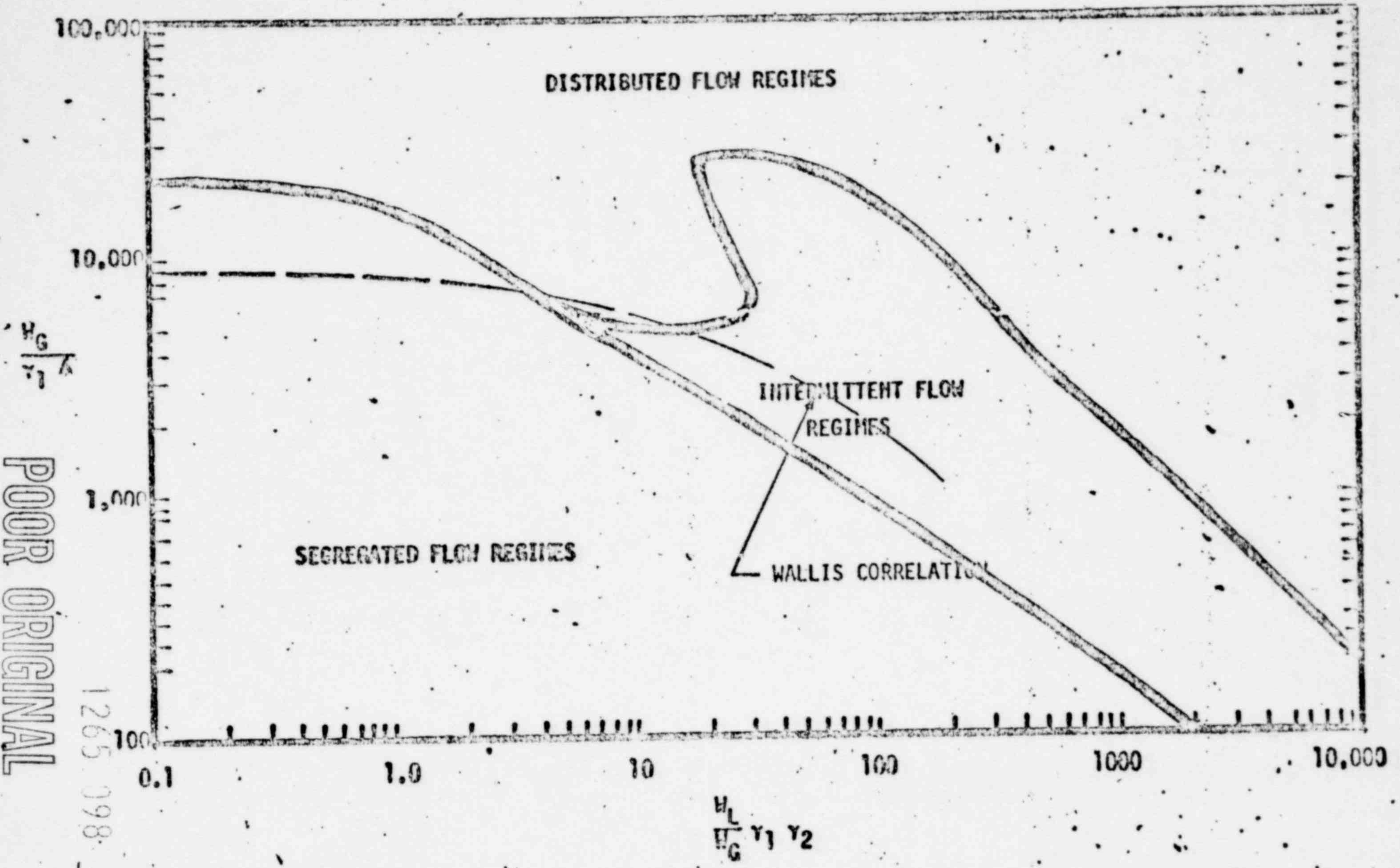
SEPARATED TWO-PHASE FLOW MODEL

SLIP RATIO DERIVED FROM EMPIRICAL CORRELATION

1265 097 76

FLOW REGIME MAP FOR HORIZONTAL TWO-PHASE FLOW

COMPARISON TO WALLIS CORRELATION FOR AIR-WATER MIXTURE IN SMALL DIAMETER PIPES



POOR ORIGINAL

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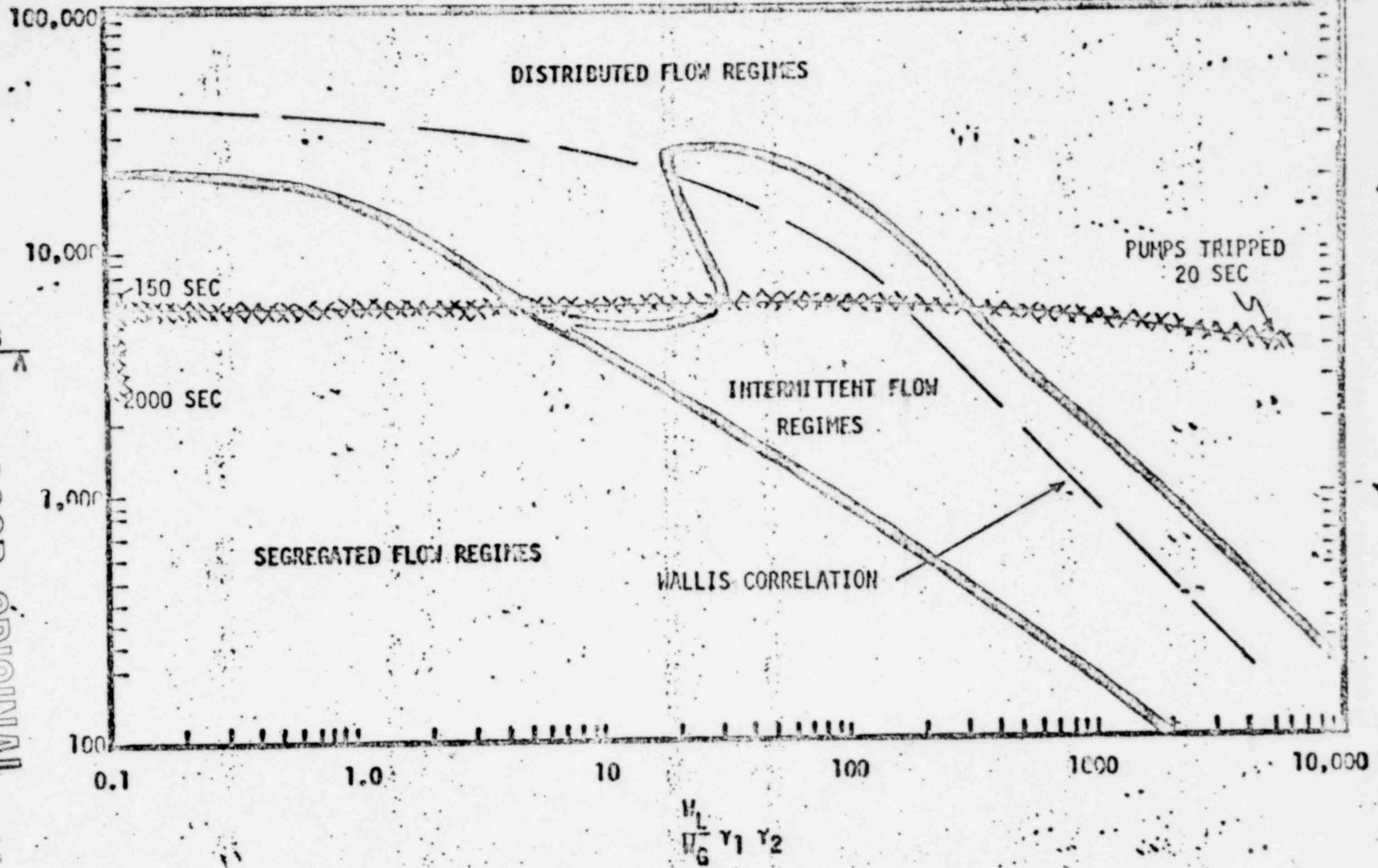
FLOW REGIME MAP FOR RIZONTAL TWO-PHASE FLOW

COMPARISON TO WALLIS CORRELATION FOR 1000 PSIA STEAM-WATER MIXTURE IN LARGE DIAMETER PIPES

APPROXIMATE RANGE OF PWR SMALL BREAK LOCA CONDITIONS



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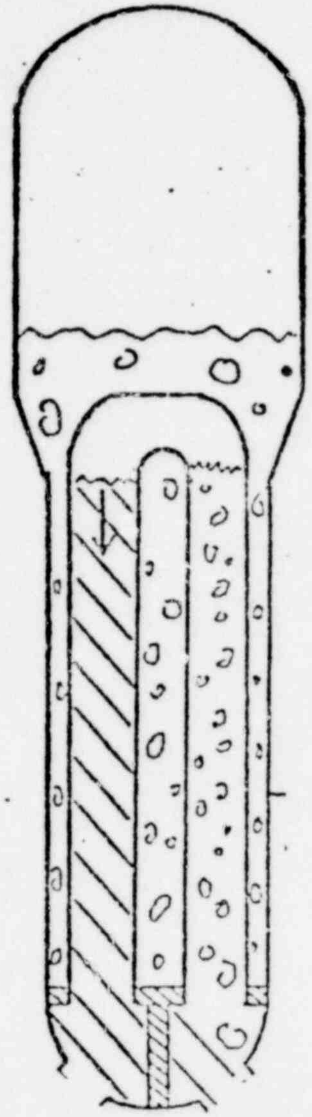


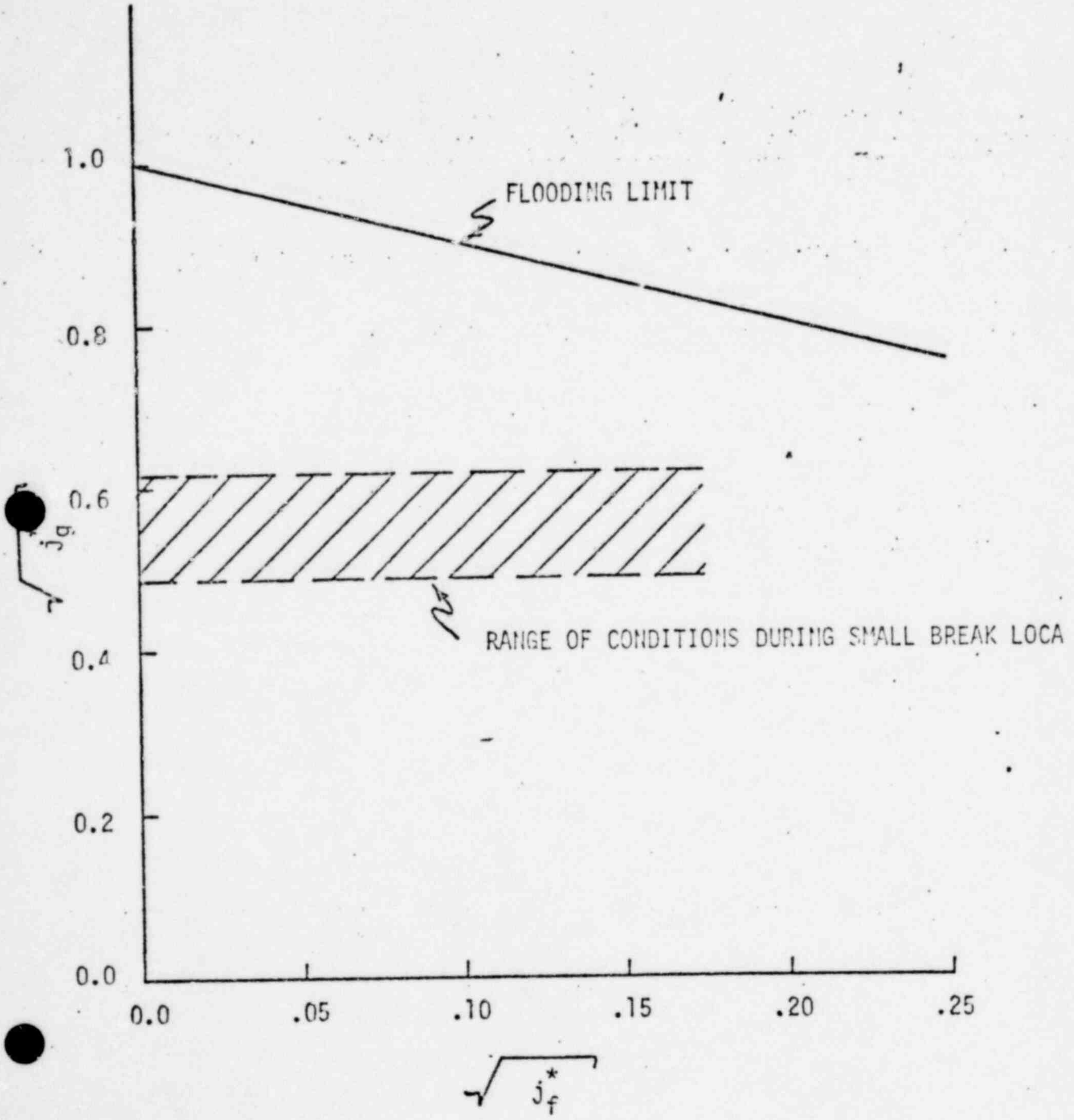
STEAM GENERATOR MODEL

DRIFT FLUX MODEL FOR COCURRENT TWO-PHASE FLOW

PHASE SEPARATION AT TOP OF STEAM GENERATOR
U-TUBES

COUNTERCURRENT FLOW DURING REFLUX BOILING PHASE

CONDITIONS FOR COUNTERCURRENT FLOW
AT STEAM GENERATOR INLET



COLD LEG MODEL

DRIFT FLUX MODEL IN VERTICAL COMPONENTS

SEPARATED FLOW IN HORIZONTAL PIPES

DYNAMIC REACTOR COOLANT PUMP MODEL BASED
ON SINGLE PHASE PUMP HOMOLOGOUS CURVES

- BREAK FLOW MODEL
- STEAM GENERATOR HEAT TRANSFER MODEL, EFFECT OF NON-CONDENSIBLES ON HEAT TRANSFER AND RETURN TO NATURAL CIRCULATION
- PRESSURIZER/SURGE LINE MODEL

