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NUCLEAR REGULATORY COMMISSION

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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

THERMAL HYDRAULIC PHENOMENA SUBCOMMITTEE MEETING

NRC-RES T/H RESEARCH PERTAINING TO

PTS RULE REEVALUATION

(ACRS)

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TUESDAY, JULY 17, 2001

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CORVALLIS, OREGON

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The ACRS Thermal Hydraulic Phenomena Subcommittee met at Oregon State University, Richardson Hall, Room 313, Corvallis, Oregon, at 8:15 a.m., Dr. Graham B. Wallis, Chairman, presiding.

COMMITTEE MEMBERS PRESENT:

GRAHAM B. WALLIS, Chairman

THOMAS S. KRESS, Member

WILLIAM J. SHACK, Member

ACRS STAFF PRESENT:

PAUL A. BOEHNERT, ACRS Engineer

VIRGIL SCHROCK, ACRS Consultant

NUCLEAR REGULATORY COMMISSION REPRESENTATIVES PRESENT:

STEPHEN BAJOREK, RES/SMSAB

DAVID BESSETTE, RES/SMSAB

NILESH C. CHOKSHI, NRC/RES/DET/MEB

JAMES T. HAN, RES/DSARE/SMSAB

JACK ROSENTHAL, U.S. NRC/RES/SMSAB

ROY WOODS, NRC RES/DRAA/PRN3

A-G-E-N-D-A

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

(8:15 a.m.)

CHAIRMAN WALLIS: The meeting will now come to order. This is a meeting of the ACRS Subcommittee on Thermal Hydraulic Phenomena. I'm Graham Wallis, the Chairman of the Subcommittee.

ACRS Members in attendance are Dr. Thomas Kress, Mr. William Shack. And also in attendance is ACRS Consultant Virgil Schrock.

The purpose of this meeting is to discuss the status of:

Item 1, the NRC Office of Nuclear Regulatory Research -- big topic -- experimental program being conducted at the Oregon State University, OSU, APEX-CE facility, pertaining to thermal hydraulic phenomena associated with pressurized thermal shock, PTS, in support of the NRC PTS Rule Reevaluation Program; and,

2, the RES Program underway at OSU to investigate phase separation phenomena in support of proposed model upgrades for the RES TRAC M and RELAP5 Codes.

The Subcommittee will gather information, analyze relevant issues and facts, and formulate proposed positions and actions as appropriate for deliberation by the full Committee.

Mr. Paul Boehnert is the designated federal official for this meeting.

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 July 6, 2001.

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

It is requested that speakers first identify themselves and speak with sufficient clarity and volume so that they can be readily heard.

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

Now I'm ready to start. I wonder if Professor Adams is here.

MR. REYES: Mr. Chairman?

CHAIRMAN WALLIS: Yes.

MR. REYES: If I might, this is Jose Reyes from Oregon State University. Our department head, Andrew Klein is here. He could give a talk about --

CHAIRMAN WALLIS: Maybe he can, yes, give us a few words, and then I'll go ahead with the meeting. Thank you very much. Very appropriate.

MR. KLEIN: My name is Andrew Klein.

THE REPORTER: Could you go to the podium so we could record you?

MR. KLEIN: Sure. My name's Andy Klein. I'm Department Head of Nuclear Engineering here at Oregon State University. And we're very pleased to have this Committee, Subcommittee meeting here at Oregon State University to review some of the work that Drs. Reyes and Wu have done over the past few years. It's been very important to the Department, to the College, and the University.

This is one of the key programs in the College of Engineering and certainly one of the key programs in the Department of Nuclear Engineering. And we're very pleased that the NRC has supported the work here, and the DOE has supported work here over the years. And we look forward to continuing to work.

If you have any questions, Teresa Culver, who is in the back there, will be able to help us out on logistics. If you have any technical questions, I'll defer those to Dr. Reyes. Thank you.

CHAIRMAN WALLIS: Thank you very much.

Now we've gained some time. Let's continue doing that.

Jack, are you ready for the opening remarks for RES?

MR. ROSENTHAL: My name is Jack Rosenthal. I'm the Branch Chief of the Safety Margins and Systems Analysis Branch in the Office of Research. And I was just asked to make some opening remarks.

We see the APEX facility as very important at this point, that there's little else of places to do pressurized water reactor experiments.

And so we're using the OSU, both the experimental facility and their analytic ability, to work on issues such as pressurized thermal shock, after which we would do some work on bore and dilution, after which -- my sequence may not be right -- we have some plans for work on -- to answer some steam generators to the accident-related issues involving flow mixing that the ACRS has already reviewed.

And then after that to work on AP1000 in some sort of yet-to-be-defined collaborative mode with the Department of Energy, similar to the arrangements that were made for AP600. So that's a continuing long-term involvement.

In preparation for the meeting we were going over some of the work on two-phase flow separation. And we intend to put those models into TRAC M within the next 12 months and probably sooner. So the work is just very important to our overall efforts.

Later Nilesh, Dr. Chokshi, will be talking about an overview of the pressurized thermal shock effort. And then the staff has just a slide or two as topics come up.

CHAIRMAN WALLIS: Are there any other remarks from NRC?

(Comments off the record.)

CHAIRMAN WALLIS: Yeah. Would you like to? Yes. Thank you.

THE REPORTER: When they speak from out there, we can't get them on the recording machine.

CHAIRMAN WALLIS: Do you have a portable mic or something, or do they have to go up to...

(Comments off the record.)

MR. CHOKSHI: Good morning. My name is Nilesh Chokshi. I'm Chief of the Materials Engineering Branch. Your agent actually is Mike Mayfield, but I think he's at the Excelon meetings. So in place of Mike, I think I'll give you a brief status and overview.

Let me start by thanking the Committee for having the meeting here. Without this meeting I would never have come to this place and see the facility or understand a little bit -- improve my understanding of thermal hydraulics.

So I'm looking forward as much as anybody to this visit and seeing the facilities. So it's going to be an interesting two days for me personally.

Since the focus of this meeting is the thermal hydraulics and research of the facility and discussion of projects, I'm going to limit myself to just a brief overview of where we are and discuss briefly the status of activities in two other areas of probabilistic fracture mechanics and PRA.

And a number of people are here from the staff, including Roy Woods. So if you have some questions on PRA and so forth, he's here to answer. But I'm going to take a very few minutes, and it won't take me half an hour, as shown on the Agenda.

We have been briefing ACRS Committees on the progress of this PTS Evaluation Project, so I think my remarks are -- basically it does not go into any background and introductory material, with a very brief introduction, so...

I'm going to take a few minutes to put in perspective this particular activity. The current 10

CFR 50.61 pressurized thermal shock rule was promulgated in 1983.

And between the '83-to-'86 timeframe work we conducted detailed studies called integrated pressurized thermal shock on the three -- three plants, I believe -- four plants, to develop methodology when somebody cannot meet the PTS screening criterion.

And as a result of this study, I think that Reg. 1.154 was published in 1987. That's -- my recollection is 1987.

And then during the '89-1990, the Yankee Rowe application, attempts were made to use the Reg., and subsequently it was discovered that there were a number of issues in applying that Reg. guide.

Since then a number of improvements in area of probabilistic fracture mechanics, some data as well as methodological. So in April '99 we initiated this project. And I think that's sort of a background.

And I think one of the features of this program -- some of the features are, one, this is the risk-informed application. There has been extensive industry and public involvement. We are working with a number of industry groups, as you know, Materials

Lab Program, EPRI, and utilities, particularly in the PRA area to make sure that our models reflect the actual plant conditions.

And, as I mentioned earlier, we have been coming to ACRS frequently.

In the program the four plants that are being looked at, as you know, are Oconee, Calvert Cliffs, Palisades, and Beaver Valley.

With this, a little bit of introduction, I'm going to jump into the status of the program.

MR. KRESS: You were using INEEL to do these four plants?

MR. CHOKSHI: We started with INEEL, but --

MR. ROSENTHAL: Yeah. I'll just put on my army voice. We're doing the Palisades' calculations inhouse.

The Oconee, Calvert, and Beaver Valley calculations are being done at ISL under Dave Bessette's supervision. But I want you think of this as a joint staff and contractor effort, because there isn't a day of the week that we don't interact with them.

CHAIRMAN WALLIS: What is "ISL," Jack? What "ISL"?

MR. HAN: Systems -- I can't remember.

(Simultaneous talking.)

MR. HAN: Information System Laboratory.

MR. ROSENTHAL: Information System Laboratory.

CHAIRMAN WALLIS: It's a Scientec derivative?

MR. ROSENTHAL: It's a Scientec derivative because there were conflicts of interest or potential conflicts of interest, so they spun off ISL.

CHAIRMAN WALLIS: Where are they?

MR. ROSENTHAL: Down the block from us.

They're in Rockville.

MR. BESSETTE: Yeah, they're two blocks down Rockville Pike.

MR. CHOKSHI: Okay. I think the current status, we are making progress in all three areas of the major technical studies: the thermal hydraulics, fracture mechanics, and the PRA.

One of the significant activities underway, particularly in the fracture mechanics area, is to finalizing the FAVOR Code inputs. The goal is to have all the uncertainty models and all the improvements by September. And then we will be going into doing plant-specific analysis.

I won't say anything about thermal hydraulics. I'll wait for the next two days, too, you know.

And in the progress on PRA, is -- I'll have more details, but you could have --

CHAIRMAN WALLIS: But you say it's completed, so if we find anything that's not completed, then --

MR. CHOKSHI: Well, that's why I sort of skipped over, because --

(Laughter.)

MR. CHOKSHI: -- because I think it's probably premature for me to say it is completed until I hear. But I guess what was planned has been completed.

CHAIRMAN WALLIS: "Completed" means they've submitted the last bill; is that what it means?

MR. BESSETTE: The money ran out.

MR. SCHROCK: Does this involve some new research, or is this massaging old data to find ways of improving its application?

MR. BESSETTE: No, it's new. This is David Bessette from Research. It's new experimental testing.

MR. SCHROCK: Done where?

MR. BESSETTE: Here, here. It's done in the APEX --

MR. SCHROCK: Oh, here?

MR. BESSETTE: -- facility.

MR. SCHROCK: Okay.

MR. BESSETTE: And you'll hear -- this is one of the main topics, is to hear about the testing that was done at -- the next two days.

MR. SCHROCK: I guess I was surprised at materials research. I --

MR. BESSETTE: Well, you're not going to hear anything about materials --

MR. SCHROCK: Well, we'll hear what it is.

CHAIRMAN WALLIS: Are we going to hear about this last one, the uncertainty in key variables in thermal hydraulics?

MR. BESSETTE: Not too much in the next two days. It's not --

CHAIRMAN WALLIS: Is that part of the work here, is to look at uncertainty?

MR. BESSETTE: Of course it feeds into uncertainty. You know, the experimental results give, you know, us much more of a feeling about uncertainty. And plus the analysis.

CHAIRMAN WALLIS: So who's going to do that work, the formulation of uncertainty?

MR. BESSETTE: Well, officially the uncertainty work is being done at the University of Maryland by the Almenas, and Mosleh, and Modarres.

CHAIRMAN WALLIS: So they're using some of the results from here to assess uncertainty?

MR. BESSETTE: That's right.

MR. KRESS: Before we take that off, Nilesh.

MR. CHOKSHI: Okay, sure.

MR. SHACK: You're saying FAVOR, reeval- -- revision of the PFM Code FAVOR will be done in September?

MR. CHOKSHI: We only -- we are in the process of implementing changes to the code.

MR. SHACK: Okay. Is that -- would that be a good time for you guys to come back to the Subcommittee, ACRS, and Materials Metallurgy Subcommittee?

MR. CHOKSHI: Oh, I think so, yeah. Yeah, we'll be -- and talked about uncertainty modeling and different things, what improvement --

MR. SHACK: Um-hum. Yeah, because I know there's been some questions about that; they wanted to see that when it was completed.

Okay. Thank you.

MR. CHOKSHI: Yeah. Right now we are at sort of documenting a number of things we are doing, so we should be ready by September.

MR. SHACK: Okay.

MR. CHOKSHI: In fact, just a last question regarding the uncertainties. And as part of the PRA work, and as David mentioned, the University of Maryland is looking uncertainties modeling in all areas of the program.

MR. KRESS: How are they dealing with epistemic uncertainties?

MR. CHOKSHI: We are considering. I mean, all right. Now how is -- I think in each of the areas is somewhat of a different question.

For example, in the materials area, on the toughness and the flaw distribution, you know they each -- on the flaw distribution, for example, we have an expert -- expert elicitation as well as the ND examination of actual vessels, trying to get, you know, the different uncertainties.

On the toughness side there has been a joint effort with industry in developing epistemic and both aleatory uncertainties. So --

MR. KRESS: But specifically it's generally by expert opinion?

MR. CHOKSHI: In part, not always. You know, because on the flaw distribution, we have both the data simulations as well as expert opinion. But epistemically more -- most part, I think I would say, an expert.

MR. SHACK: Nilesh, just on the PRA, I thought you also had some additional work going on on sort of containment performance under --

MR. CHOKSHI: Yes. Yeah. We --

MR. SHACK: That's too new to make it, or --

MR. CHOKSHI: We are -- well, I think that's sort of butted into this second bullet, for acceptable risk figures of merit. And I would say right now -- and, Roy, correct me -- that we are sort of still developing some concepts before -- and we had looked at some studies, actually, what, at Santa Barbara?

MR. KRESS: Is that Theophanus?

MR. BESSETTE: Yes. Well, we had a small effort with Theophanus where he looked at the effect of vessel failure on containment.

MR. SCHROCK: That's an application of his rho M process?

MR. BOEHNERT: Yes. He wrote up some paper on it. It's a -- I think it's at least out in draft form.

MR. CHOKSHI: But I think we are still far from, you know, settling on that issue in any sense, so...

MR. SHACK: I mean it will have substantial impact on your acceptance criteria, presumably.