COMBUSTION ENGINEERING

PRESENTATION BEFORE ACRS SUBCOMMITTEE
ON ECCS ON 10-17-79

G. MENZEL

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COMBUSTION ENGINEERING CRITICAL FLOW MODEL

FOR SMALL BREAK LOCA

1. SUBCOOLED WATER : MODIFIED HENRY - FAUSKE MODEL

2. TWO - PHASE FLOW : MOODY MODEL (REQUIRED BY 10CFR50, APP. K)

3. SUPERHEATED STEAM : MODIFIED MURDOCK - BAUMAN CORRELATION

SUBCOOLED C_D SENSITIVITY STUDY

EFFECT ON INNER VESSEL MIXTURE LEVEL

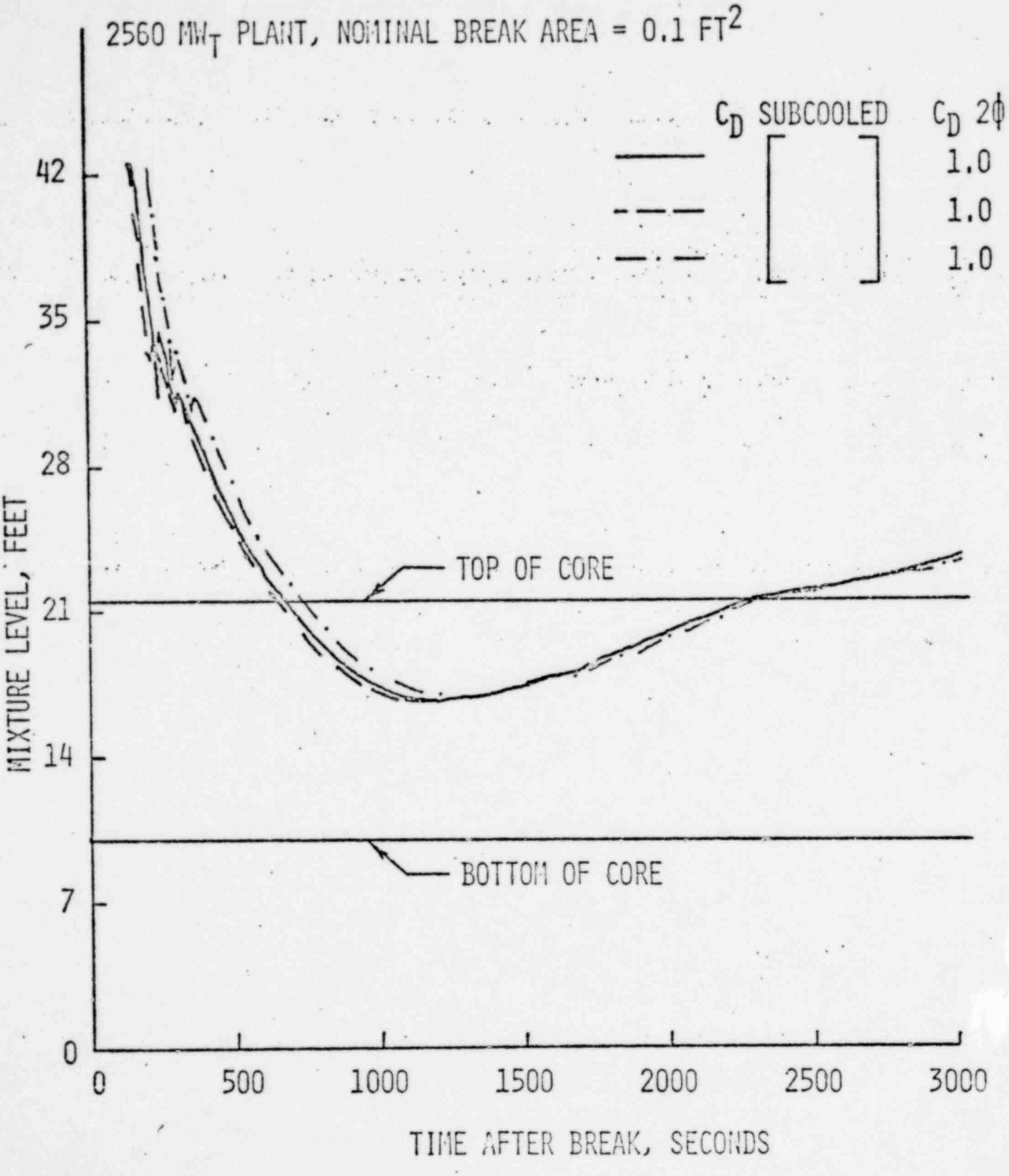
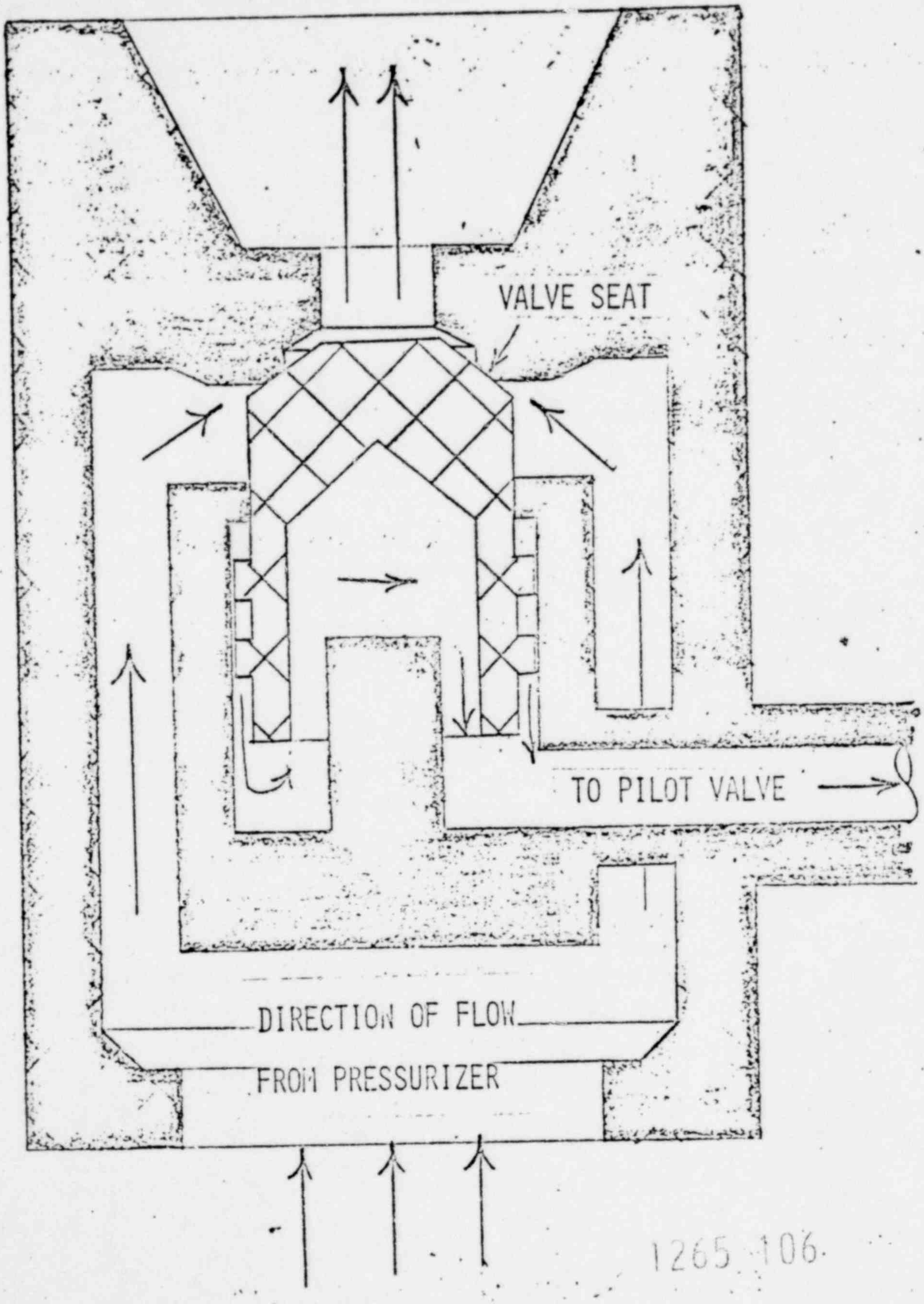


FIGURE 3.4-3

CUTAWAY SCH[illegible]IC OF A PORV



PORV FLOW CAPACITY

1. EXPERIMENTAL DETERMINATION OF DISCHARGE COEFFICIENT K_D BY MANUFACTURER:

$$K_D = \frac{\text{MEASURED FLOW RATE}}{\text{THEORETICAL FLOW RATE}}$$

2. DETERMINATION OF NAMEPLATE CAPACITY BY MANUFACTURER:

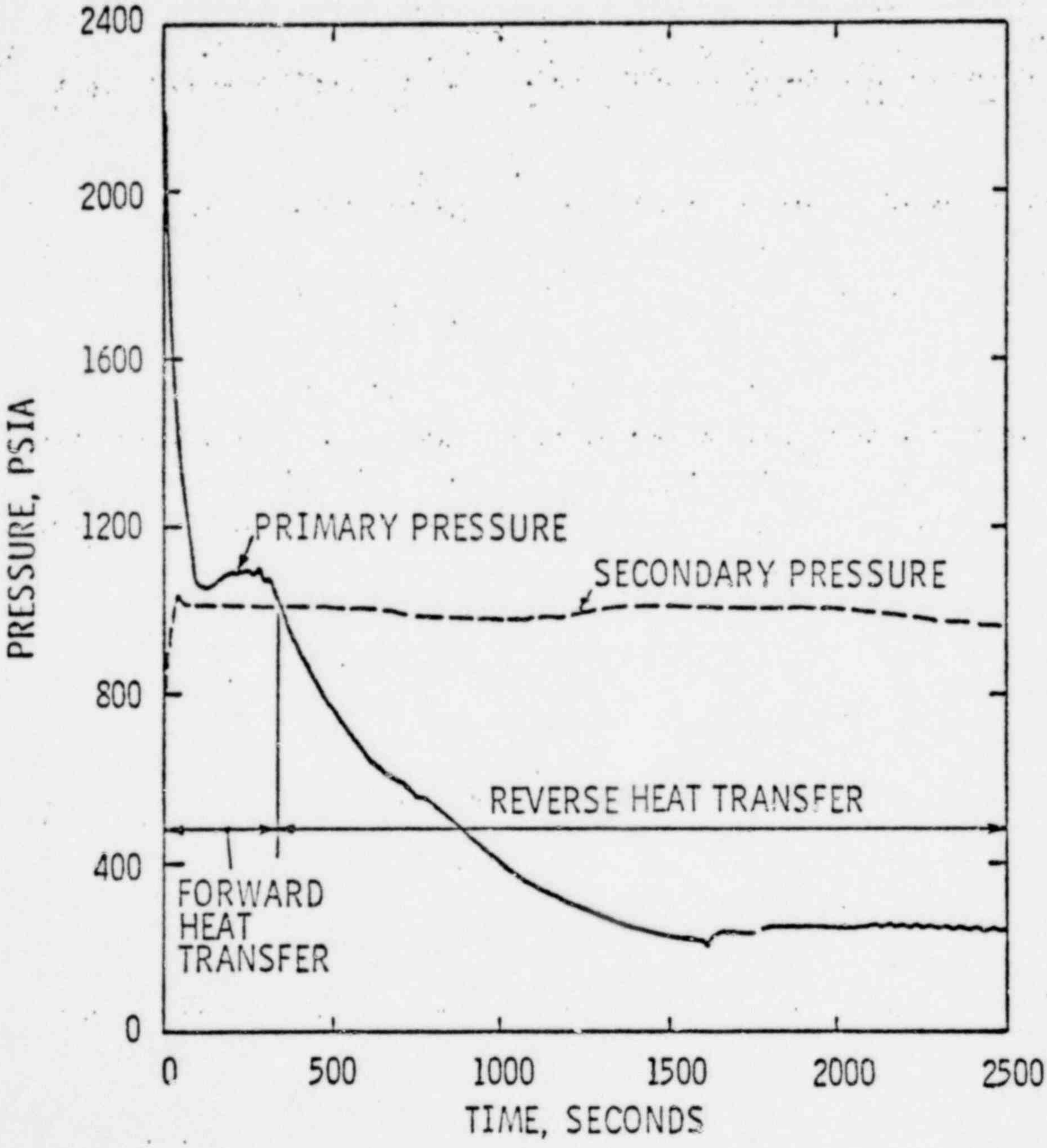
$$W = K_D * A_{VALVE} * P * 51.5$$

3. CE USAGE:
   - A. DETERMINE EQUIVALENT AREA FROM NAMEPLATE CAPACITY
   - B. USE WITH CE CORRELATION

CONCLUSIONS OF C-E SMALL BREAK LEAK FLOW EVALUATION

- SUBCOOLED LEAK FLOW IS STRONGLY DEPENDENT UPON BREAK GEOMETRY
- C-E SMALL BREAK RESULTS ARE INSENSITIVE TO SUBCOOLED LEAK FLOW OVER RANGE OF APPLICABLE EXPERIMENTAL DATA
- C-E LEAK FLOW MODEL IS APPROPRIATE TO PREDICT CORE UNCOVERY IF A CONSTANT DISCHARGE COEFFICIENT IS APPLIED FOR SUBCOOLED AND TWO-PHASE FLOW. THIS DISCHARGE COEFFICIENT CAN BE APPLIED THROUGH VARIATION OF THE BREAK AREA.
- SINCE FLOW AREA FOR AN OPEN PORV CANNOT BE CLEARLY SPECIFIED, A SPECTRUM OF FLOW AREAS WAS ANALYZED.

PRIMARY AND SECONDARY PRESSURES



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STEAM GENERATOR HEAT TRANSFER

FORWARD HTF: $T_P > T_S$

	Primary Side		Secondary Side	
HTF Period	Assumed HTF Regime	Correlation	HTF Regime	Correlation
Subcooled Forced Convection	Subcooled Forced Convection	Dittus-Boelter	Pool Boiling	Modified Rohsenow
Two-Phase Forward Flow with Condensation	Two-Phase Flow with Condensation	Akers, Dean Crosser		
Two-Phase Counter Current Flow with Condensation (SG Draining)				
Steam Condensation				

STEAM GENERATOR HEAT TRANSFER

REVERSE HTF: $T_P < T_S$

Primary Side		Secondary Side	
HTF Regime	Correlation	HTF Regime	Correlation
Steam Superheat	Dittus-Boelter	Free Convection	McAdams
Nucleate Boiling	Thom		

NON-CONDENSIBLE GASES

EFFECT ON STEAM GENERATOR HEAT TRANSFER: POTENTIAL FOR REDUCTION OF CONDENSATION RATE LEADING TO INCREASE OF PRIMARY SIDE PRESSURE/TEMPERATURE

EFFECT ON RE-ESTABLISHMENT OF SINGLE-PHASE NATURAL CIRCULATION

TABLE 3.2-2

SOURCES OF NON-CONDENSIBLES

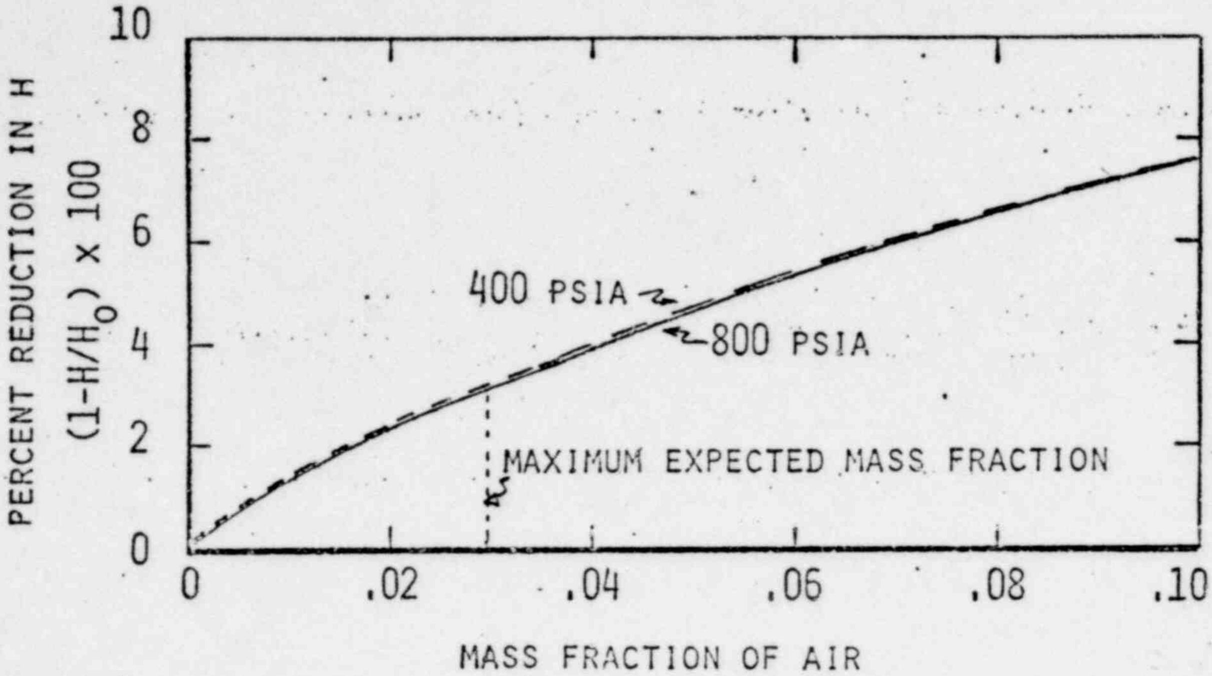
Source	Volume (STP)	Mass
1. Dissolved in primary coolant (hydrogen)	384 ft^3	2.2 lbs
2. Pressurizer vapor space (hydrogen)	793 ft^3	4.5 lbs
3. Dissolved in refueling water tank (air)	1360 ft^3	109.7 lbs[C]
4. Complete oxidation of clad (hydrogen)	448000 ft^3	2514.8 lbs[A]
5. Fuel rod fill gas (helium)	1140 ft^3	12.7 lbs[A]
6. Fission gases (Xe, Kr, I_2)	26 ft^3	~9.0 lbs[A]
7. Safety injection tanks (nitrogen)		
a. Cover gas	51820 ft^3	4042.2 lbs[B]
b. Dissolved gas	690 ft^3	53.8 lbs[B]

NOTES

a) For breaks requiring the return to natural circulation no fuel rod rupture or oxidation is predicted. Numbers are based on 36924 fuel rods.

b) For breaks requiring the return to natural circulation the SIT's do not inject water.

c) The largest amount of liquid injected from the refueling water tank (RWT) during the boiling phase for breaks that return to natural circulation is ~40% of the RWT volume.



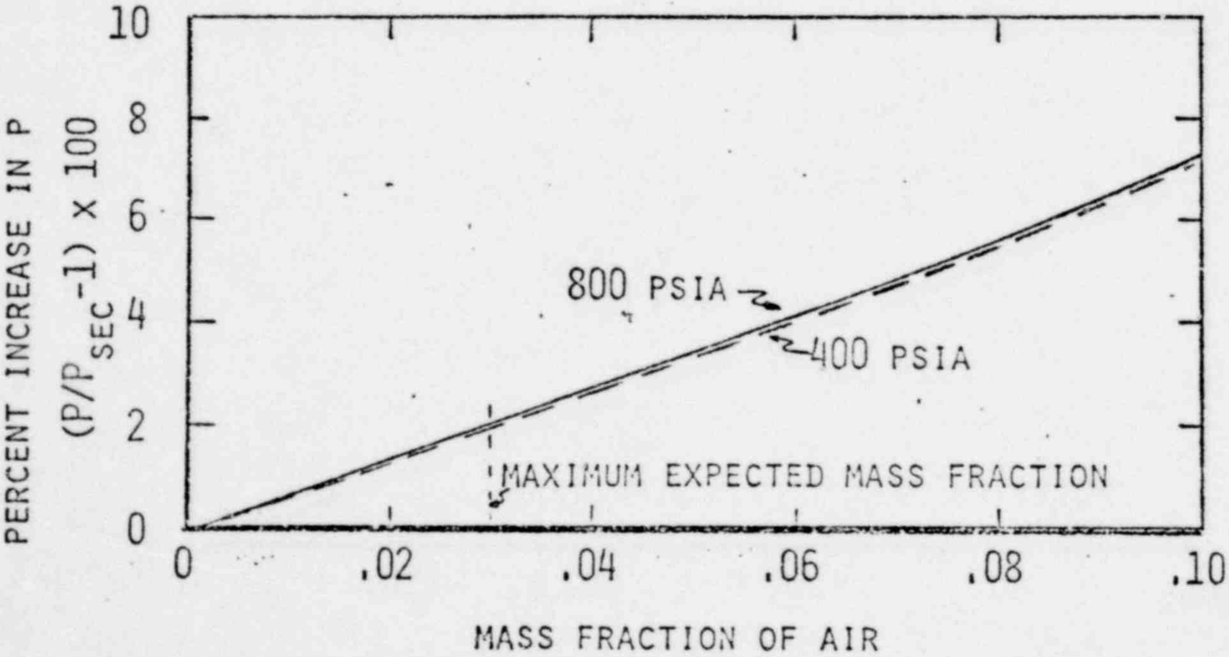
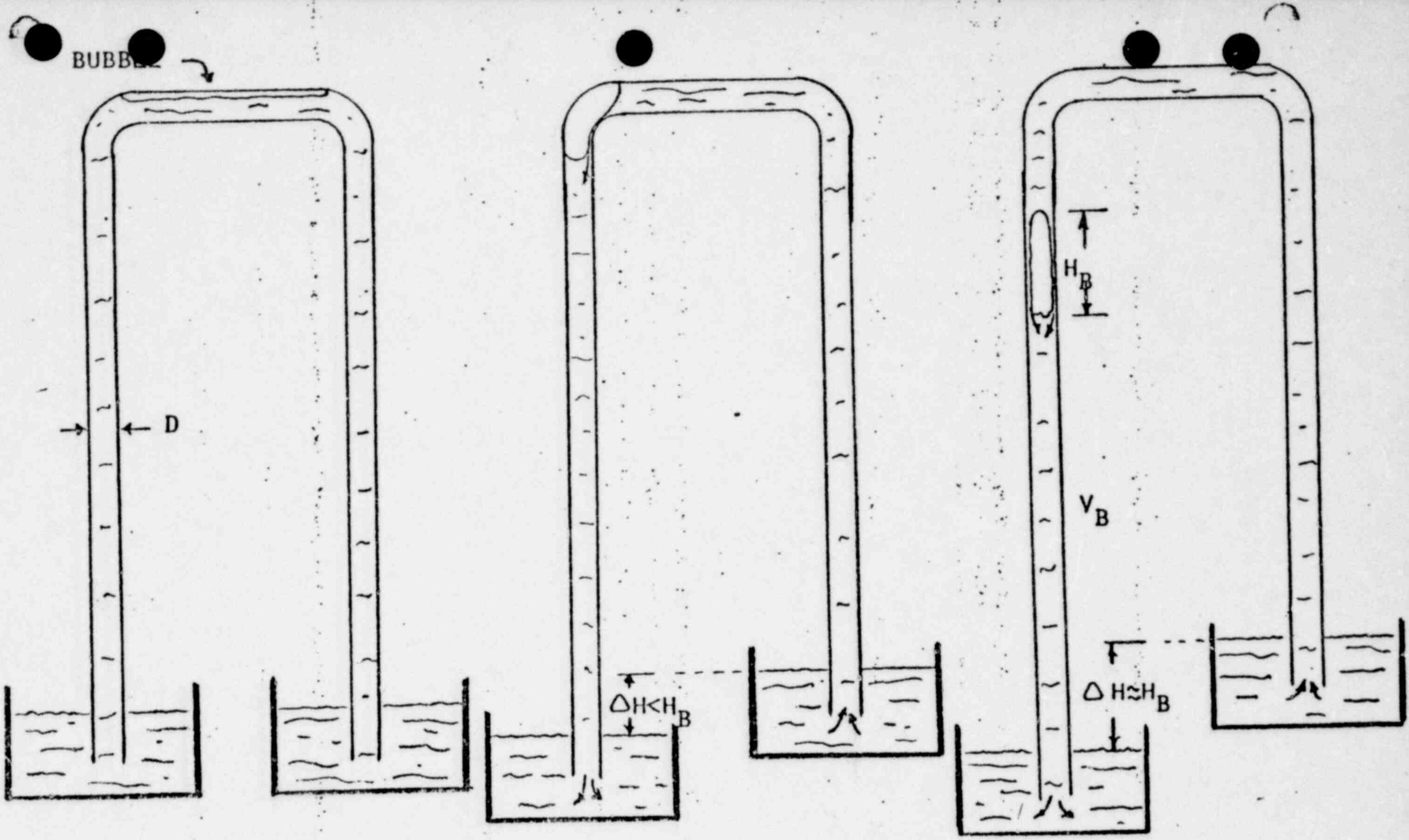


FIGURE 3.2-8. EFFECT OF NON-CONDENSIBLES ON CONDENSATION HEAT TRANSFER COEFFICIENT AND PRIMARY SIDE PRESSURE.