MR. CHOKSHI: And I think when we start doing some plant-specific analysis it will sort of start. You know, how much we need to worry about that will come into focus, I think once we get some research and --

MR. KRESS: But my impression of the rho M process is that it gives a bound that is such that you can rule out the particular issue or sequence because of the low probability.

In here you're supposed to be doing a best estimate. I'm wondering how you are going to reconcile that sort of difference with the rho M process.

MR. CHOKSHI: Let me ask David.

Did you hear Dr. Kress' question? The

calculation of what work is being done by Dr. Theophanus?

CHAIRMAN WALLIS: Well, I think maybe we should move on to what's being done at OSU.

MR. KRESS: Yeah, we'll hear more about this later. Yes.

MR. BESSETTE: Yeah.

CHAIRMAN WALLIS: We'll get to you somewhere and ask you about Theophanus' work, but maybe we should --

MR. BESSETTE: Yeah. And we also did some inhouse work as well.

CHAIRMAN WALLIS: Yeah. We should spend time here on OSU work, --

MR. KRESS: Yeah.

CHAIRMAN WALLIS: -- because that's going to take a long time to go through, I think, anyway.

MR. KRESS: Yeah. Good thought.

MR. CHOKSHI: Okay. I think on the -- the next viewgraph is a little bit more details on what exactly is happening in the PRA area currently.

CHAIRMAN WALLIS: Nothing exact ever happens in PRA.

(Laughter.)

MR. CHOKSHI: I will just give you what I read. We'll be complete -- I think by this, shown here on the last couple of bullets, that Oconee and Beaver Valley PRA models will be revised by September 2001. And we are working with utilities to make sure that all updates reflect the current plant operations.

And then the Palisades and Calvert Cliffs by mid-November. And, you know, that that -- so by September then we'll start applying FAVOR to Oconee and start doing those calculations.

And I think, as it's shown here, that we are developing the PRA models for Oconee and Beaver Valley and basically updating Calvert Cliffs and Palisades.

My next two viewgraphs are on the thermal hydraulics. And I think I would say it's -- you know, you have the -- and I will just plan to skip that, because we were going to talk about this. And let me talk about something I have more familiarity, so...

And the next major piece of the area is the probabilistic fracture mechanics Code. And, as I mentioned, that there have been significant improvements in number of areas since the mid-'80s when we completed the IPTS program.

The flaw distribution was found to be one of the biggest area of uncertainties in the application of 1.- -- record 1.154.

Since then we have looked at a couple of pressure vessels through both nondestructive examination and destructive examination as well as, as I mentioned earlier, expert elicitation and simulation of -- through the codes like prodigal codes at -- directing flaw distributions for the plate, weld, and heat-affected zone materials. These are being right now programmed to the FAVOR Code.

At Pacific Northwest National Laboratory Steve Doctor and Fred Simonen have been doing most of the work.

The other area has been the crack initiation and arrest fracture toughness. There has been also significant improvement in the modeling as well as the data.

And one of the key issues here has been of the uncertainty. And we have been working with the University of Maryland to develop the epistemic as well as aleatory uncertainties.

Significant amount of new Smoglie data for the embrittlement correlations, and a new database as well as better correlations are being incorporated into the -- we also have a plant-specific material properties.

The fluence maps. And I think the beginning of this year we came and talked to the Committee about the Regulatory Guide. And that methodology has been applied to now the four plants to make -- address the mix of the fluence.

There has been also the -- in the fracture mechanics itself improvements, things like better find element modeling, the treatment of residual stresses. So all of this sort of has been incorporated into the PFM analysis.

Early in 1998 we did incorporate some of these improvements and did a test case, going back to one of the IPTS plants. And at least based on that it looked like there could be some reduction, reduction of counterweightism in the screening criteria.

MR. KRESS: In this context what do you mean by the "risk-informed model"?

MR. CHOKSHI: I didn't hear that.

MR. KRESS: Your first bullet, I was wondering in the context of this what do you mean by "risk-informed model"?

MR. CHOKSHI: Well, because this -- all of this area has been integrated through the probabilistic risk assessment in making sure that the ultimate screening criteria and whatever we come up with has the, you know, the framework of Reg. Guide 1.174 or similar, you know, risk.

CHAIRMAN WALLIS: So you're revising a code using risk-informed methods?

MR. KRESS: Yeah. That's the part I didn't understand.

CHAIRMAN WALLIS: Will you --

MR. CHOKSHI: Well, I think that because of including the uncertainties in all the --

MR. KRESS: That means best estimate with uncertainties, is what you're saying, right?

MR. CHOKSHI: With uncertainties, right. Yeah, that's right. Exactly.

Because we're at the end of the -- when we make a run we'll have a distribution of the through-wall, correct. And then it will have been to involve -- become involve with the initiating events and plant logic and --

CHAIRMAN WALLIS: So it's not like sort of looking at some phenomena and saying, "Well, this phenomena is not important in its influence on the answer; therefore, we might as well as not use an equation. We'll just assume a coefficient of 2," or whatever, "in order to get on with it," because it doesn't matter. It's not that sort of level of risk-informing.

MR. CHOKSHI: Right. It's more, I think, a simulation, you know, Monte Carlo type --

CHAIRMAN WALLIS: Because I haven't heard of people actually trying to look at the details of codes using risk information. It would be interesting to do someday.

Where is it that your actual uncertainties in modeling have a big influence on the answer from the point of risk; that would be very interesting to do. But I don't think that you folks are doing that yet.

MR. KRESS: That was the nature of my question. I didn't understand it.

CHAIRMAN WALLIS: Yeah. That would be very interesting to do, though. So now that you've opened the door, maybe we should ask you guys to do it. Think about how to do it.

MR. CHOKSHI: I think I already talked about my next viewgraph. So let me just go to the -- give you the overall schedule and -- where we are. I think in the last three bullets, it sort of summarizes the --

CHAIRMAN WALLIS: Are you talking about OSU here, or are you talking about much more general stuff?

MR. BOEHNERT: No, just in general.

CHAIRMAN WALLIS: You're talking about much more general stuff, aren't you?

MR. CHOKSHI: In terms of the schedule?

CHAIRMAN WALLIS: No. When you say things like "good progress" thus far, that's a very general statement about --

MR. CHOKSHI: Yeah. That's some -- I'm talking about all three areas.

CHAIRMAN WALLIS: That says nothing about OSU, does it?

MR. CHOKSHI: No.

CHAIRMAN WALLIS: Okay.

MR. CHOKSHI: Because I think at the end of tomorrow you can judge.

Just to, I think, summarize. We will have the fracture mechanics analysis of all four plants by end of this year, December 2001. And then we will be putting through, you know, combining with the PRA.

And by February, next February, we should have that -- all of the plant-built specific analysis done.

And the idea is to have the technical-basis activity completed by July 2002. And then we -- at that phase is the question of whether we go, move towards -- move forward with the rulemaking and probably some develop- -- about that time we will be sending a second paper to the Commissioners and seeking their advice based on what's the results we got.

CHAIRMAN WALLIS: Well, you didn't say much about thermal hydraulics. My understanding is that thermal hydraulics are presently in the calculations, but if OSU experiments give surprises, then you would have to revise the whole analysis?

MR. CHOKSHI: Yeah. Well, I --

CHAIRMAN WALLIS: And that's a very key thing to know about, is the --

MR. CHOKSHI: Well, I thought --

CHAIRMAN WALLIS: -- is how much of this stuff that you say you're going to do all this on the schedule and you're going to achieve things by certain days. How much of that depends on getting the right answer out of OSU?

MR. CHOKSHI: Obviously a great deal, but -- but that's -- I thought since in these two days you're going to look at this in much more detail, --

CHAIRMAN WALLIS: You know, I'm just trying to put the thermal hydraulics in perspective, but I didn't quite see how much -- it does play a pivotal role, doesn't it, in your --

MR. CHOKSHI: Yeah. From --

CHAIRMAN WALLIS: -- development of whatever the rule is that you want to come out of this.

MR. CHOKSHI: Right. From my understanding, at least I -- I am not expecting, you know, that list as -- I don't know that there is anything right now which is going to adversely impact the schedule, but I -- I'll find out along with you if there is something.

MR. ROSENTHAL: Let me just make the comment that it's very easy to put a Gant chart together. And Gant charts are terrific for building office buildings where you pour the concrete and then erect the steel.

And here we're more in a design process, an iterative process. And so we don't know quite what surprises will come to pass.

One of the early and crucial issues is because FAVOR is a 1D Code was the effect of thermal plumes. And I think we have some answers for that that you'll be hearing about, because that was like a make/break issue.

A preliminary discussion from the University of Maryland says: Well, you know maybe we can be very, very precise in our calculations, but we really don't know these temperatures to within 25 C.

And -- but that's not a fatal flaw, because we can pass that information on. And it's sequence dependent with its associated probability to the fraction mechanics people.

And then the fracture -- and then having done the fraction mechanics calculations, we'll then see if we can live with those -- that lack of knowledge, that state of lack of knowledge, or if we have to loop through and attempt to refine methods.

So we're trucking down the announced schedule, but I think the fatal flaws haven't arisen yet.

MR. CHOKSHI: Yeah. And I think to some extent the schedule has built some of the administrative process that -- you know, it's all recognized that we --

MR. KRESS: The FAVOR Code uses the thermal hydraulics as an input.

MR. CHOKSHI: That's correct.

MR. KRESS: Is the plan to have a sample from that input in a Monte Carlo way, or is there some other way you're going to deal with these uncertainties?

MR. CHOKSHI: Yeah. You get the temperature, the pressure and temperature distributions and --

MR. KRESS: Pressure, temperature, and heat transfer coefficient is, I think, --

MR. BESSETTE: Yeah. You know FAVOR takes FAVOR samples from things like flaw size and those kind of distributions.

MR. KRESS: Um-hum. Yeah.

MR. BESSETTE: But it takes as a single value the thermal hydraulic input, but --

CHAIRMAN WALLIS: There are no flaws in the thermal hydraulics.

(Laughter.)

MR. BESSETTE: But, of course, you could input different --

MR. KRESS: You could -- you could --

MR. BESSETTE: -- you can change your input, of course, for the thermal hydraulics, so you can put in different temperatures. So within your range of temperature uncertainty, you can vary that --

CHAIRMAN WALLIS: Yeah. You probably should do that, at least a little bit.

MR. BESSETTE: But it just handles it at a different form of input.

MR. KRESS: Well, the good thing about that is you know how -- pretty much how it affects the outcome, --

MR. CHOKSHI: Right. That's --

MR. KRESS: -- so you can choose the bounding values, or something.

MR. CHOKSHI: Right.

CHAIRMAN WALLIS: I think that's part of the Maryland approach, is to see how uncertainty in one thing affects the outcome and develop some sort of influence coefficient, or something. And...

MR. CHOKSHI: That's the end of my presentation. So just I wanted to give you an overview.

CHAIRMAN WALLIS: Thank you very much. It's very helpful.

MR. CHOKSHI: Thank you.

MR. KRESS: Thank you. It was.

CHAIRMAN WALLIS: I note that Professor Ron Adams is here, and we'll give him a chance to say a few words a few minutes before we hear from Professor Reyes and get down to work.

MR. ADAMS: Well, good morning, everyone.

Welcome to OSU. I've got to tell you that the weather pattern today is unusual. It's normally sunny this time in July, but you won't notice, as I can see.

I am pleased that you're here today. And also this building that we're in is one of the special places at OSU because it houses the nation's best Forestry Program. And with that I want to talk about what our plans are for engineering and how the work of Dr. Reyes and Dr. Wu are impacting what we're trying to accomplish.

OSU is building an engine for the knowledge economy. And this is being driven by national needs as well as local needs here in Oregon.

One of the things that's happened in Oregon is that the technology sector is now the largest employer. In fact, the employment in the technology sector in Oregon now exceeds the combination of all of the natural resource industries combined.

Oregon State University has, in the last century, built great programs in natural resources, in forestry and agricultural and oceanography. And now we're on a quest to build one of the best engineering schools in the U.S.

It's been done before. We have

benchmarked other schools, like North Carolina State University and the University of Cal San Diego. And we're following some of the things that they have done to build excellence in their programs.

We have a plan. It -- our plan is to achieve our goal by 2010. And we're making progress towards that plan. We have a tremendous amount of momentum right now, and I'll talk to you a little bit about that.

Part of our plan is to build our Research Program. And one of the things that we've discovered is that we have a very strong competitive advantage in interdisciplinary research. We have received a number of multimillion dollar grants this year because it's easy to work across departments here at OSU.

Now I know that from being inside here and I also know that from observations from colleagues from Stanford and other places, who have become familiar with what it's like here at OSU.

The Thermal Hydraulic Program that we have and you're reviewing today is one of those examples of a very strong program, a national asset. And that's why you're here.

I want to talk about our momentum. We have been growing tremendously in student enrollment for the past four years. And today we're the twenty-third largest engineering program in the U.S.

Our Nuclear Engineering Program is also very strong and highly regarded, both for its undergraduate program as well as for the research here.

So that's our growth from a student-body standpoint.

Since 1999 our research has grown 40 percent. This past year, 27 percent. Inside of that 27 percent are several multimillion dollar contracts, including today OSU will be a center for tsunami research. That entails a partnership between Computer Science and Civil Engineering.

We're not just building the world's largest and most powerful tsunami simulator, we're going to put it on the internet. That's an example of our ability to work across departments.

There are several other awards like that. We landed $18 million in new grants and contracts this year.

Our plan calls for an investment of $180 million in public and private funds. So far we've raised over $50 million in private funds. And the Legislature closed last Sunday -- a week ago Sunday at

5:00 a.m., the State Legislature, and they appropriated $30 million to OSU.

That 30 million includes 10 million in operating expenses and 20 million to help us build a new engineering facility.

We also have a matching 20 million in private gifts for that building. So we will be starting on that project soon.

The other thing that's happened here at OSU, since we've started our path to build this great engineering college, the faculty have gotten very excited and focused, and that's why we're getting the results.

We also have the backing of the leadership of private industry, as well as the public sector here in Oregon -- again, because this is important to Oregon's future and they see also the importance of it from a national standpoint.