RATIO OF FLOW RATE WITHOUT BUBBLE TO FLOW RATE WITH BUBBLE $\approx 4.1\sqrt{H_B/D}$

FIGURE 3.2-9. EFFECT OF TRAPPED BUBBLE ON FLOW RATE DUE TO NATURAL CIRCULATION

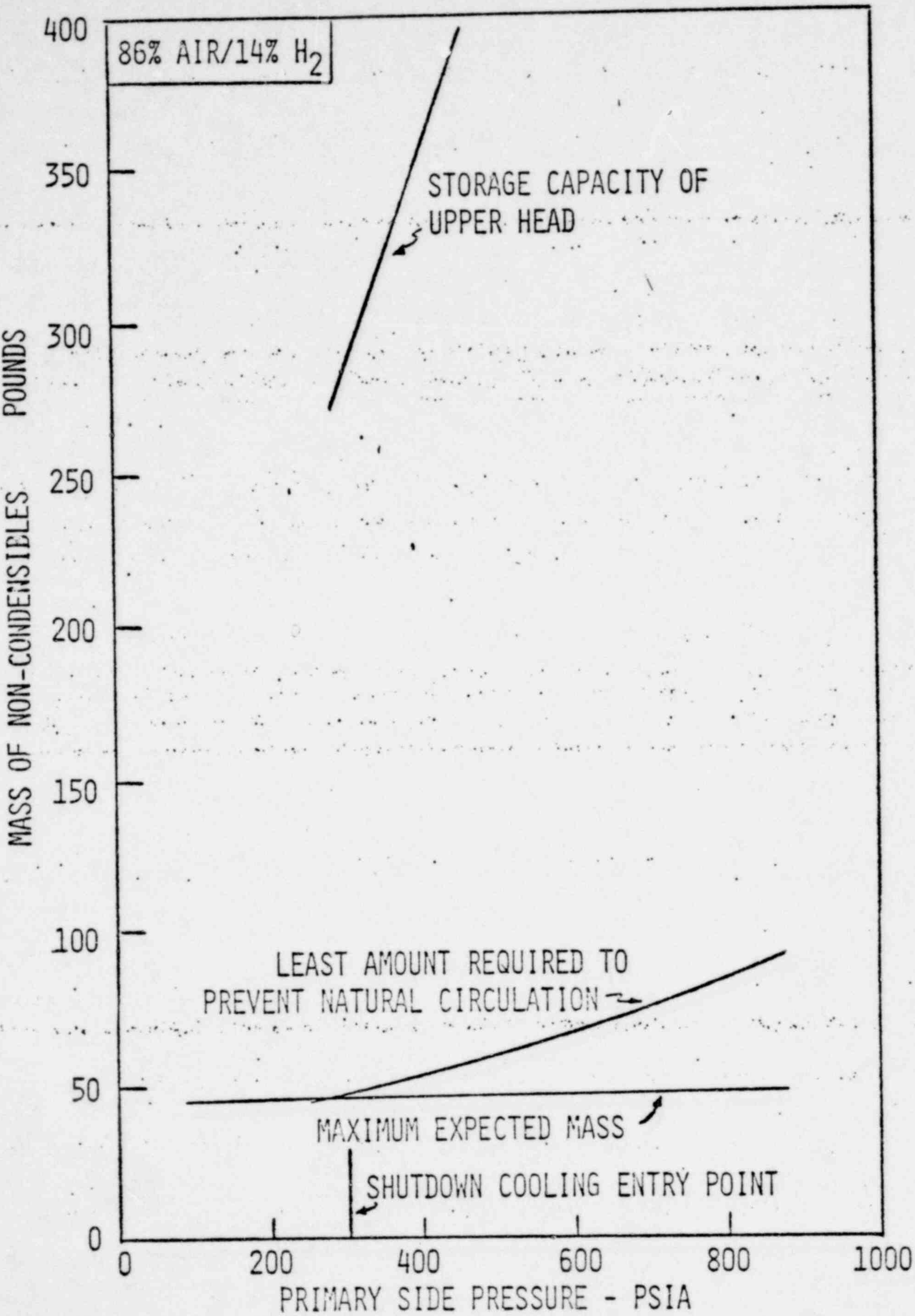


FIGURE 3.2-10. MASS OF NON-CONDENSIBLES IN STEAM GENERATORS REQUIRED TO PREVENT NATURAL CIRCULATION.

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CONCLUSIONS FROM EVALUATION OF STEAM GENERATOR MODEL

PRIMARY AND SECONDARY SIDE HEAT TRANSFER MODELS ARE ADEQUATE TO ANALYZE HEAT TRANSFER DURING EXPECTED FLUID FLOW CONDITIONS

CONSERVATIVE ASSESSMENT OF EFFECT OF NON-CONDENSIBLE GASES POINTS OUT:

NEGLIGIBLE IMPACT ON CONDENSATION RATE;
RETURN TO SINGLE-PHASE NATURAL CIRCULATION WILL NOT BE PREVENTED.

FIGURE 3.3-16

PRESSURIZER PRESSURE

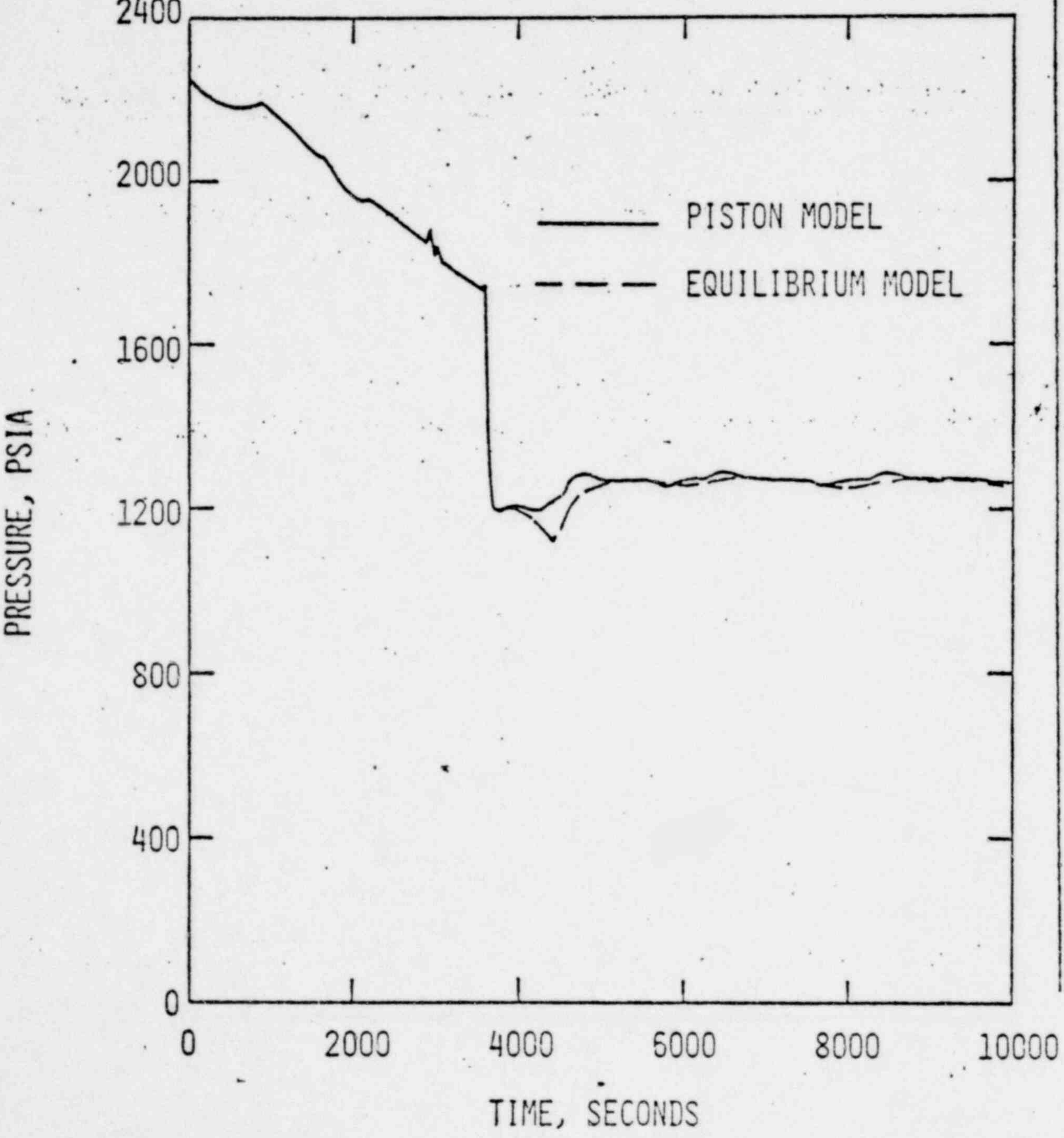

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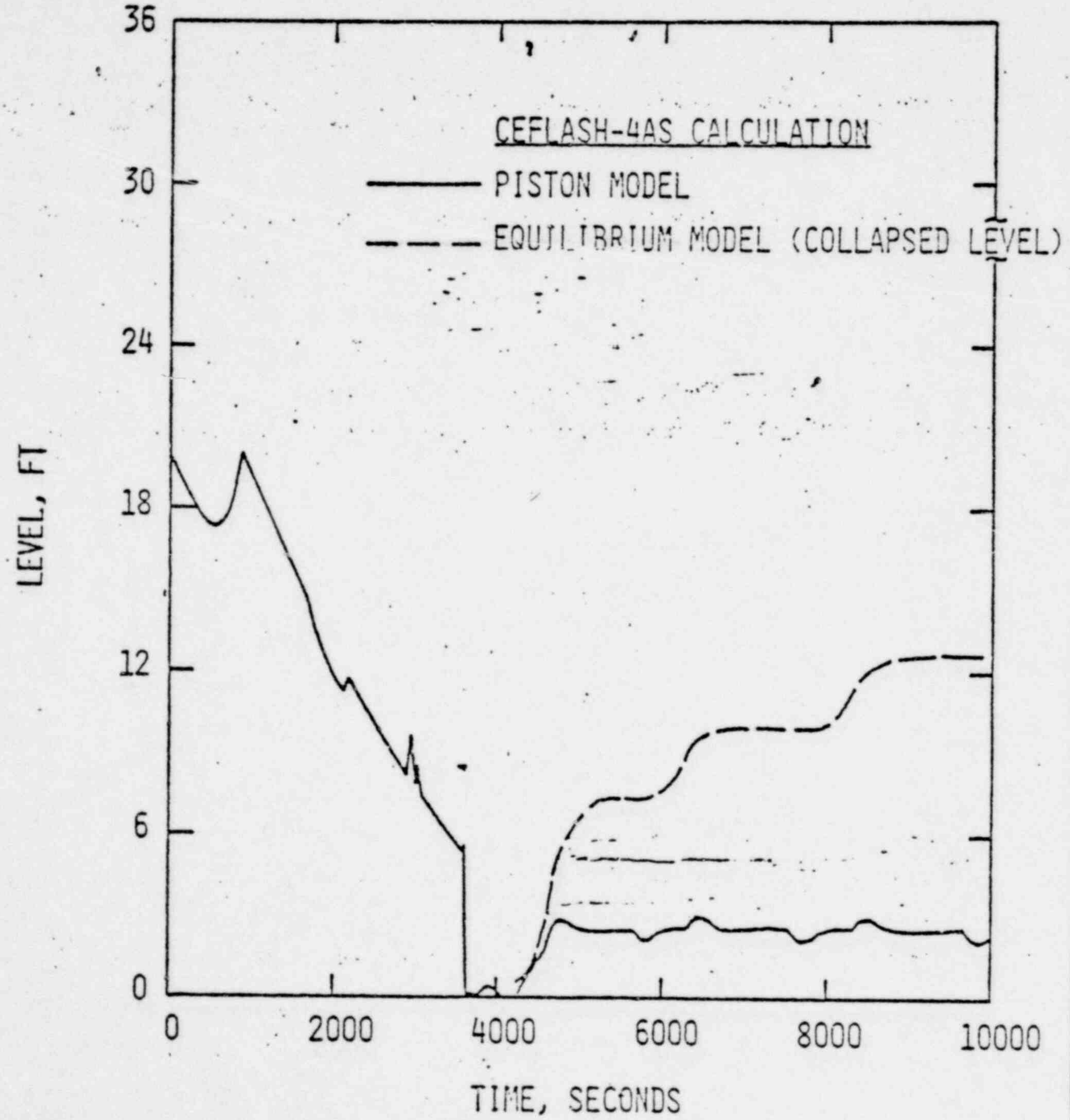
FIGURE 3.3-17