So we have that leadership backing. Oregon State is focused on results and a tremendous amount of momentum.

So today you're going to be reviewing one of our strongest research programs. And again I hope you enjoy your stay here at Oregon State. I also hope that when you depart from your hotel tomorrow morning you'll see the sun or when you leave here this evening you'll see the sun because, again, this is unusual for us.

Again we're pleased to have you here and thank you very much.

CHAIRMAN WALLIS: Thank you very much.

Well, Jose, are you ready to tell us about the work that's going on here?

MR. REYES: While that's warming up, I'll begin by saying welcome also. And I appreciate Dean Adams' comments. He's given you an overview of the college. I'm going to give you a little bit of a more parochial view of our Research Program. I want to talk about our thermal hydraulics in general, what types of research we're doing.

It works.

OVERVIEW OF OSU NUCLEAR ENGINEERING

THERMAL HYDRAULICS RESEARCH

MR. REYES: So I'll tell you a little bit our Advanced Thermal Hydraulic Research Laboratory and what our program mission is. And this is kind of an umbrella laboratory that does a lot of interdisciplinary research, and includes the work that we're doing of course here and that we'll be discussing today and PTS and in base separation.

I'll mention who are researchers are and talk a little bit about each program, so this will be a fairly quick overview of the research that we're doing.

Our goal from the beginning was to develop and maintain world-class research capabilities for assessing thermal hydraulic behavior in nuclear reactor systems and components. And that was an overarching goal for our mission.

We have five primary areas of research that we have been focusing on: Integral system research; separate effects/component research; fundamental phenomena research and model development; advanced instrumentation; and advanced thermal hydraulic computer analysis research.

So over the years we've developed in these different areas. I think we've done quite well in developing that.

We consist of a team of professional staff augmented by graduate students and undergraduate students. And during the academic year we have quite a few undergraduate students who work with us. We've had at least 30 or 40 students, undergraduate students, work with us over the years on APEX-type design issues.

And today we have a couple of undergraduate students, Ian Davis and Chris Linrud, who have graduated and are moving on. They just -- for some reason they just keep graduating and leaving, I don't know.

And there are a couple of names I haven't listed there, Dan Wachs, who's helping us out today; and Ben Ralph, who is with us.

Integral System Research Programs. We'll be talking about the PTS Program in detail, so I won't go over that at this point.

We do have some other test facilities that we're working with on the Integral System. We have the Multi-Application Small Light Water Reactors. This is a program we're doing for DOE jointly with Bechtel, Nexant, and INEEL.

We also have the AP1000 work which has just recently been funded by a DOE NERI Program.

The Multi-Application Small Light Water Reactor, which is funded by DOE, is going to be a one-third scale test facility. This is a high-pressure facility. It will be operating at about 1500 PSI and at full temperature.

This is a very simple design. The concept is basically a small -- I won't say portable -- but relatively small design. We're talking about a 40-foot tall containment section or a reactor section in a 60-foot reactor vessel or containment vessel. So it's a vessel within a vessel. A helical tube steam generator. There's no cold legs, no hot legs, so nothing to break in terms of loops.

So we're going to be -- we've done the design jointly with Bechtel and with INEEL. We're now in the process of constructing this facility. So probably next time you come you'll see a high-pressure facility in the bay where we'll be taking you for a tour later today. So that will be -- we're looking towards December having that facility operational. So when we go do the tour we'll talk a little bit more about that.

So that's one of our Integral System Tests.

Of course, the AP1000 you're familiar with. We are looking to do a testing of these new larger passive safety systems. We hope to do some design basis accident test and probably beyond design basis accident test. And this program is scheduled to begin sometime in September.

CHAIRMAN WALLIS: Well, this will look very much like your AP600 work, won't it?

MR. REYES: Correct. Correct.

We will be modifying the facility extensively. We will be -- this includes a brand new data acquisition system. And a lot of the components will -- well, several of the components will change because of the scale.

In the Separate Effects area, today you'll be seeing the ATLATS facility, which has been used for the base separation work. We'll also be looking at the APEX-CE transparent loop, which is what we've done -- we've used to do some of our visualization of the mixing in the Palisades geometry cold legs.

Fundamental phenomena. We do quite a bit of different fundamental phenomena research. Dr. Wu has certainly had a lot of capability in this area when he joined us.

Fractal enhancement of transport processes, bubble shearing-off rate, bubble-bubble coalescence rates, annular entrainment mechanisms, the natural frequency of attached bubbles, bubble condensation in subcooled liquid flows, fractal measurement of slug flow in vertical test loops.

So there's a lot of -- some of this research we'll be doing jointly with the Mechanical Engineering Department.

And the students have set up a whole bay full of displays for you. So when we go over you'll be able to see that.

This one in particular, fractal enhancement of transport processes, again it was actually kind of a mix of a program: Mechanical Engineering and Forestry. So we had one of the engineers in the Forestry Department who was interested in the way leaves work. And we worked with Mechanical Engineering. We came up with a design.

We've gotten a provisional patent already on it, which was issued on the 5th of year 2000. And then the final patent application was just submitted here 2001. And we've gotten some interest from Intel and HP. So we're kind of branching out. And again it's an example of how we do some interdisciplinary research here at OSU.

MR. KRESS: Is that just a process to maximize the surface area of transport?

MR. REYES: Essentially -- that's correct. Essentially it's an effective way of providing cooling by maximizing a surface area.

MR. KRESS: Um-hum.

MR. REYES: But we're looking primarily at an internal cooling process. And so there's a whole range of products that can come from that.

We're doing fundamental phenomena research: Two-fluid model improvements, interfacial area concentration modeling. So we've done some -- you'll see some work later on on the coalescence of breakage of droplets and bubbles in what we're doing there.

We're also looking for advanced instrumentation. You'll see some impedance probe techniques. We're looking at MRI applications. We've done some work in the past. That figure on the upper right-hand side of the screen there is an image of slug flow. It's an MRI image of slug flow. And so we find that we're able to get some good resolution of the images using MRI.

And this was with a one-and-a-half Tesla magnet. We are looking at working with Argonne, Dan Wachs is here today, and hopefully using a 9 Tesla magnet to get much better imaging. So we think we can get some good imaging of two-phase flows using MRI techniques. It's completely nonintrusive. And we get some good pictures.

Neutron and gamma radiography. Dr. Wu will be talking, showing that a little bit later on with one of his students.

Imaging processing and some double-sensor conductivity probes. So for void fraction measurement, bubble-size measurements, velocity measurements, we're using that technique here also.

We also are working hard to try to develop our computer abilities. We have been using RELAP5 Systems Analysis Codes. We have been using the RELAP5-Gamma. I guess it's mod 3. something, point something, Gamma, which is the NRC version, the latest NRC version. And we've used that for the PTS work.

We also have the DOE version of RELAP5-3D, which we've been using for the multi-application small light water reactor work. So we're getting familiar with both, both versions of the code.

We also have the GOTHIC Containment Code. We're using that for the DOE work.

And then the CFD Code we're using currently is STAR-CD, and we've used that for the PTS work.

MR. SCHROCK: What's the origin of that DOE RELAP5-5 to 3D Code?

MR. REYES: This is from the Idaho National Lab.

MR. SCHROCK: Idaho?

MR. REYES: Right. Right.

So just in summarizing as an overview, we'll be talking primarily at this meeting of two of our programs within our research umbrella in thermal hydraulics. We will be talking about the phase separation of Tee work and the pressurized thermal shock work that we have done.

We do -- we've done a good job, I think, in developing our integral system capability, not just the physical machines, but the infrastructure that's required to operate these complex facilities.

We're doing a good job, I think, in the separate effects area. We've built -- we're building model developers. And I like that. So I think Dr. Wu brings some good skills as far as model development to our program.

We are, because of the advancements in computers speed, we are able to run a RELAP5 reasonably well here. STAR-CD is a lot of work. And we will see some presentations on that later. But these Computational Fluid Dynamics Codes eat up a lot of computer time.

CHAIRMAN WALLIS: What's the origin of STAR-CD?

MR. REYES: That's a good question.

MR. HAUGH: It was built by Adapco. It's

their -- they've developed the code. Their offices are in New York.

MR. REYES: You need to say your name. This is Brandon Haugh.

MR. HAUGH: Oh, this is Brandon Haugh. I'm a graduate student.

STAR-CD was developed by Adapco, which is a private company. It's a commercially-available CFD manufacturer.

CHAIRMAN WALLIS: It's like most of the other CFD Codes?

MR. HAUGH: Yeah. It's pretty -- pretty much the same, a little more graphical use interface, just modern software engineering techniques, but pretty much the same.

MR. REYES: We continue developing in the area of instrumentation, so we've got fairly creative work going on. And you'll see some new instruments. Actually on the ATLATS you'll see a device that was developed by the students for measuring level, which is fairly unique.

And then we continue developing, doing our fundamental model research. That's more in the area of the fundamentals of two-phase flow, coalescence, breakage of bubbles, and the transport equation.

So with that I think I'd like to turn it over then to start talking about the two different areas of research that we've been working on primarily, which is the phase separation Tees and then that will be followed by the pressurized thermal shock work. And that's the presentation.

CHAIRMAN WALLIS: Thank you very much.

Now we have a break scheduled for around 10:00, so whenever it's natural for the speaker to break around that time then we'll have a break, because I noticed that the program just goes on for two hours. But there's probably a natural break point in those two hours when we can have a break.

MR. WU: My name is Qiao Wu, Assistant Professor of OSU. Welcome.

My presentation today will be about phase separation in tees. And currently the focus of our project is about the entrainment in a vertical branch of this on the horizontal main line. And my presentation is divided into six parts.

The first part, the introduction on the modeling improvement and the future efforts, will be given by myself.

And the second part, test facility and test results, model evaluation, is going to be given by Mr. Kent Welter.

For the introduction part, before we go to the details, we would like to show you a cartoon to see what is the phase separation effect.

CHAIRMAN WALLIS: Now this phase separation is very dependent on the flow conditions in the hot leg, is it not?

MR. WU: Yes.

CHAIRMAN WALLIS: And so this is -- so that rate is dependent? It's very much tied in with the particular design of AP600, AP1000.

MR. WU: Exactly.

CHAIRMAN WALLIS: It might not be portable to a different situation.

MR. WU: That's what we're going to evaluate. And I'll show you why we're doing and --

CHAIRMAN WALLIS: So one might have to be careful about putting it into NRC Code for some other situation and using it?

MR. WU: We're going to show you how we develop a model in the general sense and see how we can apply it to this situation.

CHAIRMAN WALLIS: Did you do separate effects tests, too, with other, other end conditions, and things like that?

MR. WU: No, because we have some data from Schrock and Smoglie. And we are going to use that as a general case with simplified or idealized unit condition, the outlet condition. And for our purpose --

MR. SCHROCK: I'm having difficulty hearing you. Could you speak into the mic a little better?

CHAIRMAN WALLIS: Is there a PA system here that --

MR. REYES: No.

CHAIRMAN WALLIS: There isn't. So it doesn't help to speak in --

(Simultaneous talking.)

CHAIRMAN WALLIS: It doesn't work.

MR. KRESS: Just have to speak louder.

CHAIRMAN WALLIS: It doesn't help to speak into the mic. You just have to speak up then.

MR. WU: We would like to use this facility to generate the data because we don't have such data available, and then to evaluate the existing models. If we can find the efficiency of the models, then we try to improve it, because we don't know if it's practicable for this situation or not.

So the entrainment the process basically, so when the liquid level is below the off-take, you could still continue the work. Under the process, it's similar like this, we show the experiment process.

CHAIRMAN WALLIS: So the experiment doesn't look quite like the picture?

MR. WU: No. This picture is ideal. That --

CHAIRMAN WALLIS: So you can develop a nice model for the picture, but the experiment is very intermittent?

MR. WU: Yeah.

CHAIRMAN WALLIS: I think the waves depend upon what's happening at the end of that hot leg.

MR. WU: That's correct.

CHAIRMAN WALLIS: So it's -- you know, if you did it in a long pipe, it might be quite different.

MR. WU: That's correct. I show you the effect of the length.

MR. BESSETTE: And I think our ultimate intent for us to be generalistic, I mean, so that we had different end-point conditions, you know, from a closed and to -- it's a symmetric condition, with different development lengths as well.

MR. SCHROCK: I'm concerned about the sort of mixing together of so many different physical problems in what you've referred to as your database. I know you have that report which has been sitting dormant for a couple of years now that summarizes the data.

I think the concept originally was: Let's assemble what is known about this problem and lend some clarification to that. I don't think that data report did that. But I guess I'm looking forward to hearing what's being changed in relationship to that report that's going to guide you.

It seems to me you're pretty far down the line for it to be in that uncertain state. And what you've just shown is, as Dr. Wallis has pointed out, indicating that there are many different circumstances.

There are distinctly different physical processes that are important at different times and, to some degree, dependent upon the geometry.

If I look at the list of cited references in this database, it covers the waterfront. And many of them have no relationship whatsoever to the problem that initiated this research program, which is the difficulty in calculating ADS flow in AP600.

So I think you need to focus a bit more in what you're telling us about why you're doing what you have and are doing and what --

MR. WU: Yeah, the first --

MR. SCHROCK: -- what you know about what has gone before you, because that's not very clear. Okay.

MR. WU: Yes. The cartoons show you the process. And you already pointed out the complexity. So the introduction. It's obvious, it's very significant. It's a high-ranked phenomena in the OSU-CE meeting for the thermal hydraulics and u-sonics coupled code of development.

And also RELAP5 could not have predicted the core heat-up in the APEX of the NRC-25 series test which pinpointed the code deficiency for the vertical off-take entrainment process.

So for the database for entrainment model, if we build the database, we found that all these models were developed for breaks of relatively small sizes. So there is a need for the new data for the larger breaks. And it's scaled to prototype conditions.

And using these data to reevaluate the existing model, if we can, I think identifies a deficiency of the model, then we improve it or perhaps develop the new model.

MR. SCHROCK: So this is, again, a little unclear to me. What you're saying is there may be deficiencies in existing correlations that arise as a result of a lack of experimentation on an adequate range of geometries.

Now you're going to or are doing tests with larger ratios of the break diameter to the main-line diameter. And now you're saying as a result of what you learned from those experiments, you'll reassess deficiencies in the previous experimental results or their correlations.

It's unclear to me how you can accomplish that unless you redo the experiments using the same diameter ratios.

MR. WU: We treat your data and Smoglie's data as one of the targets that we're going to compare with. And because you already -- already small breaks of data, or the data, we are not going to repeat it.

So the best look at the database, we don't have this larger break data. So that's the motivation. We say, "Well, we're going to do larger break data," and that --

MR. SCHROCK: I think you missed the

point. The point is that you've said that you're going to reevaluate model deficiencies in the prior correlations or experimental results.

You're going to do this on the basis of data that are collected for larger ratios of diameters for the break line to the main line.

It's unclear to me how you will assess anything if it turns out that those correlations do not scale -- previous correlations do not scale to the range-of-diameter ratios that you're experimenting with, that you'll have anything to say about how good they are for the smaller diameter ratios.

I think that's what I heard you say you're going to do.

MR. BESSETTE: I think they did put a lot of effort in to collecting and, you know, digitizing, and whatever, all the database in order to make sure that whatever they came up with encompassed or, let's say, was applicable to the range of conditions of, you know, the off-take diameter.

MR. WU: I --

MR. BESSETTE: But -- go ahead.

MR. WU: Thank you.

The model deficiency, what I therefore hear is, say, when the model is being applied to the larger breaks and that obvious -- and these models were or correlations were geared with respect to the small-break data and we're already being evaluated thoroughly with the existing data.

And what I say are called the deficiencies is when we forcefully apply these models, correlations to the larger breaks, what effect and what other kinds of discrepancies we can get.

I hope I answered your question, sir.

MR. SCHROCK: No, but go ahead.

MR. WU: Okay.

MR. HAN: Can I say something? This is James Han from NRC.

Let me just add one quick comment. I thought initially we conducted this research was because the existing database was not quite sufficient in the sense that it has a small-branch diameter over the main pipe diameter ratio. And also the L over D is different. So I saw that Professor Wu, do you want to show your review of --

MR. WU: Yes.

MR. HAN: -- of the existing database --

MR. WU: I'm proceeding to there.

MR. HAN: -- to start with?

MR. WU: Um-hum.

For the database we collected, we wrote letters, emails to the researchers. We collected 20 sets of experiment facility on the data. It ranged from 1980s to 1993.

All the data and the test facility and the analyses, preliminary analyses, are being ready in NRC's report and some first version was submitted -- submitted to NRC for comments.

And some of the data were published in a product form. We actually digitized, bought us -- purchased -- purchased the software and digitized this data in an Excel format. So it's convenient for further analysis.

When we look at the -- focus on the vertical branch on horizontal main line, the models were developed in two steps. First is entrainment onset modeling.

The top figure shows when the liquid level below certain point, there's no liquid being drawn into the off-take. That's called the entrainment onset condition.

And Smoglie, Schrock, and Maciaszek, all of them related that onset level to a Froude number based on the off-take gas velocity and the off-take size.

And the second step, if the level is above the onset entrainment level, then all of the liquid had been pulled into the off-take. And Schrock's correlation, Yonomoto's correlation, and Smoglie's correlation basically correlate the branch quality to the real -- the real gas chamber height to the onset height.

CHAIRMAN WALLIS: This must depend on the flow in the main tube. And if you have a large liquid flow in the main tube, I would think you would carry that wave away. There must be quite a dependence. And then the gas flow in the main tube is going to -- it has to go over that wave. It's going to do a lot to its stability, or whatever.

MR. WU: That's -- we found --

CHAIRMAN WALLIS: So the flow rates in the main tube must have a big -- it can't just be the flow rate in the branch that matters.

MR. WU: That's what we found in our experiment.

CHAIRMAN WALLIS: Yeah. That's what you found?

MR. WU: Yeah.

CHAIRMAN WALLIS: Yeah.

MR. SCHROCK: Let me try to clarify for

you a little better what my problem is.

In your database you have a number of references, notably the work by Lahey and his students, that deal with the bubbly flow in the main line. And the question then of what is the phase separation as a result of the turning of the flow when it is a bubbly pattern upstream.

That's totally different physics from what you've shown a picture of here and totally different physics than the case of the quiescent stratified fluid, which is in the proximity of a take-off line that either sucks in the vapor phase when the break is submerged under the liquid or it may suck in the liquid when it's above.

And it's that latter case that you're addressing here that seemed to be a problem in the application of the existing correlations in RELAP5 for the ADS flow in AP600. That's one isolated thing.

But in the broad range of things that are covered by all of these things that you have here, there are many different distinct two-phase flow problems that ought not be confused with the one that you're addressing here in these experiments. So --

MR. WU: The database --

MR. SCHROCK: -- I'm really puzzled by why you want to do that.

MR. WU: The database was built for all type of entrainment, like vapor pull-through, side branch. And like at the beginning I pointed out currently our project phase is for the vertical or entrainment on the horizontal branch.

And the database itself is more generous and covered all type of branch with phase separation. And we picked the data for the vertical branch on the horizontal for this analysis. That's part of our work.

MR. SCHROCK: Putting together numbers, a database, for a broad range of different physical problems is not a service unless you do something about telling the user of that compilation what physical problems each set of data addresses.

And there are different problems being addressed by this collection of prior works.

MR. BESSETTE: Yeah. I guess -- I can only say that we agree.

MR. SCHROCK: But I hear the story coming out that we're going -- we're going to reassess deficiencies in all of this collection of things on the basis of, --

MR. BAJOREK: It is --

MR. SCHROCK: -- again, one isolated -- I mean you could say the criticism of all of these previous things is that they didn't cover the waterfront. None of them were either funded at such a level that they could cover the waterfront, nor was it the intent either of the researchers or the sponsor. So --

MR. BAJOREK: This is Steve Bajorek.

I think there's two issues that are involved.

First, there is a lot of data that was taken, all sorts of different flow regimes, all sorts of different physics. Many of the conditions in geometries were nonprototypic of the AP600 or AP1000 design.

MR. SCHROCK: Yeah.

MR. BAJOREK: What Dr. Wu's been doing at this point is trying to group all of the experimental data that has taken a look at off-take and Tees.

Now the next step has to be to segregate that.

MR. SCHROCK: No, the --

MR. BOEHNERT: Only a couple of those datasets were --

MR. SCHROCK: -- the very first step

should include critical comment about these results. And that is lacking in this data report. There's just no --

CHAIRMAN WALLIS: Now you're saying that because you've read the report and you've seen it.

MR. SCHROCK: I've said it because I've read the report.

CHAIRMAN WALLIS: Well, I think that you're making very good points. I think we will return to them as you make your presentation, because now we've sort of set the stage --

MR. SCHROCK: Okay.

CHAIRMAN WALLIS: -- for what we're looking for.

MR. SCHROCK: I'll back off.

CHAIRMAN WALLIS: And we'll see if we find it.

So I'd like you to continue the presentation, please.

MR. WU: When we found the data for the vertical or off-take on the horizontal branch, it's several sets of data available, like Dr. Schrock pointed out, as Schrock, and Smoglie, and Anderson's data.

And when we compare, compare with the

prototype condition, you'll see the prototype condition for the D over -- the branch size over the main pipe size is relatively large. It's about .3. However, all the test data is like .1, around there, and below .1.

And also the -- for the inlet condition, inlet length over the main pipe, it's very far from the inlet. It's about over 20.

So for the real case, the inlet is very short. So we think it's necessary for the -- from the horizontal pipe inlet to the branch location.

CHAIRMAN WALLIS: You've got two inlets, one from the steam generator, one from the reactor vessel. They're both short.

MR. WU: No, from the offstream. The inlet side.

CHAIRMAN WALLIS: Well, it could be flowing both ways -- either way.

MR. WU: Yes. Yes. But the other side is much longer, so we focused on the shorter side.

CHAIRMAN WALLIS: So whenever you see a short L over D like that you say the inlet conditions to the big pipe must be very important?

MR. WU: We would like to look into it.

And for the data sets, again, we covered all different branches of different orientations. And we found only two sets of data were used for the horizontal entrainment to the vertical branch. That is Smoglie's data and Schrock's data.

And all of them, except Smoglie's, data goes into a slug flow, but at a very low gas flow rate. Smoglie's data is in the horizontal flow regime. This flow regime map is a traditional flow regime map.

CHAIRMAN WALLIS: So these are fluxes in the main pipe? Is that what the j_gs and j_fs are here?

MR. WU: Yes.

CHAIRMAN WALLIS: They're based on the main pipe?

MR. WU: Yes. Yeah, that's superficial velocity. That's a traditional flow regime map for horizontal pipe over two-inch size.

So the conclusion for this introduction was a correlation --

CHAIRMAN WALLIS: Excuse me. You didn't show AP600 on this plot?

MR. WU: It's in the prototype because originally, when I prepared the transparency, I decided this is sensitive information, so I put a big spot there, about there so you can at least tell exactly what the number is. It's .3 for the off-take size to the main pipe.

So the correlation is based primarily on this stratified flow data. And branch size is relatively small compared to the prototype off-take. And the inlet and the downstream conditions were simplified.

So for the objective of this project, the database construction and the design gave the facility for experiment, the investigation, conduct the test to generate the onset entrainment of the data and the entrainment to read the data.

And then using this data to evaluate the existing model correlation, see, for it's -- they are able to be applied for this situation.

And if they can, that's good news, and we don't need to go do further work. If there is room for improvement, then we're going to do model or correlation improvement or development.

That's our logic of this project.

So for the second part and to the fifth part I'm going to hand to Kent Welter, and I'm going to come back to talk about the model improvement.

MR. WELTER: Thank you, sir.

My name is Kent Welter. I'm a Ph.D.

candidate in the Department of Nuclear Engineering.

Before I go on to this, I'd like to take one minute and address Dr. Schrock's question since I am, I guess, the person who wrote the database that he's speaking about.

When we first constructed the database we had several things in mind. And I've considered it as two parts.

The last half of the database which actually contains the experimental descriptions, facility descriptions, and data uncertainties, is a collection of phase separation experiments. And those are very different.

Through them I've reviewed all the papers by Saba and Lahey and their models. They consider, you know, a full set of Navier-Stokes equations. It's different than what we are looking at here.

The phase separation is a larger set, so you can consider liquid entrainment as a subset of phase separation.

The first three chapters of the database is adding an analysis as applicable only to the AP600 prototypic conditions.

The second half is a database that could be used more generally. It could be used for different applications as a starting ground.

If I want to know about phase separations, there's no one place to go. And that was the purpose of the second half of the database, which is why it includes a large collection of stuff. The first half includes analysis only pertaining to the AP600 and liquid entrainment of vertical branch.

MR. SCHROCK: Well, what is the status of that report? The one that I've read --

MR. WELTER: The one that you've read --

MR. SCHROCK: -- has been said to be two years old and --

MR. WELTER: Exactly.

MR. SCHROCK: -- I don't know the extent to which you've --

MR. WELTER: Revised that, --

MR. SCHROCK: -- made a revision on it, --

MR. WELTER: -- correct, sir.

MR. SCHROCK: -- but it had serious flaws in it.

MR. WELTER: It did, sir.

I wrote that report three years ago and about three months when I came into the program here. And it was mostly a collection, a collection of basically leave-no-rock-unturned. Okay.

I looked through everything, found everything, looked at it, reviewed it, and that's what I submitted. And for the last two years, as I've increased my research, I've realized, well, that's not what I want to submit. We've revised it.

The revision that we've now sent the NRC has condensed the experiments into the last section. And we've added several chapters on the analysis.

MR. SCHROCK: And so that exists?

MR. WELTER: Yes.

MR. SCHROCK: And when was it submitted to NRC?

MR. WELTER: That was submitted to the NRC when we submitted our ACRS stuff several weeks ago.

MR. REYES: That batch is still under review.

MR. WELTER: And it's still under review actually. So I am -- I am hoping that that will help clear up a lot of discrepancies that the first one saw. And you are correct --

CHAIRMAN WALLIS: This is under review by the NRC?

MR. WELTER: No, not yet.

CHAIRMAN WALLIS: Not yet.

MR. REYES: It's being reviewed now.

MR. WELTER: It's being reviewed now.

MR. SCHROCK: Did NRC ever review the draft that you've had for two or three years?

MR. WELTER: I received one comment back, --

MR. SCHROCK: I'm asking the NRC that.

MR. WELTER: -- several comments back on it. And then we revised it. It's still in the original process.

MR. SCHROCK: I didn't hear your answer, David.

MR. WELTER: Oh, I'm sorry.

MR. BESSETTE: The answer -- the answer is yes, but we most -- mostly we relied upon your review of it for --

CHAIRMAN WALLIS: What you want to avoid is a situation we sometimes get where all this stuff goes through and the NRC thinks it's great and it's the basis of a rule. Then it comes up to the ACRS and we don't like something about the whole basis of the analysis. That's too late in the process to have much influence.

MR. BESSETTE: Well, in this case you saw the first draft.

MR. SCHROCK: Well, it was never reviewed by the ACRS, as far as I know. I saw it in February 19- -- or 2001, which is very late in the game. I don't know how...

MR. KRESS: Well, we only get into the picture and if there are intentions to use it for basically decisionmaking or rulemaking. And then we look at the basis for that, but I mean we wouldn't review a document like that just to review it.

CHAIRMAN WALLIS: No. No. That is part of the problem, --

MR. KRESS: Yeah.

CHAIRMAN WALLIS: -- is that we don't see it until it becomes important. By the time that happens it may be too late to do anything about it.

MR. KRESS: Yeah. Well, I --

MR. BESSETTE: In this case you did -- you did see an early draft, or it was distributed at least. The early draft was distributed.

CHAIRMAN WALLIS: But it doesn't mean to say that we worked on it. We work on it when it's part of our schedule to work on it.

MR. BESSETTE: And -- and --

CHAIRMAN WALLIS: We're not your reviewers.