PRESSURIZER LEVEL



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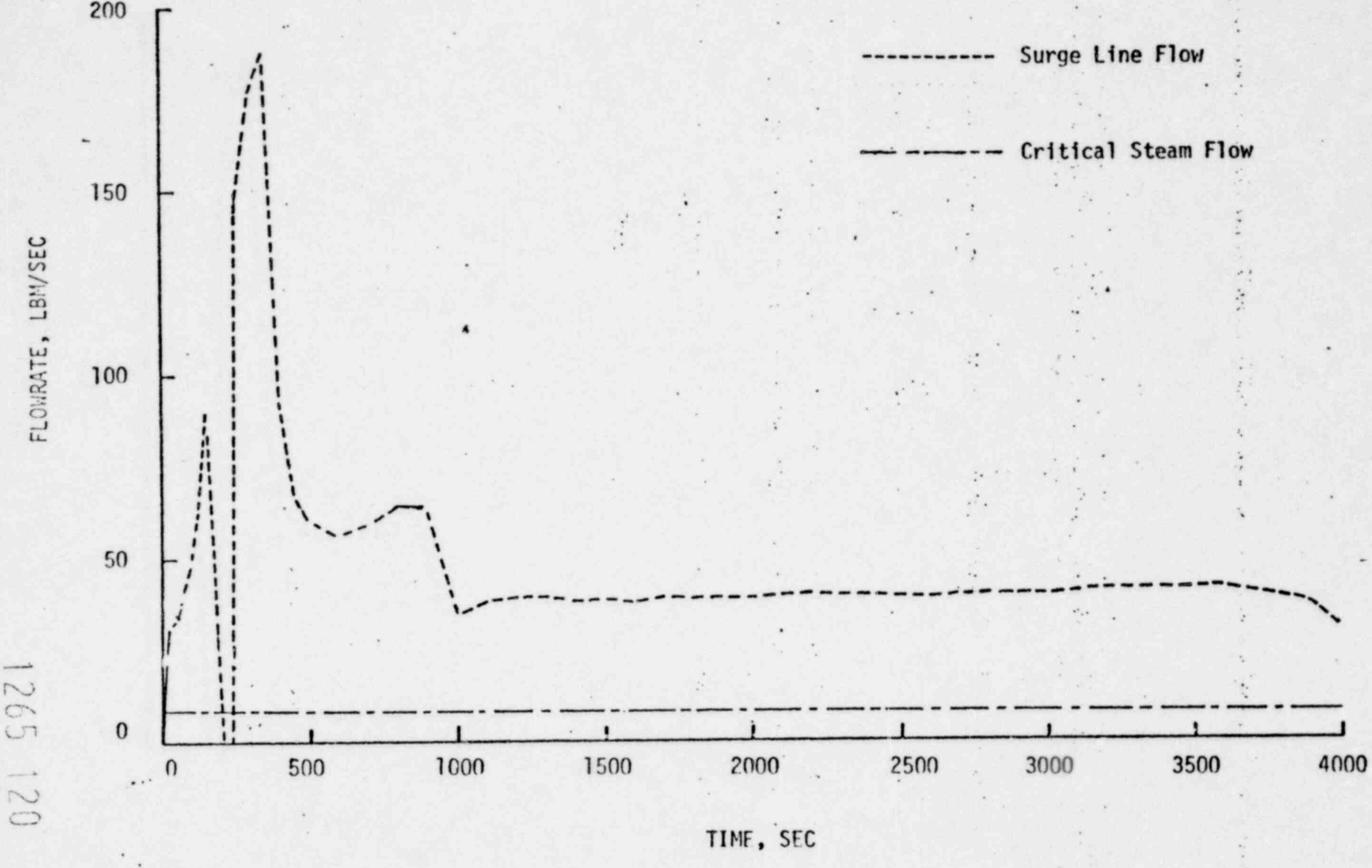
PORV STUCK-OPEN

COMPARISON OF SURGE LINE FLOW AND CRITICAL STEAM FLOW RATE



CONCLUSION FROM PRESSURIZER/SURGE LINE EVALUATION

EQUILIBRIUM PRESSURIZER MODEL IS ADEQUATE FOR ANALYSIS OF SYSTEM REFILL/PLATEAU PRESSURE. WATER LEVEL IN PRESSURIZER IS PROBABLY OVERPREDICTED, RANGE OF EXPECTED LEVEL CAN BE ESTIMATED BY COMPARISON WITH PISTON MODEL.

COCURRENT FLOW REPRESENTATION OF SURGE LINE IS ADEQUATE FOR ANALYSIS OF PRESSURIZER LEAKS.

SPECIAL MODEL FEATURES
FOR CONTINUED RCP OPERATION

I. PHYSICAL EFFECTS OF RCP OPERATION

II. MODIFICATIONS TO C-E SMALL BREAK LOCA EVALUATION MODEL

III. SENSITIVITY OF CALCULATIONAL RESULTS TO MODEL CHANGES

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PHYSICAL EFFECTS OF CONTINUED RCP OPERATION FOLLOWING A SMALL BREAK LOCA

I. RCP'S REDISTRIBUTE PRIMARY COOLANT WATER MASS FROM COLD LEG PIPING TO REACTOR VESSEL

II. RCP'S MAINTAIN TWO-PHASE FLOW AT HIGH VELOCITY UNTIL COLD LEG PIPING IS VOIDED

III. RCP'S PRESSURIZE UPPER DOWNCOMER REGION, DEPRESSING DOWNCOMER LEVEL AND SUPPORTING HIGHER LEVEL IN VESSEL

IV. WITH FOUR RCP'S OPERATING, DOWNCOMER LEVEL IS DEPRESSED TO BOTTOM OF OF CORE BARREL, AND STEAM IS PUMPED INTO INNER REACTOR VESSEL

MODIFICATIONS TO THE C-E SMALL BREAK LOCA EVALUATION MODEL FOR CONTINUED RCP OPERATION

FEATURE	EVALUATION MODEL	LICENSING RCP MODEL	BEST-ESTIMATE MODEL
1. FLUID MODEL	DRIFT FLUX	DRIFT FLUX FOR UPWARD FLOW OR DOWNWARD FLOW AT LOW VELOCITY, HOMOGENEOUS FOR DOWNWARD FLOW AT HIGH VELOCITY	
2. PUMP HEAD DEGRADATION	NOT CONSIDERED	CALCULATED AS A FUNCTION OF VOID FRACTION BASED UPON ANC DATA	
3. DOWNCOMER TO U.P. BYPASS	NOT CONSIDERED	EXPLICITLY MODELED →	→
4. SECONDARY SIDE PRESSURE CONTROL	PASSIVE ONLY (SAFETY VALVES)	TURBINE BYPASS AND ATMOSPHERIC DUMP VALVES OPERATIONAL	
5. TWO-PHASE LEAK FLOW	MOODY →	→	HOMOG. EQUIL.
6. INNER VESSEL VOID DISTRIBUTION	LICENSING MODEL →	→	IMPROVED MODEL

DRIFT FLUX/HOMOGENEOUS MODEL OF PRIMARY SYSTEM HYDRAULIC BEHAVIOR

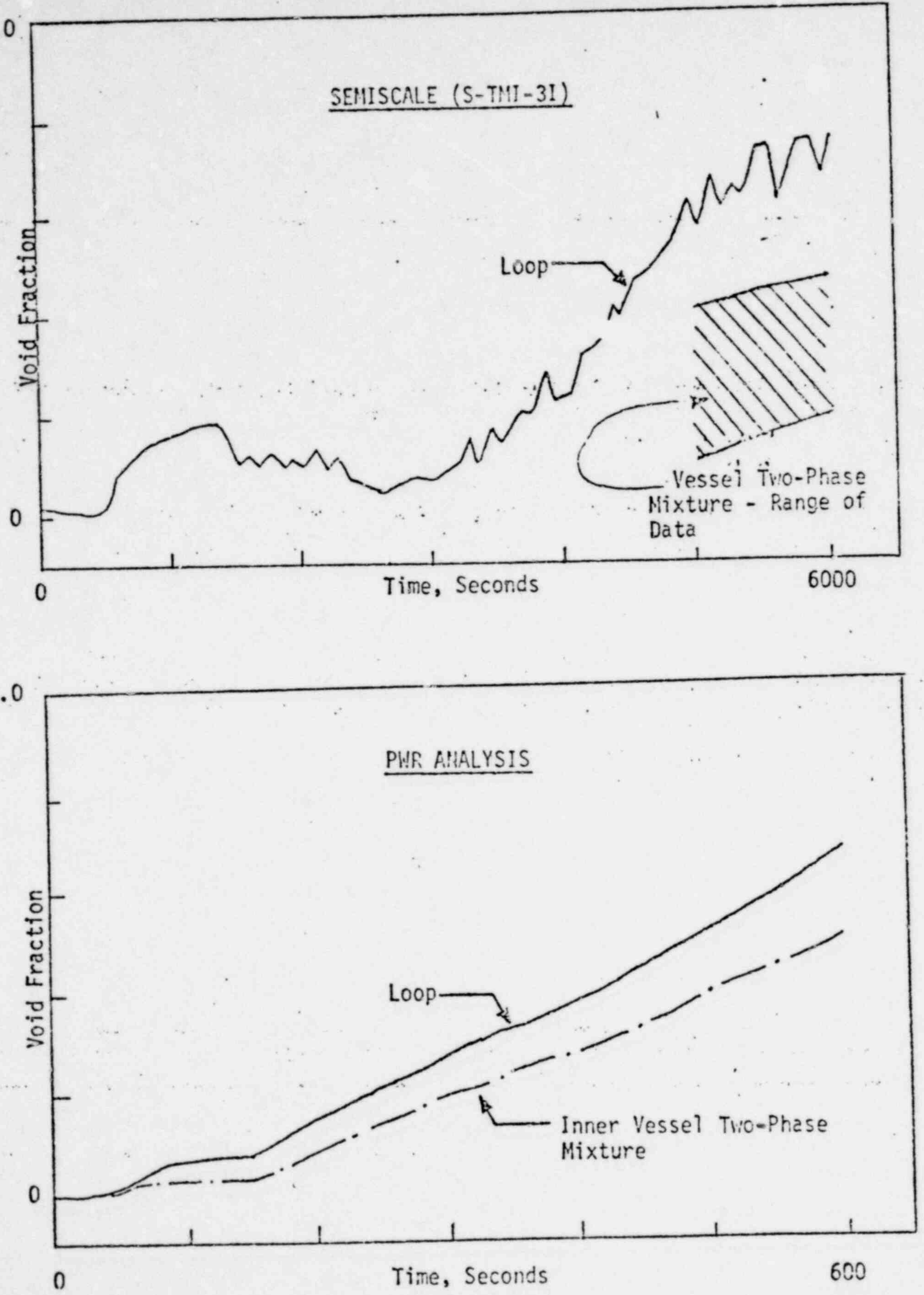
I. DRIFT FLUX MODEL IS USED AT ALL TIMES IN THE REACTOR INNER VESSEL, HOT LEGS, AND STEAM GENERATOR RISER SIDE

II. HOMOGENEOUS MODEL IS USED AT ALL TIMES IN THE COLD LEG PIPING, LOOP SEALS, AND STEAM GENERATOR COLD SIDE

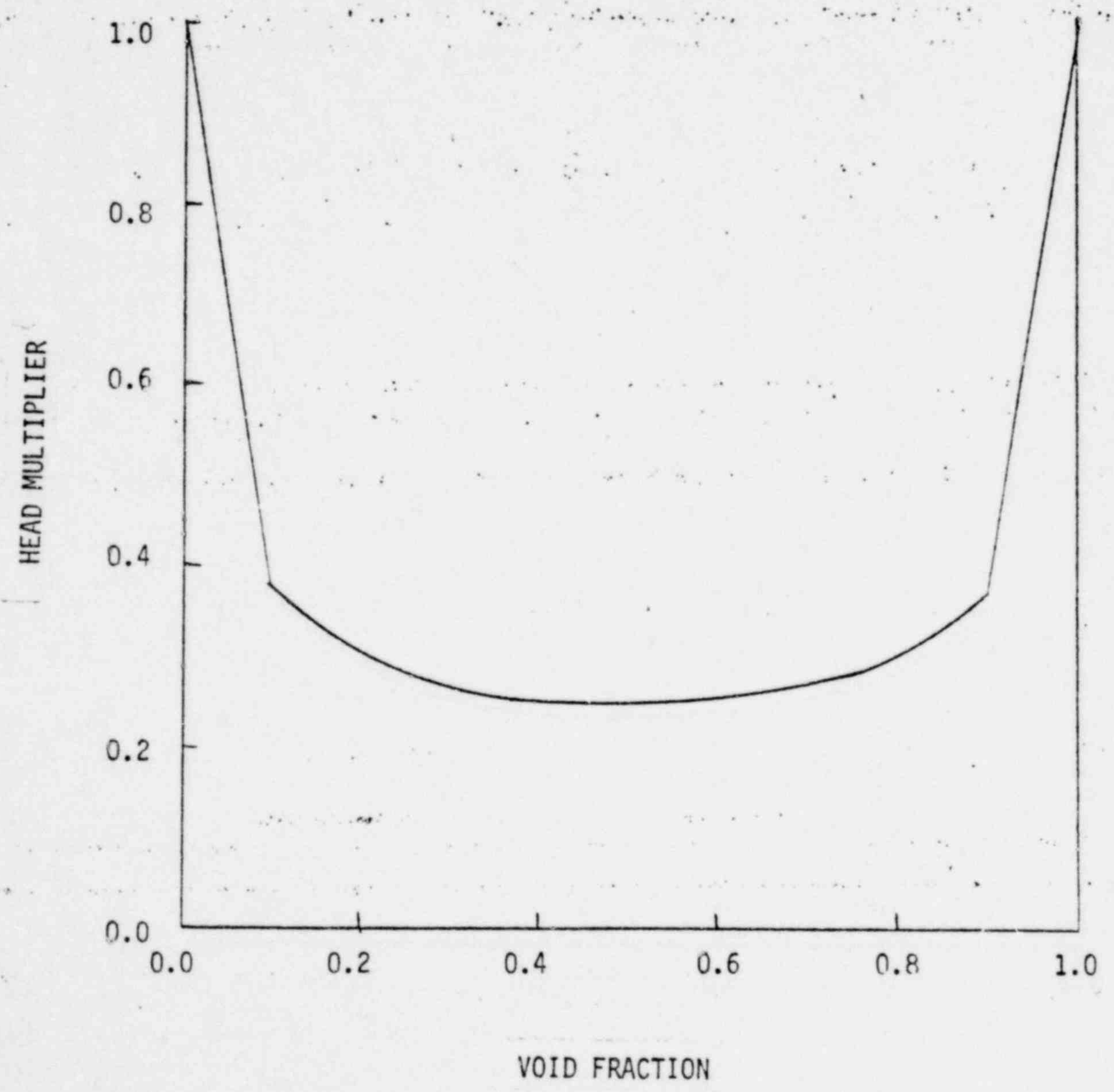
III. DOWNCOMER IS MODELED HOMOGENEOUSLY WHEN DOWNWARD MIXTURE VELOCITY IS HIGH. DRIFT FLUX MODEL IS USED WHEN MIXTURE VELOCITY FALLS BELOW SWITCHING CRITERION