MR. BESSETTE: No. And we don't count on

you as being the official reviewers.

CHAIRMAN WALLIS: Well, again we should probably proceed with the presentation.

MR. WELTER: Okay. Thank you, sir.

CHAIRMAN WALLIS: And maybe we'll be acting as reviewers today.

MR. WELTER: Thanks.

I'd like to talk, take off where Dr. Wu left off, and speak about the scaling involved when we develop our separate effects test facility.

It includes considering the hot-leg flow condition using flow transition criterion developed by Zuber. And if we determine the superficial gas velocity in the main line, we can get an appropriate HL over D, or a hot-leg liquid level to hot-leg diameter.

To preserve the geometry of the AP600, we also considered the main-line diameters of the hot leg and of the vessel and also of the inlet from the reactor vessel to the branch over the main-line diameter.

MR. SCHROCK: So the problem that you're scaling is a quiescent stratified flow; is that correct?

MR. WELTER: For Zuber's flow condition,

that's correct.

MR. SCHROCK: Oh, I'm not talking about Zuber --

MR. WELTER: I'm sorry.

MR. SCHROCK: -- or anybody else. I'm talking about the problem that you are presenting scaling analysis for. You have to define your problem. Your problem is stratified quiescent.

CHAIRMAN WALLIS: By "quiescent," you mean it doesn't have big waves --

MR. SCHROCK: It doesn't have waves on it.

MR. WELTER: Sir, --

MR. SCHROCK: And the picture you showed us a few moments ago with waves is a different problem. So --

MR. WU: No, that's not -- not what we --

MR. SCHROCK: Not true?

MR. WU: This flow regime is like a -- you can say, well, we preserve the flow regime phenomena by guaranteeing the Froude number on the left side is the same. So whatever you -- your run, you say from a stratified to slug or stratified to annular, if you keep your Froude number the same as is this prototype condition, then you preserve the phenomena of flow regimes. So we didn't say we keep that Froude number as under the transition line. That's what you refer to the quiescent stratified flow.

CHAIRMAN WALLIS: Now I'm trying to think here. The liquid -- is the liquid actually flowing up into the steam generator?

MR. WELTER: In through the steam generator?

CHAIRMAN WALLIS: Is this flow going out of the reactor up into the steam generator?

MR. WELTER: To the lower plenum, but it does not make the loop.

CHAIRMAN WALLIS: It doesn't make it? So any liquid which comes in the pipe has to go out the break?

MR. WELTER: Exactly.

CHAIRMAN WALLIS: Nowhere else to go. So this -- all the entrainment a hundred percent.

MR. WELTER: In terms of injection flow, that's correct. The correlations are developed on determining level in the hot leg and how that relates to the entrainment rate.

CHAIRMAN WALLIS: So you've got down to the point where the level is so low that there's no entrainment going up into the steam generator?

MR. WELTER: We've reached that point in

experiments, yes.

MR. WU: It's dry.

MR. WELTER: It's dry.

CHAIRMAN WALLIS: So that's just the exit condition? You have to say something about the exit condition, which --

MR. WU: Yes.

CHAIRMAN WALLIS: All right. And so this is one where there's no way in which liquid can get carried out at the end --

MR. WELTER: That's on my next slide, --

CHAIRMAN WALLIS: -- into the steam generator --

MR. WELTER: -- which is the onset criterion we used.

One of the things that we also considered was the inlet flow condition. And we used the void fraction from the vessel to properly scale the decay heat.

CHAIRMAN WALLIS: Now what does that mean? I didn't quite understand alpha vessel.

MR. WELTER: Alpha vessel. You have decay, and there's of course boiling in the core. And we wanted to make sure that we had the appropriate void fraction from the AP600 going into the hot leg so that we preserve the inlet condition from the reactor vessel.

CHAIRMAN WALLIS: So you're going -- this is a bubbly flow sort of thing in the vessel that's going to be the same?

MR. WELTER: A bubbly flow that, as the fluid is draining, will be going into the hot leg, or when you're -- sir?

CHAIRMAN WALLIS: Okay.

MR. WELTER: Yes.

MR. WU: Basically if we run this test, the different void fraction in the vessel, then we'll get a different -- again from the vessel to the hot leg inlet, there is a phase of separation. So if you don't guarantee the void fraction's the same, then you get a different level in the --

CHAIRMAN WALLIS: So you have to maintain the vessel geometry?

MR. WELTER: Correct.

CHAIRMAN WALLIS: Correct. Not just L over D hot leg. You've got to have D vessel.

MR. WELTER: We also maintain the diameter of the vessel --

CHAIRMAN WALLIS: Yeah, okay. Okay.

MR. WELTER: -- on the right of their D

vessel --

CHAIRMAN WALLIS: Are there all kinds of internals in the vessel? Are there internals in the vessel that --

MR. WELTER: There are no reactor terminals on top of the vessel, no.

CHAIRMAN WALLIS: But there are in reality?

MR. WELTER: There are in reality, that's correct.

To preserve the onset criterion, which would make sure that we are at the correct flow rates at which entrainment begins, we use the onset of liquid entrainment developed by Zuber, Smoglie, and Schrock, where if we know the gas velocity in the branch, then that will give us the onset of liquid entrainment height, h_b. So it's a ratio of gravitational to inertial forces. If the inertial force is greater than the gravitational force, onset will begin.

CHAIRMAN WALLIS: Now h_b is something you have to calculate?

MR. WELTER: h_b is onset of gas entrainment height. So it's a gas chamber height. It's the opposite of liquid level.

CHAIRMAN WALLIS: It's not an independent variable? It depends on all the other things you're doing?

MR. WELTER: That's correct. It depends on -- in this sense right here, it depends on the gas velocity in the branch.

CHAIRMAN WALLIS: Well, it depends on the amount of liquid. Again, I get back to what -- how much --

MR. WELTER: In the onset entrainment experiments there's no liquid injection flow. So you can consider it as a small pool in the hot leg; that's correct.

CHAIRMAN WALLIS: So it's just -- there's no liquid flow, okay. So you can control it simply by the --

MR. WELTER: Yes.

CHAIRMAN WALLIS: -- the void fraction in the vessel, I guess. If you bubble through the vessel you raise the level of everything, including h_b?

MR. WELTER: That's correct. Which gives the effect of the inlet.

From these scaling parameters we constructed an integral -- I mean a separate effects test facility. I'd like to go through and explain the different components.

The critical complaints of the test section is a clear PVC with a horizontal hot leg, the vertical branch. We have a stainless steel reactor vessel. We have a steam generator connected to the downstream, which is appropriately scaled for the friction factor.

We have clear tigon tubing, and you'll see these in the tour also, for the steam generator tubes.

Injection flow is provided by a water pump from a large 5,000-gallon water tank. Injection flow for the air is provided by an air compressor that goes through a 100-PSI air receiver.

We have 25 channels that record temperature, pressure, flow, and catch tank max, along with the mixture level and the hot-leg level. And I'm going to introduce later how we determine the hot-leg level using instrumentation.

CHAIRMAN WALLIS: Now where does the air go in this experiment? It comes in through the bottom of the vessel?

MR. WELTER: That's correct.

CHAIRMAN WALLIS: And some of it goes out the water tank, I guess?

MR. WELTER: The air goes -- I was just

going to -- the next slide shows a cut-away of the reactor vessel, which talks a little bit more how the air comes in.

CHAIRMAN WALLIS: Well, I'm ahead of you then, I guess.

MR. WELTER: Yeah. So if we take a closer look, this is a cut-away of the inside of the reactor vessel. It's approximately a one-quarter length scale compared to the AP600. It has air, water, and atmospheric temperature and pressure.

We use seven porous tubes in a shown configuration to simulate decay heat boiling. Air flows through the bottom of this reactor vessel and through the porous tubes.

CHAIRMAN WALLIS: Well, I guess I was looking at the previous figure. The air has to decide whether it's going to go out through the catch tank and the drain line or to go out through the steam generator.

MR. WELTER: Exactly.

CHAIRMAN WALLIS: I don't quite see where it goes when it gets out through the steam generator. It's not clear to me there's any outlet from the steam generator for air.

MR. WELTER: Everything goes through the

catch tank. So air coming from the steam generator --

CHAIRMAN WALLIS: Everything has to go that way?

MR. WELTER: -- is going to come this way.

CHAIRMAN WALLIS: So nothing goes out through the steam generator?

MR. WELTER: We have a return line, a one-inch return line to equalize the pressure on the reactor head. And so --

CHAIRMAN WALLIS: But all the air that comes through the reactor goes out the catch tank?

MR. WELTER: Well, yes.

CHAIRMAN WALLIS: That's not reality, though, is it?

MR. BESSETTE: Well, yes.

CHAIRMAN WALLIS: Well, it's a very limited reality, isn't it?

MR. BAJOREK: Sort of. Yeah, it's kind of real. Where else can it go? I mean there's only one opening.

CHAIRMAN WALLIS: The steam generator -- there is no flow-through steam generator in the accident?

MR. KRESS: As long as you don't build up much back pressure in that tank.

MR. SCHROCK: It goes the opposite way.

MR. KRESS: It's like --

MR. WELTER: There's flow through the steam generator, but it's backwards.

MR. BESSETTE: Generally speaking, it can only go out the one place.

MR. BAJOREK: It's going in the opposite direction here in the test. In the AP600 and for the ADS-4 it was split through the intact loops, go through the steam generator, and you would have a gas velocity approaching the branch line from both sides.

CHAIRMAN WALLIS: From both sides, right.

MR. WELTER: From both sides. Yeah, it's going the opposite way.

MR. SCHROCK: See, this doesn't look like a clean-cut separate effects experiment. I had thought that that was the objective for the OSU test, but --

MR. WELTER: We varied the downstream -- I'm sorry, sir.

MR. SCHROCK: -- what you have is a system here which is not representative of any reactor system that I know of. And so I don't know what the value of the results would be as a systems test. But as a separate effects test, it misses the mark.

You have a variety of conditions entering the test section that result from system effects. If you look at the KFK experiments, the Berkeley experiments, which I think are the main database for the phenomenon with a quiescent interface, what you see is that in those separate effects experiments pains were taken to smooth the flow, to ensure that there would be a smooth stratified flow.

What was sought was the conditions for the onset of entrainment and then the phase distribution following the onset of entrainment, those factors, for that specific condition at the onset of entrainment.

Your system has these system effects, which are atypical. And I don't understand then how clarity is going to be brought to the problem if separate effects are addressed via some kind of randomly-put-together systems.

MR. BESSETTE: Well, I think --

MR. SCHROCK: It just doesn't follow.

MR. BESSETTE: I think the system -- I mean, in fact, one of our objectives was to include some system effects because, as he's just pointed out, the system effects are -- see, you're correct that that Zuber -- the initial Zuber formulation was for smooth stratified flow, smooth stratified conditions

--

MR. SCHROCK: David, we're talking about the distinction between separate effects and system effects, okay.

MR. BESSETTE: Yes. But --

MR. SCHROCK: And the code has separate effects models in it.

MR. BESSETTE: Yes.

MR. SCHROCK: And what you set out to do is to improve on the code's separate effects models so it could calculate AP600 ADS flows better. Isn't that where we started?

MR. BESSETTE: That's -- yes. But what we have seen at least is that the system effects are at least as important to the --

MR. SCHROCK: Of course they are.

MR. BESSETTE: -- or more important --

MR. SCHROCK: If you have a wavy flow, as the previous --

MR. BESSETTE: Yeah.

MR. SCHROCK: -- cartoon showed us with animation here, it had a tremendous effect --

MR. BESSETTE: Yeah.

MR. SCHROCK: -- on the result that you get. It would be naive to believe that it wouldn't.

But that's a different situation.

MR. BESSETTE: But that's what we wanted to include. We wanted to include the --

MR. SCHROCK: Well, then do it in such a way that you have control over what the upstream phase distribution is. And --

MR. BESSETTE: But --

MR. SCHROCK: Your code is going to have to know --

MR. BESSETTE: That's correct.

MR. SCHROCK: -- what the upstream phase distribution is --

MR. BESSETTE: That's correct.

MR. SCHROCK: -- in order to properly calculate what the branch flow rate.

MR. BESSETTE: But what we have seen is that the code has to be able to calculate the flow regimes in the upper plenum in order to calculate the correct conditions in the hot leg.

So the code has -- the code has to be -- you have to back up. It's both in the experiments and in the code. You see that you have to get the upper plenum conditions correct in order to get the right conditions in the hot leg.

So you have to feed the right flow from

the upper plenum to the hot leg. And we've seen that both in the code calculations and in the data.

CHAIRMAN WALLIS: I think we'll have to accept this as not the totally separate effects test, not at all, but it seems to the --

MR. SCHROCK: Well, I think --

CHAIRMAN WALLIS: -- hybrid separate effects, system effects --

MR. SCHROCK: -- it's a basic problem in the thinking of how you can improve what the codes are doing.

The codes attempt to calculate, using correlations, for a wide range of different physical phenomena. And unless you have adequate flow regime characterization, you can't begin to come up with a set of correlations that are going to correctly calculate --

CHAIRMAN WALLIS: Well, the version --

MR. WELTER: But that's correct.

MR. SCHROCK: -- those flows.

MR. BESSETTE: Yeah, I think we agree. It seems to us that the conditions, the model for smooth stratified flow is quite -- quite transparent, let's say, and adequate, good. There's nothing you could improve upon. So --

MR. SCHROCK: No, and I don't think that was your initial argument for starting this program.

It was that the choice of diameter ratios made in those earlier experiments, before there was any knowledge of what the AP600 geometry was going to look like, didn't envision that there would be need for data with such large -- large break diameters.

MR. BESSETTE: Yes. That was one of the motivations, yes. Yes.

MR. SCHROCK: Right. All right.

MR. BESSETTE: But there was no -- we did not see any obvious problems with the stratified flow off-take modeling, other than the range -- the diameter ratio.

The other thing was that we did not believe that it adequately covered these conditions of stratified -- wavy flow and --

MR. SCHROCK: Well, it doesn't. And you need -- you need experiments for wavy flow, --

MR. BESSETTE: Yeah.

MR. SCHROCK: -- if that occurs in the real reactor systems.

MR. BESSETTE: Yeah. And that was, of course, one of the motivations.

CHAIRMAN WALLIS: Well, I think we have to see the whole presentation and then maybe come back to these issues in a discussion later.

MR. WELTER: Thank you, Mr. Chairman.

CHAIRMAN WALLIS: But --

MR. SCHROCK: I think the objective --

CHAIRMAN WALLIS: -- these questions are going to emerge later --

MR. SCHROCK: -- needs to be set out more clearly in the beginning, Mr. Chairman.

CHAIRMAN WALLIS: But if we spend all the time on the prologue we'll never see the play, so I think we have to go on.

MR. SCHROCK: All right.

MR. WELTER: Thank you, sir.

The test facility, let's take a closer look at the test section geometry used. This is the PVC test section.

Two test sections were constructed to enable three different inlet lengths for testing. They were constructed by welding two PVC pipes together. This enabled us to save a tremendous cost on test section. Each one of these test sections is approximately $150 plus parts and labor, compared to casting acrylic which costs 4,000 to $7,000.

CHAIRMAN WALLIS: You weld PVC?

MR. WELTER: Weld PVC. The investment was a $400 PVC welder.

CHAIRMAN WALLIS: It doesn't electric use arcs, though, does it?

MR. WELTER: Not usually, no.

MR. ROSENTHAL: I'm sorry. I know it's a divergence.

MR. WELTER: Please.

MR. ROSENTHAL: I'm just curious. I'm used to gluing PVC together. So what is a PVC welder?

MR. WELTER: John.

MR. GROOME: My name is John Groome. It's basically used on a hot air gun.

THE REPORTER: Would you come to a mic, please?

MR. GROOME: Good morning. My name is John Groome.

And on the question of welding PVC, basically you use a hot air gun. And you have a filler rod. And you actually melt PVC to do the welds. So it's kind of like tape welding PVC, but you don't -- you don't actually melt the base material. And you'll see some examples today of that when you look at the test sections.

CHAIRMAN WALLIS: It's like mending many

holes on the base of your skis.

(Laughter.)

MR. GROOME: I couldn't tell you anything about skis, but --

MR. ROSENTHAL: Says the man from New Hampshire.

MR. WELTER: Thank you.

I'd like to take a moment to introduce the hot-leg measurement instrumentation. It is a half-ring-type conductivity probe. In this illustration there are two stainless steel semicircle wires placed within a PVC ring.

This PVC ring is then bolted between two flanges, the hot leg. There are two of these, these types of instrumentation: one on the reactor side of the test section to give -- measure inlet hot-leg level, and one on the steam generator side to measure out-leg hot-leg level.

These wires are connected to signal conditioning. We have a 100-kilohertz sine wave oscillator. We use AC power to make sure there's no iron migration that you'd encounter with DC.

It goes through a current driver that's amplified, rectified, and then filtered. And then we go ahead and measure the voltage. And --

CHAIRMAN WALLIS: This is just -- this is just conductivity, --

MR. WELTER: A half-ring type --

CHAIRMAN WALLIS: -- or is it impedance? Is it --

MR. WELTER: It's an impedance probe.

CHAIRMAN WALLIS: It says "conductivity," but -- so it measures actually --

MR. WELTER: Impedance of the air and water, basically air.

CHAIRMAN WALLIS: It measures capacitance, or does it measure...

MR. WELTER: Resistance -- impedance.

MR. WU: Impedance.

MR. WELTER: Yes.

CHAIRMAN WALLIS: So you could control the chemistry of the water pretty closely to measure resistance?

MR. WELTER: We calibrate -- we calibrate the test section every test series --

CHAIRMAN WALLIS: Every day, okay.

MR. WELTER: -- to account for the impurities in the water.

CHAIRMAN WALLIS: So is it mostly resistance, or is it mostly -- or it's a hybrid of some sort?

MR. WU: Mostly --

CHAIRMAN WALLIS: Mostly resistance?

MR. WU: The AC current -- this is Qiao Wu.

The AC current put inside just want to avoid as the iron accumulated to one electrode, so cause kinds of drifting. But we didn't raise to that high frequency. Run just the probe, we -- in the capacitance mode.

MR. WELTER: This -- this work was done by the Department of Oceanography to measure wave height in their wave pools. And we've borrowed it, their circuit, and modified it for our case.

So before each test a calibration curve is run. That's a picture of the calibration curve. There's an output voltage on the bottom. And we calibrate with the DP we have in the reactor vessel.

So I flood and then drain the reactor vessel and get output versus height in the hot leg.

And I run this before each test series.

CHAIRMAN WALLIS: So during the test you've got this continuous output from this probe and it shows waves and things?

MR. WELTER: At a one-second scan rate.

CHAIRMAN WALLIS: A one-second scan rate, so it doesn't show waves?

MR. WELTER: There is some oscillation involved.

MR. SCHROCK: The calibration curve is done with static conditions?

MR. WELTER: That's correct. No gas flow, just water draining and filling.

MR. SCHROCK: Oh, the water is moving?

MR. WELTER: That's correct.

Okay. So I went and I described the test facility. The --

CHAIRMAN WALLIS: Excuse me. Where --

MR. WELTER: I'm sorry. Yes.

CHAIRMAN WALLIS: Where is the probe in the circuit?

MR. WELTER: There are two -- yes, there are two probes. One is on the reactor side. I'll back up a bit.

CHAIRMAN WALLIS: Are they both ends of the test section?

MR. WELTER: Yes.

CHAIRMAN WALLIS: Okay.

MR. WELTER: That's correct.

Can you back up about three slides on the test facility?

(Comments off the record.)

MR. WELTER: This is break time; is that what you wanted?

CHAIRMAN WALLIS: No, you're going to finish before break time.

MR. WELTER: Okay. This is --

CHAIRMAN WALLIS: No, wait a minute. You're going to finish this topic.

MR. WELTER: Yeah, okay. That will be pretty fast.

Here are both of the impedance probes. One is on the inlet side and the other one is on the outlet side. That's correct.

CHAIRMAN WALLIS: So are you finished describing the facility?

MR. WELTER: That's correct. I'll be moving on to the tests, results.

CHAIRMAN WALLIS: Do you want to take a break now?

MR. WELTER: Great.

CHAIRMAN WALLIS: Does that allow us time to finish the rest of the --

MR. WELTER: Yes, I believe so, enough time, yes.

CHAIRMAN WALLIS: You're going to do sections 3 and 4 this morning, or you're going to do all of this. Okay. Let us take a break for 15 minutes.

(Recess taken from 9:54 a.m. to 10:10 a.m.)

CHAIRMAN WALLIS: Go ahead.

MR. WELTER: Okay. Thank you.

Just before the break I finished speaking about the test facility and instrumentation. I'd like to go on and describe the two groups of tests that we ran, one for the onset of entrainment, determining that; and then one for determining the rate of entrainment through the AF 4 line, or the off-take.

The first will be the onset of entrainment. I'd like to describe the test procedure that we went through to achieve the onset of entrainment.

At first, from this figure, the hot leg is flooded. Then gas is throttled to a specified flow rate at constant value. And when that happens, from this animation, entrainment will begin, and you will lose primary inventory and the level in the hot leg will drop.

CHAIRMAN WALLIS: Well, it's not

entrainment to start with. It's just flowing out, because it has to go somewhere.

MR. WELTER: There's no liquid injection.

CHAIRMAN WALLIS: Yeah, but there's gas.

MR. WELTER: Which is pulling the liquid with it.

CHAIRMAN WALLIS: It displaces the liquid.

MR. WELTER: There's pulling the liquid up through the vertical branch.

CHAIRMAN WALLIS: Well, in the first picture it was all full of liquid, so...

MR. WELTER: It was flooded initially. So initially -- so we get the same -- the accurate -- we start at the same spot every time, a flooded hot leg.

After a certain amount of time liquid entrainment will stop, and basically there will be only gas flowing through the ADS-4 line and you will receive a constant level in the hot leg. This is the point at which onset of entrainment begins.

And we go ahead and run a test series for different gas flow rates to get the liquid level for each gas flow rate.

CHAIRMAN WALLIS: Now in reality there might be some boiling in the steam generator because this secondary is a heat source and things. There's all kinds of scenarios where things happen in the steam generator.

MR. WELTER: That's correct.

CHAIRMAN WALLIS: Here it's just a deadend for you.

MR. WELTER: That's correct.

And in this figure, it's not shown, there is actually an air line connected to the bottom of the porous tubes.

The test scope of the onset of entrainment includes determining the effect of the inlet length. We want to know what the effect of the inlet length in regards to the effect of the reactor vessel and the void fraction that we scaled.

Also the effect of the steam generator. We have a valve on the three-inch cold-leg return that can be opened and closed so that we can simulate. A close would simulate a filled loop seal in the cold leg.

CHAIRMAN WALLIS: There's a challenge here of oscillations imposed between the cold leg and the react- --

MR. WELTER: The oscillations occur in the entrainment rate tests with a steady injection flow. No oscillations occur for the onset of entrainment with zero injection flow.

CHAIRMAN WALLIS: Nothing's happening?

MR. WELTER: Nothing's happening.

MR. SCHROCK: Is --

MR. WELTER: Sir?

MR. SCHROCK: Is the condition with a voided steam generator and dome but a flooded hot leg a condition that's calculated for AP600?

MR. WELTER: It's part of the -- sir. Sir, go ahead.

MR. BESSETTE: It's -- of course, the situation when ADS-4 opens is that the generator is voided and the hot leg is full.

MR. SCHROCK: What's the condition of the steam dome -- or of the vessel?

MR. BESSETTE: The vessel is -- when ADS-4 opens the vessel is filled to about the top of the hot leg.

MR. WELTER: May I go on?

Okay. Thank you.

We also are curious to the effect not only of the steam generator and its influence, mainly the lower plenum, but also the effect of gas flow direction. Meaning that if we open the three-inch cold-line return, how much -- what is the effect of gas flowing through both the cold leg and the hot leg so that you get gas from both directions up through the branch, not just a flow from a single direction.

Flow through. The cold leg is -- is smaller than the hot leg, of course, because it has to travel all the way through the cold leg into the other side of the steam generator. So the majority of flow is still from the hot leg.

Brandon, can you have the next one for me? Okay.

Some test results. This is a plot that we have used the same convention that Zuber used to classify his onset data. It is a flow regime map with the Froude number in the main line based upon the superficial gas velocity in the main line.

I've plotted against h_1, which is the liquid level in the hot leg over the main line diameter. The regions you see here are in the bottom left are stratified, plug, and slug, and annular, and dispersed.

Our onset data for this case, which we're trying to determine the effect of the inlet condition, falls within the stratified flow regime.

The different test series and the different dots are for different L over Ds, from 2.71

up to 4.75. We can see that there is not a significant impact due to hot-leg inlet length on the onset of entrainment level. So this is a case where we have taken into effect the inlet conditions.

Effects of the steam generator. We are interested in knowing what happens when we basically put a static pressure boundary on the exit. So we have col- -- the previous onset data, there was no three-inch cold-line return.

In this case we opened the three-inch cold line, cold-line return. And the new -- the data for with the steam generator has brought the onset level to a slug transition line. So --

CHAIRMAN WALLIS: So you're saying that the onset of entrainment is the same as the onset of slug flow?

MR. WU: Yeah.

CHAIRMAN WALLIS: So it's nothing to do with droplet entrainment. It's the formation of the big wave and --

MR. WU: I think physically later you will see it's the same argument. And the surprise -- that's not a surprise. But the surprise is you don't need to -- so this coefficient that you get is exact in the line for the larger breaks.

CHAIRMAN WALLIS: So what is the steam generator doing to make the data different when it's attached?

MR. WU: It's --

MR. WELTER: Flow direction. This is the effect of the steam generator. One of the things is that there is flow coming from the cold leg. So basically you're not just flowing past, you're flowing from both.

CHAIRMAN WALLIS: Flowing air?

MR. WELTER: Air, that's correct, sir. There's no injection.

MR. SHACK: It would be more accurate to say loop seal or no loop seal, right?

MR. WELTER: Exactly. One, one is where the loop seal is filled and the other is where the loop seal is blown out.

CHAIRMAN WALLIS: I don't understand how the air gets around the other side in your experiment.

MR. WELTER: The cold leg is above the hot leg, and so air flowing from the reactor vessel can go either to the cold leg or the hot leg since the --

CHAIRMAN WALLIS: In your experiment? Your experiment has a cold leg down the bottom of the --

MR. WELTER: Oh, I'm sorry. The cold leg in the AP600 is above the hot leg. In the illustration I have connected it just back to the reactor vessel.

CHAIRMAN WALLIS: The illustration, oh, is wrong then?

MR. WELTER: That's correct, sir.

CHAIRMAN WALLIS: Oh, it's probably misleading.

MR. WELTER: Okay. Thank you.

CHAIRMAN WALLIS: Okay. So now really the cold leg is attached to the proper place?

MR. WELTER: The cold leg is attached above the hot leg.

CHAIRMAN WALLIS: But it's drawn below the hot leg in the diagram.

MR. WELTER: Another figure. That's correct.

CHAIRMAN WALLIS: Gee whiz.

MR. WELTER: That is misleading. I apologize for that.

CHAIRMAN WALLIS: Okay.

MR. SCHROCK: So is the wavy condition from one set of these data and not the other, is that the distinction?

CHAIRMAN WALLIS: No, it's coming from both directions. What's the *J* in the Froude number?

MR. WELTER: The *J* we used is the inlet.

CHAIRMAN WALLIS: The inlet.

MR. WELTER: That's correct.

MR. WU: Now the *J* is totally calculated from the branch of the take, and we consider it's only coming from one side for this, for regime transition.

MR. WELTER: It's only coming from one side, okay.

CHAIRMAN WALLIS: So this Wallis transition is sort of --

MR. WU: For the one side.

CHAIRMAN WALLIS: -- entirely fortuitous because this fellow Wallis, --

(Laughter.)