IV. SWITCHING CRITERION IS DEFINED BY NET VELOCITY OF VAPOR PHASE (MIXTURE VELOCITY - DRIFT VELOCITY ≤ 0)

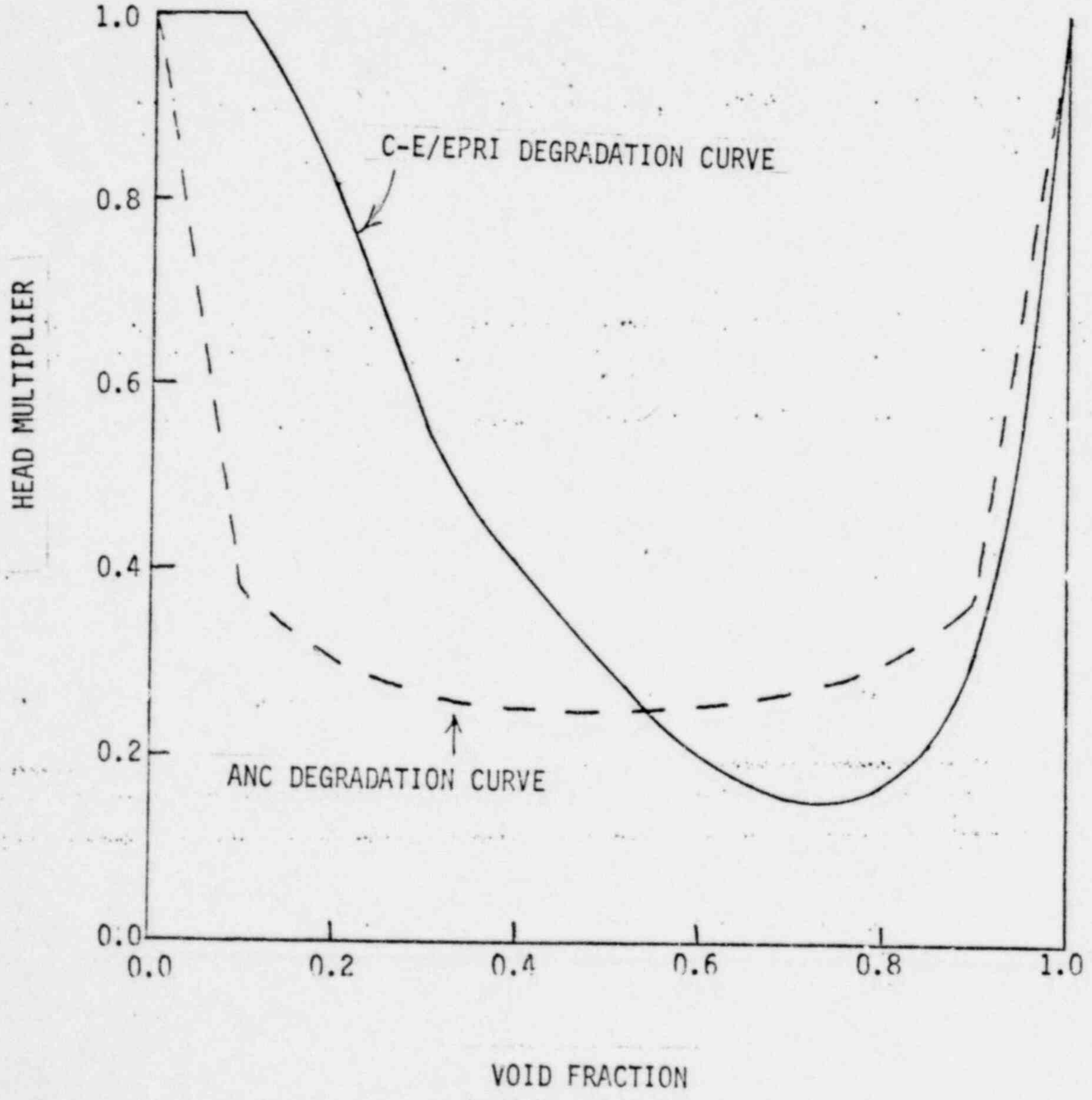
Loop and Vessel Void Fraction



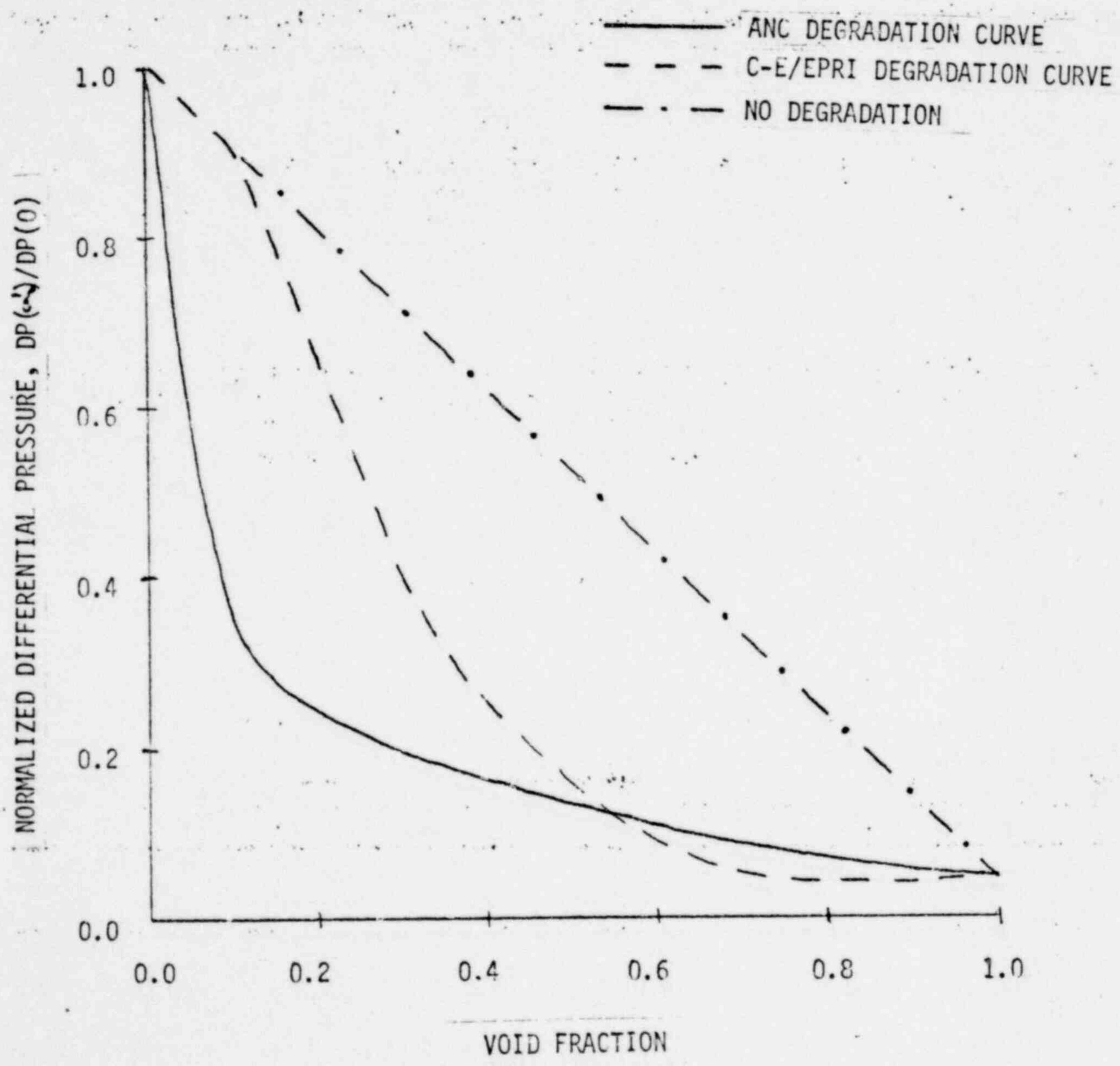
PUMP HEAD DEGRADATION CURVE BASED UPON ANC DATA



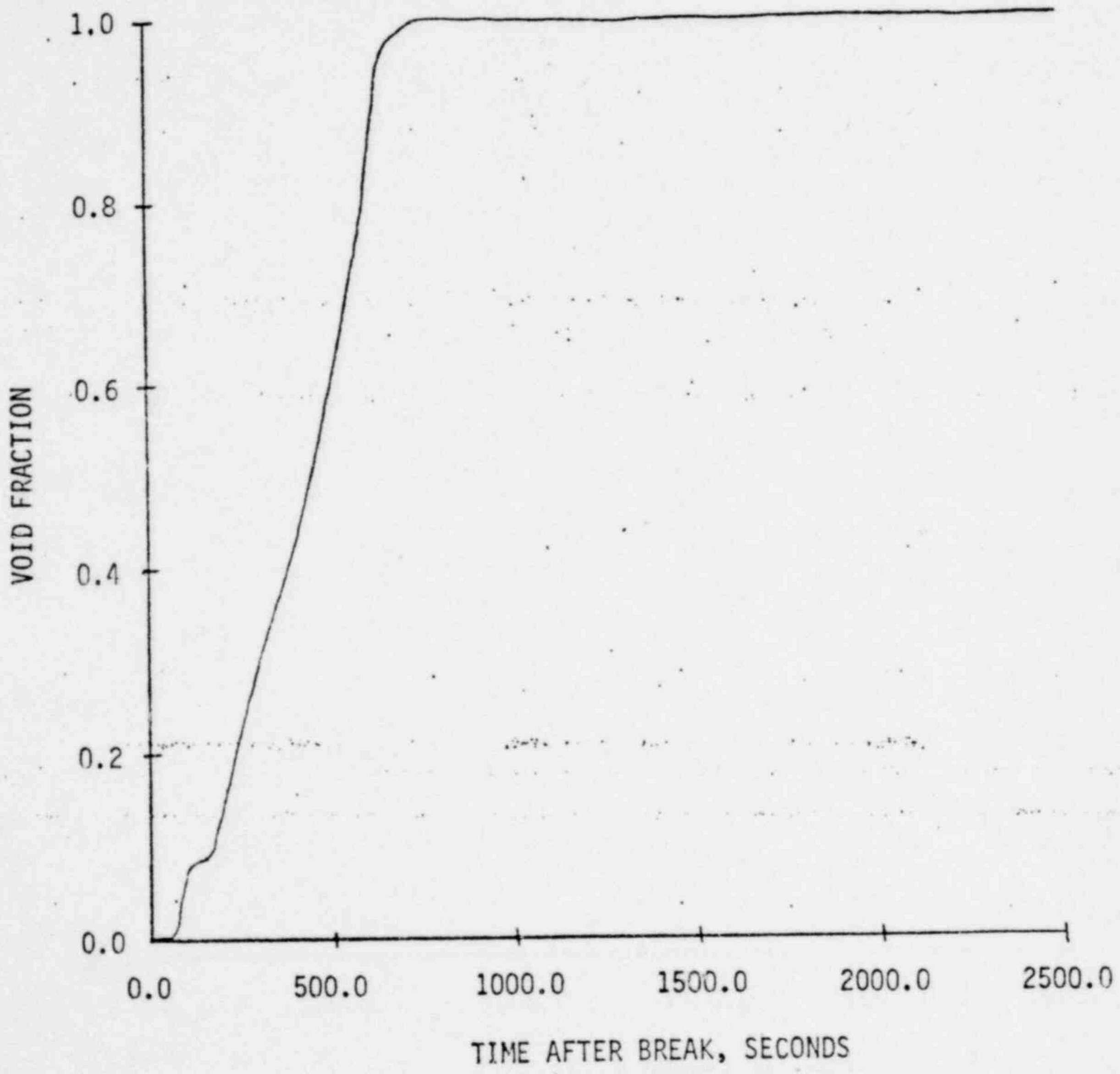
PUMP HEAD DEGRADATION CURVE BASED UPON C-E/EPRI DATA