CHAIRMAN WALLIS: -- whenever it was, over 30 years ago, didn't have the prescience to realize that you were going to connect a cold leg at the other end of the pipe.

MR. WU: Yeah, but that's the surprise here, you see. That can use a --

CHAIRMAN WALLIS: This is invocation of a correlation which doesn't really apply to the situation.

MR. WELTER: That's correct.

CHAIRMAN WALLIS: So, well, --

MR. WELTER: An interesting fact.

CHAIRMAN WALLIS: The impression, though, that you get some authority by quoting this fellow, but I'm not sure --

(Laughter.)

CHAIRMAN WALLIS: I'm not sure that's true.

MR. WU: No. It's...

(Laughter.)

MR. SCHROCK: I'm still trying to understand what you're saying about the two sets of data. I don't understand. Is it --

MR. WELTER: The first set of data --

MR. SCHROCK: Is it that there are waves on the surface in one case and not the other case, or --

MR. WELTER: What does the flow regime look like when I look at my experiments; is that correct?

MR. WU: Quiet.

MR. WELTER: Quiet. They're both calm. So the effect you're seeing is the flow direction.

MR. SCHROCK: The flow direction?

MR. WELTER: Right. Through this case with a steam generator, your gray dots are for a blinded outlet, which means that we have placed a blind, a physical blind, where the steam generator is, so it just smacks into a wall. For that case it is calm.

For the case where we have a steam generator attached, the blind is removed, it's also calm, but the level --

MR. SCHROCK: Do you -- do you --

MR. WELTER: Yes.

MR. SCHROCK: -- see it or are you imagining this?

MR. WELTER: No. We have a clear PVC pipe, and we've recorded the flow regime.

CHAIRMAN WALLIS: So the difference isn't only that you've got some flow in the cold leg, it's that you removed some sort of a plug at the end of the pipe.

MR. WELTER: Exactly.

CHAIRMAN WALLIS: An open-ended pipe instead of a closed pipe.

MR. WELTER: Exactly, yes.

CHAIRMAN WALLIS: So I guess what you're showing us is what we've been saying all along, the end conditions make a difference.

MR. WELTER: Exactly, yes.

MR. BAJOREK: Do you have an idea of what the flow split is, how much of the gas is coming from --

MR. WELTER: We are currently --

MR. BAJOREK: -- the vapor side versus the steam generator side?

MR. WELTER: In terms of actual figure, no. We are going to install a meter on that side to meter that. In terms of just considering friction, there's at least a hundred times more length to go through on the cold-leg side. So we, of course, expect a lot less flow.

CHAIRMAN WALLIS: The difference in flow, it's an h over D of a half is a factor of about three, log paper. It's a big difference.

MR. WELTER: Yes. This is a log on the horizontal axis; that's correct.

MR. SCHROCK: That's why I have a hard time believing that it's a flat interface in both conditions.

MR. WU: It's no entrainment. There's no liquid that has been pulled out of the branch, so it's calm. The key part is to --

MR. SCHROCK: The data for the onset of entrainment.

MR. WU: -- see which level is higher when it's become too quiet. So for the waves of the steam generator case, it's a -- the higher level, then it becomes quiet. And without the pressure boundary there, your plant flooded. Then it's a lower level and the level becomes quiet. So that means when you're bring flooded, there is a kind of wave bouncing back from that pressure boundary, and that will entrain more liquid out. Then that causes the entrainment --

MR. SCHROCK: So the open circles, --

MR. WU: -- onset a level lower --

MR. SCHROCK: It's -- the open circles, it's picking up liquid off the tops of waves; is that right?

MR. WU: That's -- that's right. And at the end there's no more liquid being pulled out. The liquid level becomes quiet.

CHAIRMAN WALLIS: So you have a plug at the end of the pipe so waves can reflect from it, right?

MR. WELTER: Exactly.

MR. WU: That due course of the

entrainment.

CHAIRMAN WALLIS: Because one thing that happened in this, where you quote here, which had a wave-absorbing thing at the end of the pipe, so it wasn't a reflection.

MR. WU: It's because -- if you open the return line, it becomes quieter.

CHAIRMAN WALLIS: So now I'm a bit happy of it, because there is something -- you know, we took care to have no waves reflected from the end of the pipe in these experiments that you quote here. Okay.

MR. WELTER: Thank you, sir.

So that was a test series that was ran to determine the effect of a steam generator blinded or open --

CHAIRMAN WALLIS: Wait a minute.

MR. WELTER: Yes, sir.

CHAIRMAN WALLIS: My colleague's asking me how do you know h_1. Is h_1 something you measure before you turn on the --

MR. WELTER: H_1 is the hot-leg level at which entrainment stops.

CHAIRMAN WALLIS: And this is as determined by your probe?

MR. WELTER: It's determined by the

impedance probe.

CHAIRMAN WALLIS: Whatever the probe is measuring. And it's an average of --

MR. WELTER: It's an average over time. And we determine if it's constant, if it approaches some moving average.

MR. BAJOREK: Is it based on both the vessel side and the steam generator side conductivity probes?

MR. WELTER: For the onset of entrainment, there is -- the same. For the onset of entrainment, the levels are the same.

When you encounter the entrainment rate levels we'll show that that's different when we do the entrainment rate tests.

We ran a test series to better understand the effect of downstream condition. We also installed a one-inch return line to the top of the reactor vessel to give us a little bit of refinement to the effect of the downstream condition.

What we have seen here is with the steam generator installed no return line, which means both the three-inch and the one-inch line are closed, which gives the effect of the lower plenum of the steam generator on the onset level.

Then we have the three-inch line open. And then we have the one-inch line open. And of course the three-inch closed.

CHAIRMAN WALLIS: I just have to ask you something else, too.

MR. WELTER: Yes, please.

CHAIRMAN WALLIS: Once you get this entrainment, it goes up into the ADS line.

MR. WELTER: Yes.

CHAIRMAN WALLIS: And I assume that you have enough flow rate to carry it up that line, --

MR. WELTER: Yes, yes.

CHAIRMAN WALLIS: -- because if the line is too big, it's not going to go over the line; you have a different condition where you actually entrain it, but it runs back down into the pipe again.

MR. WU: Yes, we guarantee its annular flow. It's over 14 --

CHAIRMAN WALLIS: So you have enough flow --

MR. WU: The minimum is a 14-meter per second *JG*.

CHAIRMAN WALLIS: So it doesn't actually go up like a jet in the middle. It actually splatters onto the wall, or something?

MR. WELTER: That's correct.

I assume you're referring to the illustration of the jet in the middle. Okay.

CHAIRMAN WALLIS: Most of the flow is coming from the vessel so that entrainment is probably carried to the left as it goes around the corner into the branch pipe, or something.

MR. WELTER: Yes, that's correct.

CHAIRMAN WALLIS: It doesn't go off the middle.

MR. WELTER: Yes.

Okay. This shows the case with the effect of the downstream condition flow, which means basically I am changing the amount of flow that comes in from one side.

So with the return line closed there, of course, is only flow from one direction from the reactor vessel to the hot leg through the ADS-4 line. And then I open up the cold leg, and so I get a varied amount of flow rates from the other direction.

MR. KRESS: Does the gas flow spiral as it goes up the tube?

MR. WELTER: Spiral?

CHAIRMAN WALLIS: Spiral.

MR. KRESS: Spin.

MR. WELTER: Spin.

MR. WU: We can't tell.

MR. WELTER: I can't tell exactly. I wish I could measure that.

MR. SCHROCK: What is the return line that's referred to here?

MR. WELTER: Which one, the one-inch or the three-inch, sir? Both of --

MR. SCHROCK: Gosh, I don't know. I'm asking you --

MR. WELTER: Okay. The return -- the three-inch --

MR. SCHROCK: -- to tell me what is the return line.

MR. WELTER: Okay. The return -- the three-inch -- okay. The three-inch return line goes from the outlet of the steam generator. And it's basically a model of the cold leg, which returns to the top of the vessel head.

MR. SCHROCK: And can you relate it to a picture you've shown us of the system?

MR. WELTER: I can relate it.

MR. WU: System 1.

MR. WELTER: The system 1.

Brandon, can you go back about 12 slides?

This is not an elevation view, so this doesn't dip this far down. The cold leg, the three-inch return line comes off the exit of the steam generator. It comes back around. We have a valve there. It comes back into the top of the reactor vessel.

CHAIRMAN WALLIS: Now why should there be any circulation in that loop at all?

MR. WELTER: Circulation?

CHAIRMAN WALLIS: There's no pump in that loop. Why would anything flow around that loop?

MR. WELTER: If there's flow from decay heat boiling, there's vapor flow from here. Air is being supplied through the porous tubes up through here. The flow can choose.

CHAIRMAN WALLIS: Oh, it could go the other way around?

MR. WELTER: Right, exactly.

CHAIRMAN WALLIS: Okay. Okay.

MR. WELTER: It can choose which way, depending on the friction. Exactly.

CHAIRMAN WALLIS: It's on its way to the break, okay.

MR. WELTER: Exactly. We're trying to determine basically how much goes the other way. So we're either cutting it off, opening it, or opening a small one-inch return line that isn't shown here, which is basically the same as a three-inch.

CHAIRMAN WALLIS: Okay. Okay.

MR. SHACK: The one-inch return line has the same geometry?

MR. WELTER: As the three-inch return line?

MR. SHACK: Yeah.

MR. WELTER: In terms of geometry? No.

MR. SHACK: No.

MR. WELTER: It's smaller and just goes straight across.

MR. SHACK: Okay.

MR. WELTER: Yeah.

MR. KRESS: If you have a valve in the line, why did you need a one-inch line?

MR. WELTER: Because --

MR. KRESS: Couldn't you simulate a one-inch --

MR. WELTER: -- we didn't -- we don't -- it's a gate valve, as you'll see. And so --

MR. KRESS: Oh, you can't set it very --

MR. WELTER: No.

MR. KRESS: Okay.

MR. WELTER: You can't set it, but open, close.

MR. KRESS: Okay.

MR. WELTER: So this shows the effect of the gas flow direction. All of the data is still well behaved, and so there is little effect of the gas flow direction, meaning there is not very much flow going through the cold leg or going through the return lines. Most of the flow is still from the reactor vessel into the hot leg through the ADS-4 line.

CHAIRMAN WALLIS: I notice there's a lot of data scattered. It doesn't seem to be consistent. If you make the return line size bigger, that's sort of a consistent trend.

So these are some sort of data points, but presumably if you repeated the experiment you wouldn't get quite the same point?

MR. WELTER: Are you asking about the repeatability of our experiment?

CHAIRMAN WALLIS: Well, it just seems that if you look inside the trends, when you have no return line, one-inch, three-inch, there's no sort of obvious trend. And so --

MR. WELTER: Sure. There is an effects --

CHAIRMAN WALLIS: -- I conclude this is

just scatter that you're showing.

MR. WELTER: There is no significant trend.

MR. WU: Yes, he said that.

MR. WELTER: Yeah, there's a scatter.

MR. WU: He already shows that the --

MR. WELTER: The dots are above.

MR. WU: -- symbol, circle is above --

CHAIRMAN WALLIS: They're sort of above, yeah.

MR. WU: Yeah. We choose this plot to represent our experiment data, as we want to leave the correlation comparison later, because this was originally initially using this -- you noticed that before.

When we calculate the Froude number, we use the gas, all the gas for -- to one side to calculate it there. So basically you see that shifting I think is because of the flow direction.

CHAIRMAN WALLIS: So this Froude number is based on the total gas flow?

MR. WELTER: From the injection, exactly.

MR. WU: Yes.

MR. WELTER: From the meter.

CHAIRMAN WALLIS: It's the only thing you know. You don't know how much is going each way. So --

MR. WU: That's right. So that means when that pipe is getting bigger, like you said, maybe it's going to shift up because one side of the gas flow rate is not that much.

So if we can't -- right now we installed -- we are going to install a flow meter. Maybe we can bring that down, we hope. But this is not the final correlation or model we are going to use for this entrainment answer --

CHAIRMAN WALLIS: So I guess I have to --

MR. WU: -- test --

CHAIRMAN WALLIS: -- ask: What's the purpose of showing this picture?

MR. WU: Just to see the effect of gas.

CHAIRMAN WALLIS: Just to show that having a return line doesn't make much difference?

MR. WELTER: Exactly.

CHAIRMAN WALLIS: But, you see, in the code you'd have to actually calculate the flows in the return line and use some kind of a correlation. I'm not quite sure how that captures what's shown here.

MR. WU: Originally we -- in this figure we expected a scatter, and -- like you already said.

And we -- my intention was to say, well, this is for regime map -- for regime transition criteria; it shouldn't work for this case, and -- but right now it's very -- grouped like that give you maybe false information.

You'll say, "Well, this is -- this is correlation can't work for that." I apologize for that.

CHAIRMAN WALLIS: Is that the correlation that's in the code?

MR. WU: The correlation of that is for our transition.

CHAIRMAN WALLIS: Is that what's in RELAP?

MR. WU: It's not the one we are going to use. We are going to use the one --

CHAIRMAN WALLIS: You're going to use something else?

MR. WU: -- in the code or improve it, trying to compare with other correlations like Maciaszek's correlation.

MR. SCHROCK: You have a horizontal solid line. Is that part of the slug transition? What's the meaning of that?

MR. WELTER: That's the difference between annular, dispersed, and a plug and slug flow regime.

CHAIRMAN WALLIS: That's a Dittus-Boelter transition criteria?

MR. WU: Yeah.

MR. WELTER: Yeah, okay.

So I summarized the test results on the onset of entrainment. And the second group of tests was to discuss -- or take a look at was the steady state entrainments. And the major difference here is that we have a steady injection flow.

CHAIRMAN WALLIS: Are you getting onset of entrainment by extrapolating back from finite amounts, or something? How do you know onset? How do you know zero?

MR. WELTER: You mean when does it stop, when does it start?

CHAIRMAN WALLIS: When does it start, yeah. Sometimes --

MR. WELTER: We take a look at the data and we take a look at the liquid level. If it approaches a moving average, then we assume that no liquid is being pulled out and the level does not drop. That is the level at which onset begins.