NORMALIZED DIFFERENTIAL PRESSURE ACROSS AN OPERATING RCS PUMP DURING THE TWO-PHASE FLOW PERIOD



VOID FRACTION IN COLD LEG PIPING



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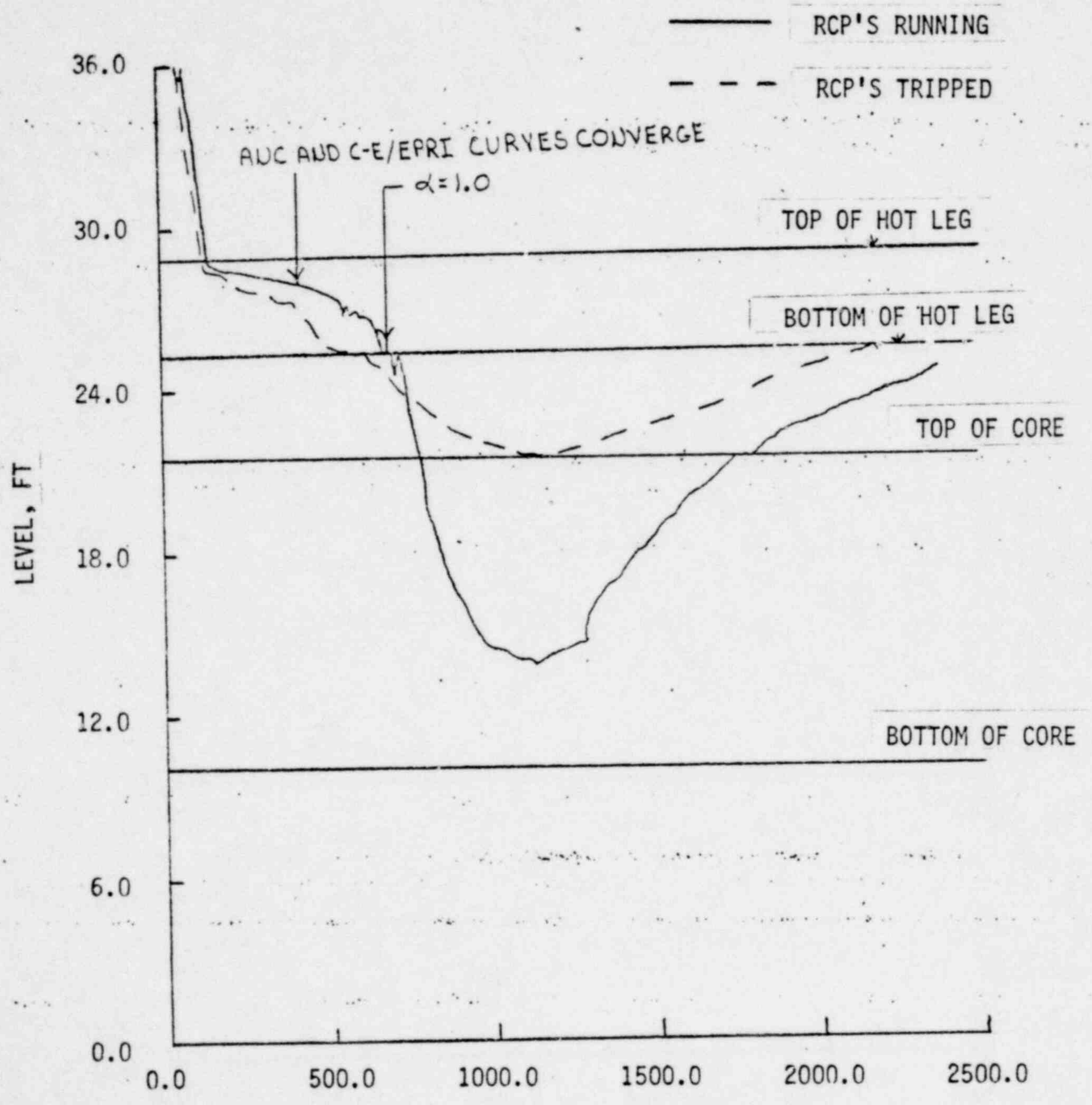
MIXTURE LEVEL IN REACTOR VESSEL



TIME AFTER BREAK, SECONDS

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SUMMARY OF SPECIAL MODEL FEATURES FOR CONTINUED RCP OPERATION

I. C-E HOMOGENEOUS/DRIFT FLUX FLUID MODEL PREDICTS PRIMARY SYSTEM VOID DISTRIBUTION SIMILAR TO THAT OBSERVED IN MOD-3 SEMISCALE

II. DURING TWO-PHASE FLOW PERIOD, EFFECT OF RCP OPERATION ON REACTOR VESSEL MIXTURE LEVEL IS NEGLIGIBLE AND INSENSITIVE TO HEAD DEGRADATION MODEL

CALCULATIONS TO STUDY THE
EFFECT OF RCP OPERATION
ON THE SMALL BREAK LOCA

PART I

WHAT IS REQUIRED TO ENSURE PRESENT LICENSING ANALYSIS RESULTS REMAIN LIMITING

-- BREAK SIZE
-- BREAK LOCATION
-- RCP SHUTOFF TIME

PART II

WHAT IS REQUIRED, BY MORE REALISTIC EVALUATION, TO MINIMIZE THE ADVERSE EFFECT OF RCP's?

-- EFFECT OF BEST ESTIMATE MODEL
-- ALLOWABLE OPERATING CONDITIONS
-- EFFECT OF ECCS DESIGN

ANALYSIS MATRIX

PART I

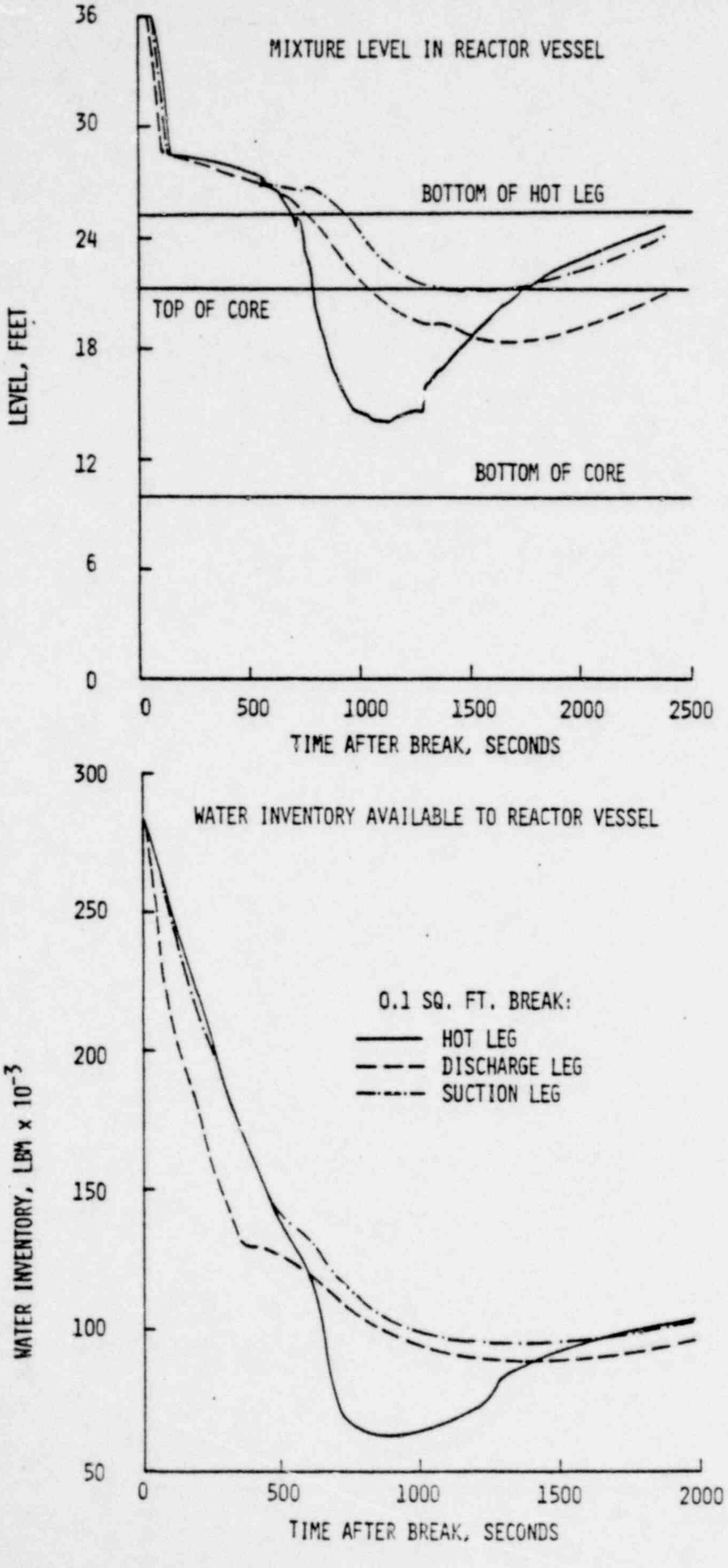
CASE	BREAK SIZE	BREAK LOCATION	RCP #	RCP SHUTOFF TIME	DECAY HEAT
EFFECT OF BREAK SIZE					
P7	0.1	HL	4/4	∞	1.2
P8	0.05	HL	4/4	∞	1.2
H.C.	0.02	HL	4/4	∞	1.2
EFFECT OF BREAK LOCATION					
P3	0.1	CL	4/4	∞	1.2
P7	0.1	HL	4/4	∞	1.2
A	0.1	SL	4/4	∞	1.2
EFFECT OF RCP SHUTOFF TIME					
P4	0.1	HL	4/0	RT	1.2
P11	0.1	HL	4/0	6 MIN	1.2
P9	0.1	HL	4/0	10	1.2
P7	0.1	HL	4/4	∞	1.2

SUMMARY OF RESULTS

PART I

	CORE UNCOVERY			WATER INVENTORY		HOT ROD
	Start(sec)	Duration(sec)	Depth(ft)	Time (sec)	Minimum (lbm)	PEAK TEMP(°F)
EFFECT OF BREAK SIZE						
P7 (0.1 ft^2)	800	950	7.6	900	61,000	>2200
P8 (.05 ft^2)	1700	1150	4.8	1850	63,000	>2200
HC (.02 ft^2)	--	0	0	3600	102,000	~550
EFFECT OF BREAK LOCATION						
P3 (CL)	1050	1450	3.1	1500	86,000	<2200
P7 (HL)	800	950	7.6	900	61,000	>2200
A (SL)	1450	100	0.4	1350	94,000	~600
EFFECT OF RCP SHUTOFF TIME						
P4 (RT)	1200	<60	0.2	1050	102,000	~600
P11 (6 min.)	625	950	3.1	850	90,000	1468
P9 (10 min.)	750	1000	5.3	900	80,000	>2200
P7 (∞)	800	950	7.6	900	61,000	>2200

EFFECT OF BREAK LOCATION



CONCLUSIONS

PART I

(1) THE BREAK SIZES FOR WHICH RCP OPERATION HAS A SIGNIFICANT EFFECT IS LIMITED TO A NARROW RANGE (.02 - 0.1 FT^2).

(2) THE LIMITING BREAK LOCATION FOR RCP OPERATION IS THE HOT LEG.

(3) THE LIMITING BREAK SIZE IS THE LARGEST WHICH AVOIDS SIGNIFICANT ACCUMULATOR (SIT) INJECTION TO RECOVER THE CORE.

(4) THE LIMITING BREAK SIZE FOR RCP OPERATION IS 0.1 FT^2; THIS BREAK REQUIRES THE RCPs OFF IN 6 MINUTES TO KEEP CLAD TEMPERATURES BELOW CURRENT LICENSING LIMITS.

ANALYSIS MATRIX

PART II

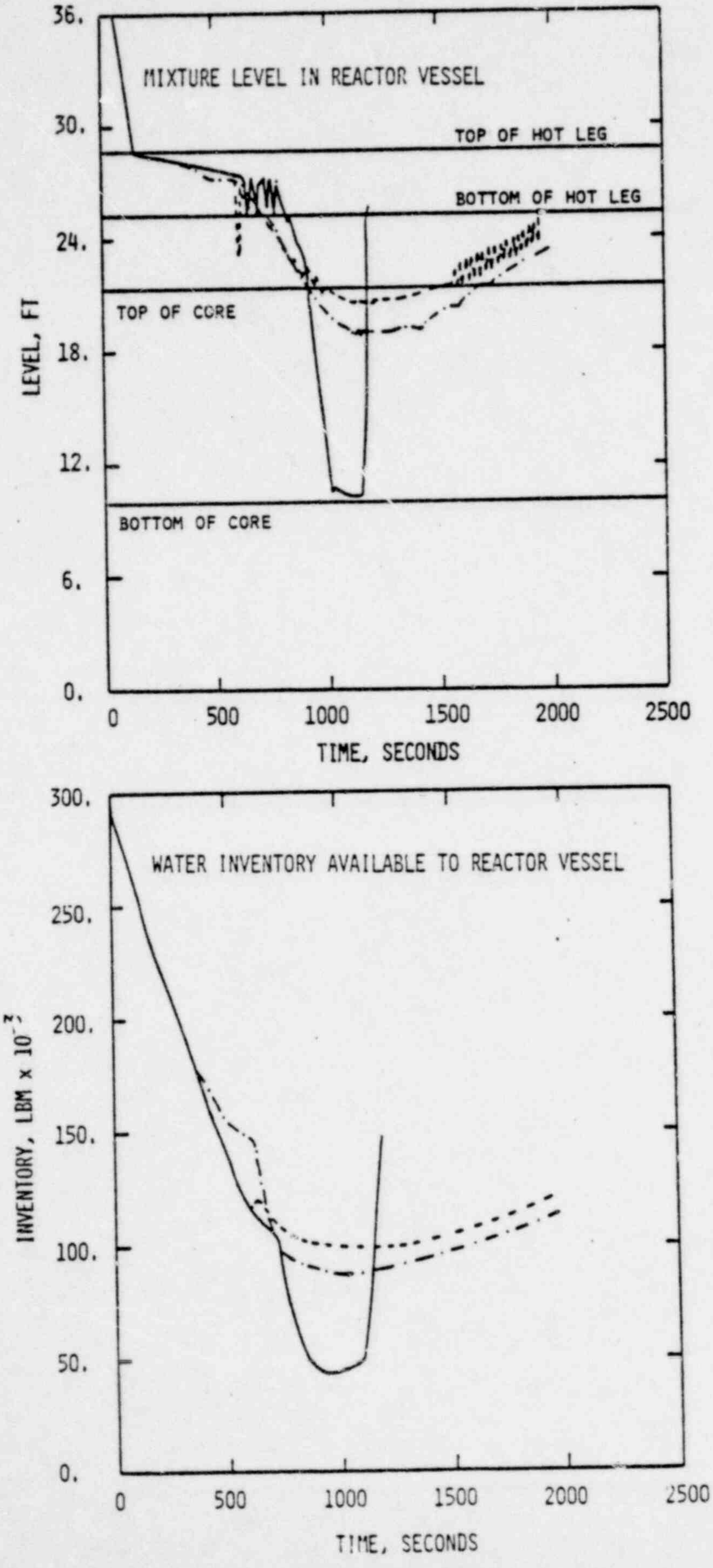
CASE	BREAK SIZE	BREAK LOCATION	RCP #	RCP SHUTOFF TIME	HPSI #	HPSI SHUTOFF TIME	DECAY HEAT	LEAK FLOW	SIT PRESSURE	HPSI SHUTOFF PRESSURE
EFFECT OF 'BE' ANALYSIS										
P14	0.1	HL	4/4	∞	2	∞	1.0	HEM	200	NOM
P10	0.1	HL	4/4	∞	2	∞	1.2	M	200	NOM
H	0.1	HL	4/0	10 MIN	1	∞	1.0	HEM	200	NOM
P11	0.1	HL	4/0	6 MIN	1	∞	1.2	M	200	NOM
ALLOWABLE OPERATING CONDITIONS										
B	0.1	HL	4/0	$T_{MIN\ INV}$ FROM P14	2/1	$T_{MIN\ INV}$ FROM P14	1.0	HEM	200	NOM
C	0.1	HL	4/2	RT	1	∞	1.0	HEM	200	NOM
D	0.1	HL	4/4	∞	1&1 CP	∞	1.0	HEM	200	NOM
G	.07	HL	4/4	∞	1&1 CP	∞	1.0	HEM	200	NOM
H	0.1	HL	4/0	10 MIN	1	∞	1.0	HEM	200	NOM
I	0.1	HL	4/2	5 MIN	1	∞	1.0	HEM	200	NOM
EFFECT OF ECCS DESIGN										
E	0.1	HL	4/4	∞	1	∞	1.2	HEM	600	NOM
F	0.1	HL	4/4	∞	1	∞	1.2	HEM	200	HIGH

SUMMARY OF RESULTS

PART II

	CORE UNCOVERY			WATER INVENTORY		HOT ROD
	Start(sec)	Duration(sec)	Depth(ft)	Time(sec)	Minimum(lbm)	PEAK TEMP(°F)
EFFECT OF 'BE' ANALYSIS						
P10	650	250	1.5	800	72,000	<1200
P14	---	0	0	900	87,000	∿ 550
P11	625	950	3.1	850	90,000	1468
H	985	550	0.9	1075	98,250	< 800
ALLOWABLE OPERATING CONDITIONS						
P14	---	0	0	900	87,000	∿ 550
B	950	810	4.2	1050	83,800	1683
C	920	800	2.5	1030	86,800	1211
D	915	255	11.2	945	44,094	<2200
G	1380	870	9.0	1390	49,488	>2200
H	985	550	0.9	1075	98,250	< 800
I	930	790	2.6	1030	86,800	<1300
EFFECT OF ECCS DESIGN						
P7	800	1050	7.6	900	61,000	>2200
E	790	100	4.5	880	61,345	<1200
F	850	915	5.4	915	66,866	>2200

EFFECT OF TRIPPING RCP



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CONCLUSIONS

PART II

(1) MORE REALISTIC MODELING CONFIRMS THAT RCPs MUST BE SHUT OFF IF ONLY ONE HPSI PUMP IS ASSUMED AVAILABLE.

(2) THE MINIMUM REQUIRED TIME TO SHUT OFF ALL RCPs IS EXTENDED FROM 6 TO 10 MINUTES AFTER SIAS. ALL RCPs SHUT OFF AT $\leq$10 MINUTES WILL ENSURE ADEQUATE CORE COOLING.

(3) IT IS SUFFICIENT TO SHUT OFF ONLY TWO RCPs. IF TWO RCPs ARE SHUT OFF AT $\leq$5 MINUTES ADEQUATE CORE COOLING IS MAINTAINED.

(4) RCP SHUT OFF TIMES DERIVED FOR THE 'TYPICAL' DESIGN ARE CONSERVATIVE FOR HIGHER PRESSURE SITs AND/OR HIGHER PRESSURE HPSI PUMPS.

IMPACT OF REACTOR COOLANT PUMP TRIP ON NON-LOCA TRANSIENTS

- NON-LOCA TRANSIENTS EVALUATED
- IMPACT ON SPECIFIED ACCEPTABLE FUEL DESIGN LIMITS
- IMPACT ON ACCIDENT CONSEQUENCES
- CONCLUSIONS

NON-LOCA EVENTS WHICH CAN

DEPRESSURIZE RCS TO SIAS SETPOINT

1. INCREASED HEAT REMOVAL BY THE SECONDARY SYSTEM
   - A) EXCESS LOAD (DUE TO STEAM SYSTEM VALVE MALFUNCTION)
   - B) STEAM LINE BREAK

2. DECREASE IN RCS INVENTORY
   - A) PRESSURIZER LEVEL CONTROL SYSTEM MALFUNCTION
   - B) STEAM GENERATOR TUBE RUPTURE

3. RCS PRESSURE CONTROL MALFUNCTION
   - A) PRESSURIZER PRESSURE CONTROL SYSTEM MALFUNCTION

IMPACT ON SPECIFIED ACCEPTABLE FUEL DESIGN LIMITS

- ASSOCIATED WITH SIMULTANEOUS LOW PRESSURE TRIP AND SIAS OR BY HIGH RATE OF DEPRESSURIZATION
- IMMEDIATE RCP TRIP MAY RESULT IN FLOW DECREASE BEFORE HEAT FLUX DECAYS DUE TO ROD INSERTION
- POSSIBLE SHORT TERM VIOLATION OF SAFDL ON DNBR
- THEREFORE WAIT AT LEAST FIVE SECONDS FOLLOWING FULL ROD INSERTION BEFORE TRIPPING RCPs

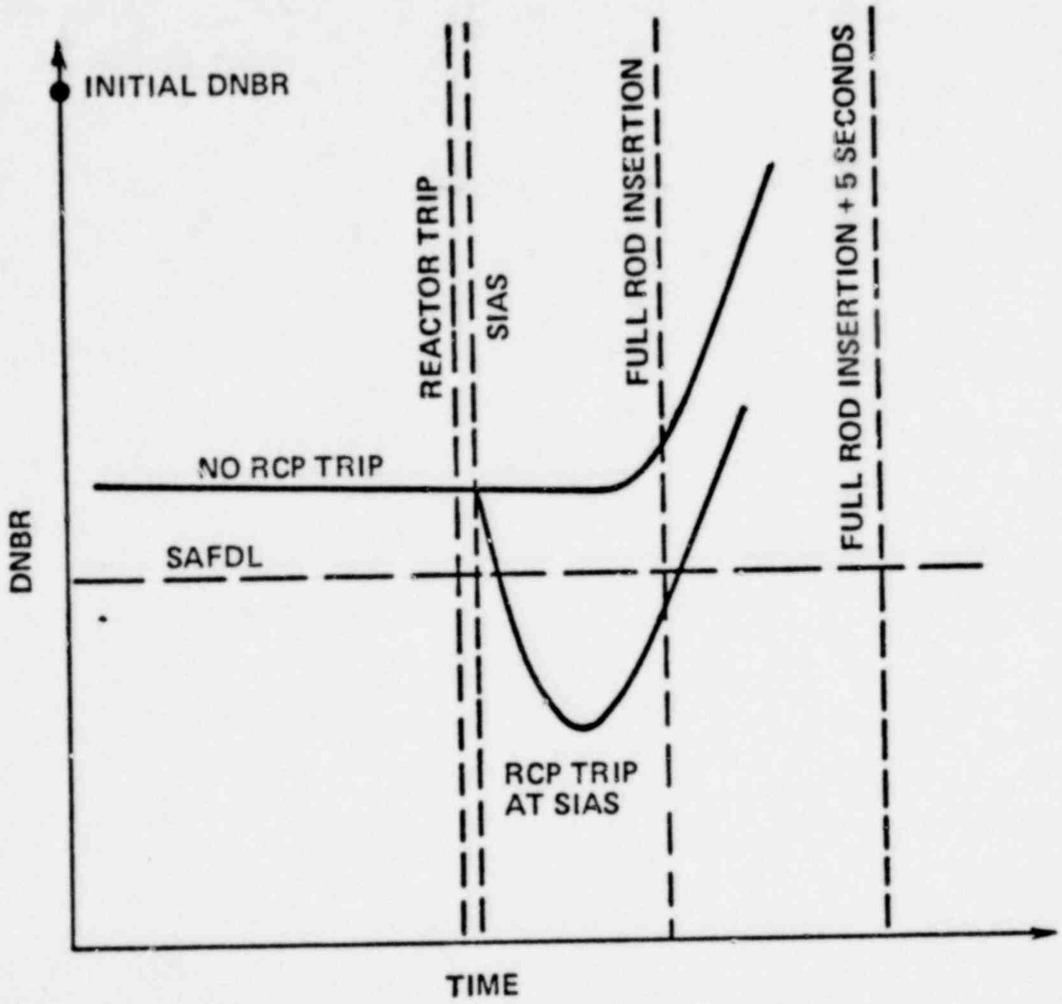

Figure 1
SHORT TERM RESULT OF RCP TRIP

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IMPACT ON MARGIN TO FUEL FAILURE
DURING STEAM LINE BREAK POST-TRIP
RETURN-TO-POWER

- FLOW COASTDOWN PRIOR TO OR DURING POST-TRIP RETURN-TO-POWER REDUCES MARGIN TO FUEL FAILURE
- ANALYSES ON RECENT DOCKETS SHOW NO FUEL FAILURE EXPECTED FOR SLB WITH CONCURRENT RCP TRIP
- CONTINUED OPERATION OF AT LEAST ONE RCP IN EACH SG LOOP IS PREFERABLE TO TRIPPING ALL RCPs

IMPACT ON RADIOLOGICAL RELEASES

- REDUCING RCS FLOW INCREASES COOLDOWN TIME
- FOR SGTR REDUCED RCS FLOW INCREASES TIME MAIN STEAM SAFETY VALVES MAY BE OPEN
- INCREASED RELEASES ARE NOT EXPECTED TO EXCEED DOSE LIMITS
- CONTINUED OPERATION OF AT LEAST ONE RCP IN EACH SG LOOP IS PREFERABLE TO TRIPPING ALL RCPs

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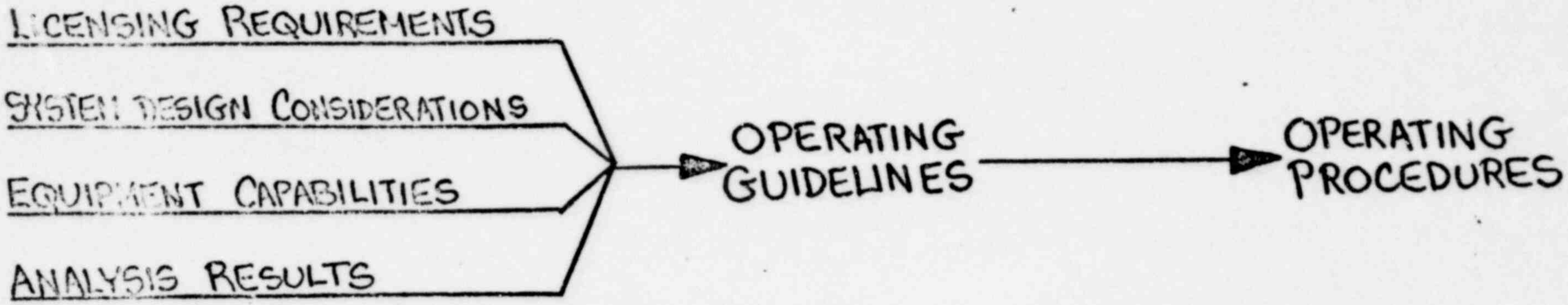
CONCLUSIONS OF EVALUATION OF
RCP TRIP ON NON-LOCA TRANSIENTS

- CONSEQUENCES OF TRANSIENTS ARE MORE ADVERSE: HOWEVER, ACCEPTANCE CRITERIA ARE NOT EXPECTED TO BE VIOLATED

- WAIT AT LEAST FIVE SECONDS FOLLOWING FULL ROD INSERTION BEFORE TRIPPING RCPs

- CONTINUED OPERATION OF AT LEAST ONE RCP IN EACH SG LOOP IS PREFERABLE TO TRIPPING ALL RCPs

INPUTS TO OPERATIONAL GUIDANCE



LICENSING REQUIREMENTS

SYSTEM DESIGN CONSIDERATIONS

EQUIPMENT CAPABILITIES

ANALYSIS RESULTS

OPERATING GUIDELINES

OPERATING PROCEDURES

FEATURES OF CE GUIDELINES

BASES SECTION

SYMPTOMS PRIORITIZED

FOCUS ON CRITICAL SAFETY FUNCTIONS

ACTION STATEMENTS PRIORITIZED

ACTIONS THAT MUST BE CARRIED OUT ARE CLEARLY IDENTIFIED

THE GOAL OF THE GUIDELINE IS TO ACHIEVE A STABLE PLANT CONDITION

RCP GUIDANCE

STOP TWO REACTOR COOLANT PUMPS ONE IN EACH LOOP AFTER IT HAS BEEN VERIFIED THAT THE RODS HAVE BEEN INSERTED FULLY FOR 5 SECONDS. IF THIS ACTION HAS NOT BEEN COMPLETED WITHIN THE FIRST 5 MINUTES AFTER SIAS, ALL REACTOR COOLANT PUMPS MUST BE STOPPED WITHIN 10 MINUTES.