CHAIRMAN WALLIS: Do you extrapolate it then back from when it is dropping? Measuring zero is not very easy.

MR. WELTER: There is still a level in the hot leg, but there is a level at which entrainment does not drop the level any farther. Basically --

CHAIRMAN WALLIS: So it has come to an equilibrium level?

MR. WELTER: It -- yes, it comes to a constant level --

CHAIRMAN WALLIS: So you're extrapolating to equilibrium?

MR. WELTER: It just stops.

CHAIRMAN WALLIS: Okay. So you do --

MR. WELTER: That's correct, yes.

CHAIRMAN WALLIS: -- have an extrapolation of the thing going on.

MR. WELTER: Okay. Yes. I was confused. I'm sorry. Thank you.

MR. SCHROCK: The onset as reported in the previous literature is dependent to some extent on the method of observation.

MR. WELTER: That's correct.

MR. SCHROCK: In the KFK experiments, for example, they used an acoustical method for measuring the onset. We looked at it visually.

And in both cases there were circumstances in which you would get intermittent lifting of the liquid at a certain level. And then at a slightly higher level you get continuous flow of the liquid. So you have to make a decision what is it that you're using as the basis in your correlation, because you need that h_b or h_1, as you've designated it, in your correlation for the flow in the break line after the onset of entrainment as a function of the level in the stratified zone.

So I'm simply mentioning that, because I don't hear any significance attached to the method of observing the level for the onset.

CHAIRMAN WALLIS: He's measuring the --

MR. SCHROCK: Are you --

CHAIRMAN WALLIS: -- the opposite. He's measuring the stopping of entrainment.

MR. SCHROCK: Are you giving the value for continuous entrainment, the value for intermittent entrainment, a value that's seen visually, or a value that's detected by some instrument, such as the KFK experiments using an acoustical detection in the branch line?

MR. WU: For the entrainment onset level, like Dr. Wallis' point, we measured when it stops so that level is quiet --

MR. SCHROCK: When it stops?

MR. WU: Yeah.

CHAIRMAN WALLIS: So -- could you draw on the thing here --

MR. SCHROCK: So you're not giving the onset; you're giving the cessation?

CHAIRMAN WALLIS: Draw us what you actually -- what you actually measure.

MR. KRESS: They're actually using those probes on each end, I think they said.

CHAIRMAN WALLIS: You measure h_1 versus time, or something?

MR. WU: Yeah.

MR. WELTER: Okay. So I'll draw -- I think you were wondering what the data looks like, draw a picture of what --

CHAIRMAN WALLIS: Yeah. How -- what actually -- when do you say it stops and that sort of thing.

MR. WELTER: Okay.

CHAIRMAN WALLIS: Could you use a thing that shows up, not the plain red one.

MR. WELTER: Yeah.

Okay. So this is the time during the test.

CHAIRMAN WALLIS: Right.

MR. WELTER: And this would be with the calibration curve then, the level in the hot leg, h_1.

CHAIRMAN WALLIS: Right. That's h_1.

MR. WELTER: That's correct.

You would see -- at the beginning of the test you would see a full hot leg right there. And as you throttle the gas flow, you would, of course, see a sharp drop in the level in the hot leg. And after a period of time --

CHAIRMAN WALLIS: You leave the gas flow constant now?

MR. WELTER: Leaving the gas flow as constant. There's no injection rate. After a period of time this level will go like that, the level in the hot leg.

CHAIRMAN WALLIS: Okay. So --

MR. WELTER: This is the level --

CHAIRMAN WALLIS: It's its last gasp. In fact, it's the level at which the last little piece of wave comes off.

MR. WELTER: Exactly. And so we take a look, and we say that this level right here, we take an average of time and we compare it, of course, the time's average between this one, average there, a moving average. And we compare what does this approach to, what does that value approach to. That's where onset stops. And we have then said that's when onset begins.

MR. WU: So for --

MR. SCHROCK: Well, how do you know there's not a hysteresis involved in the phenomenon?

MR. KRESS: You would expect some.

MR. WU: We tried to bring the liquid level up. But once you overbring it, it's going to put it out. Because of our branch size, we guarantee the branch's velocity is overly, a full regime transition for the annular flow. So anything being put to that branch exit is going to pull out. So it mustn't pull out.

So if you go for -- we go -- we went from the bottom up, bring liquid there, and to come back to -- if we overshoot it, it will bring up to the stopping point. That's the same result.

MR. BAJOREK: But can you tell, when you bring that level up, whether you're getting entrainment and then it drops back down to the level? You could have been getting entrainment at a lower level and you won't see it until you've entrained a whole bunch of it --

MR. WU: Well, --

MR. BAJOREK: -- and drop back down. So --

MR. WU: No, no. There's no drop back, back down significant. We bring it up to the -- when the entrainment occurs, you -- you obviously, when you say "entrainment," that's already overshooting the level, right?

Then you bring down a little bit, and actually it's the same condition as what we -- we are talking about.

You have a minimum in the gas count constant, and then the entrainment stops. Here is you just overshoot a little bit, and it just finally stop. For our case it is from the top to the stop. It's --

MR. BAJOREK: But it's a question of whether there's a hysteresis if you get entrainment at a lower case in g- --

MR. WU: We didn't find that. For our test we didn't show that. We didn't find that.

CHAIRMAN WALLIS: I'm uncertain about the time now because you're describing a test and you've had about four or five different correlations and analyses to go through. And if we ask as many questions about each one of those you're going to be here until about three o'clock before we get lunch.

But we may -- you know, it may be worthwhile asking those questions. We just don't have the time.

MR. SPEAKER: You have to do what you can to keep us going.

MR. WELTER: Okay. Thank you, sir.

I didn't describe those, okay.

For the steady state entrainment test, this is for constant liquid injection and a constant gas flow rate. We will go ahead and the reactor vessel will start basically dry. And I will throttle the flow rate of the liquid to fill the reactor vessel, at the same time throttling the air at a specified flow rate.

And this will go ahead and will raise -- the two-phase mixture will raise. At a certain point the hot-leg level will start to entrain.

And we will then take this data for a period of time, approximately four to six minutes. And this is the time the *h*, the level at which there's steady state entrainment.

And in this case, since flow cannot go around the steam generator, the injection is equal to the entrainment rate. We're trying to determine what the hot-leg level is for those flow conditions.

The test scope, the matrix that we did is the effect of the steam generator, close it, open it -- the blind. I'm sorry. And the effect of the gas flow direction on that entrainment rate.

CHAIRMAN WALLIS: Now when you do a theory, are you going to use different theory in the different places in the flow regimes in the different -- in the next figure?

MR. WELTER: Theory?

CHAIRMAN WALLIS: You've got plug, slug, stratified, wavy. I'm just following ahead.

MR. WELTER: Oh, yes.

CHAIRMAN WALLIS: Are you going to use different theories in the different parts of the picture?

MR. WELTER: Oh, okay. I'll go ahead there.

CHAIRMAN WALLIS: Are you going to use different theories in those different flow regimes?

MR. WELTER: I'm sorry. Could you clarify "theory," what you mean by "theory"?

CHAIRMAN WALLIS: On the right you've got four flow regimes.

MR. WELTER: This is classic flow regime map.

CHAIRMAN WALLIS: Are you going to use the same theory for all points?

MR. WELTER: In terms of the model development, sir?

MR. WU: This one, in this case you have liquid flow. For the previous one you don't have liquid flow.

CHAIRMAN WALLIS: Yeah, but I'm just saying you're going to develop a theory for liquid --

MR. WELTER: All of them, he wants to know that.

CHAIRMAN WALLIS: Is it the same theory, or different?

MR. WU: For this flow regime map we use -- if you -- you don't have a JF you cannot do it, right? That's for this stratified, okay. So without the liquid flow in the main pipe you cannot use this for a regime map.

The one Zuber proposed for that one is a -- said that VF equal to zero. We'd use your transition criteria. We said we have equal to zero. Okay.

MR. WELTER: Okay. I think it would be more explained when he talks about the model improvement, when he talks about the actual model part.

The test matrix includes gas flow rates of up to 300 standard cubic foot per minute. We can -- our compressor is capable of at least three times that, but with corresponding pressures we, since it is PVC, rate at 20 PSI, we maintain low, so we maintain integrity of our test section.

Similar with that, our liquid flow will go up to 60. Our pump is capable of 600. We maintain it low so the test section does not break or leak.

These are the data points we ran. We wanted to get a good full spectrum as possible. And when we look at a classic flow regime map, this is different in the fact that this is not the flow regimes that we see in our test section because we do not have a developed flow. We have a short inlet. But if it were, this is where the data would fall.

This is an illustration or a visualization from the separate effects. We would like to see what's happening, and so I have a clear PVC test section.

This is a visualization data that we recorded. I have another animation. And it illustrates the oscillatory phenomenon that you see when the three-inch return line is closed or the loop seal is filled.

CHAIRMAN WALLIS: Are you going to show us movies? I guess you are.

MR. WELTER: I'm going to show you a movie. So that is the oscillatory nature and that is approximately real time.

CHAIRMAN WALLIS: I would think that no theory is going to predict that.

MR. WELTER: That -- okay. It comes to a point that previous studies, of course, what liquid level are you going to use for h. There are two levels. And since we have two probes that measure a hot-leg level, we have two distinct different levels.

CHAIRMAN WALLIS: And this stuff about potential flow out to a sink or something isn't going to be relevant to that picture, is it?

MR. SCHROCK: Let's see. This is what I was trying to point out earlier. What you're showing here illustrates that the phenomenon that you're studying has nothing to do with the physics of the flow of the gas creating a low-pressure zone that lifts liquid off of a smooth interface and entrains it into that branch flow.

CHAIRMAN WALLIS: It doesn't matter, Virgil.

MR. SCHROCK: These --

CHAIRMAN WALLIS: The theory's going to work anyway.

MR. SCHROCK: Huh? I mean --

MR. WELTER: This is -- I'm sorry.

MR. SCHROCK: -- how you could imagine you'd fit this into the format of the correlation --

CHAIRMAN WALLIS: Well, it may well --

MR. SCHROCK: -- that represents the onset of entrainment as a function --

MR. WU: No. We hope --

MR. SCHROCK: -- of a liquid level. There is no definable liquid level in this thing.

CHAIRMAN WALLIS: There is whatever's measured.

MR. WU: There's an average in the --

MR. SCHROCK: No. There is not --

CHAIRMAN WALLIS: It's whatever's measured by the probe.

MR. SCHROCK: -- even a definable average. Try to define it. See how far you get.

MR. WU: So that means we may need to do some more modeling or --

CHAIRMAN WALLIS: No, no, no, no. You finished the program, we heard. I think we've got to go on, --

MR. WELTER: Thank you, sir.

CHAIRMAN WALLIS: -- but obviously there's some skepticism.

MR. WELTER: Thank you, sir.

So we are concerned with, of course, the real case. There are two levels. How to determine, when we're using a model, which level to use, average the reactor side, the steam generator side.

And part of our test scope I wanted to illustrate what we just spoke about which is the step phenomenon, and that is these data points. The square dots are for the test series with a closed return -- I mean -- I'm sorry. This is mislabeled.

(Presenters Mr. Welter and Mr. Wu confer off record.)

MR. WELTER: So with the closed line there is not a large difference in the levels when we open the steam gen- --

(Presenters Mr. Welter and Mr. Wu confer off record.)

MR. WU: So the upper circle is the -- within the same -- oh, yeah, it's over it.

MR. WELTER: It's opposite, yes. I'm sorry. The graph is incorrect. These data points should be switched in terms of the squares are with the three-inch line open. And the circles are with the three-inch line closed.

So when the three-inch line is closed, then the oscillatory behavior is seen. And you can tell that by the difference in level. One level is the react- -- this is the steam generator side, hot-leg level. This is the reactor hot-leg level.

And when the case -- when the three-inch line is open it's a much more calm surface and the levels are much more similar.

MR. SCHROCK: What is the meaning of "step phenomenon"?

MR. WELTER: "Step phenomenon" is meaning -- I'm sorry -- that there is a step in your level. You're basically seeing a lower level in the inlet to your test section and a higher level on your steam generator side, so the level is stepping.

MR. SCHROCK: Well, the thing that you refer to as steady is shown, in three different views, something that's very unsteady and you imagine some average condition about it. But can --

MR. WELTER: We have taken a time average of that condition; that's correct.

MR. SCHROCK: Yeah. But for step

phenomenon, what do you imagine, that you have a level that suddenly changes as the liquid progresses?

MR. WELTER: I'm sorry. I was not clear.

MR. SCHROCK: I want you to explain to me what the term "step phenomenon" means.

MR. WELTER: The term "step phenomenon" means to me, in the way that we have described it, is that there is a difference in levels between the reactor side and hot leg, if we look at an average.

CHAIRMAN WALLIS: It seems to me what's happening is that you have a plug of liquid in the steam generator and then the -- everything's clear for the --

MR. WELTER: Exactly.

CHAIRMAN WALLIS: -- hole, so the gas goes out, the plug runs back. As soon as it comes back to the hole, it blocks the hole, the pressure goes up, --

MR. WELTER: Right.

CHAIRMAN WALLIS: -- and it gets shot back up into the steam generator. You're generating oscillation of a slug of water.

MR. WELTER: And the plug does not reach the inlet side.

CHAIRMAN WALLIS: Right. This is very system dependent. So what you're studying is entrainment. When you have an oscillating plug going into a steam generator, it's completely different from Professor Schrock's experiment --

MR. WELTER: That's correct.

CHAIRMAN WALLIS: -- and Lahey's, and so on. It's a different thing altogether, but it may apply to AP600.

MR. WELTER: Yes. Thanks.

So this is also the --

MR. SCHROCK: It may not, too.

MR. WELTER: This is also the effect of the steam generator, again similar to the onset, with a blind compared to with the steam generator. You see with no steam generator there is going to be a higher liquid level, similar to what we discussed with the onset of entrainment tests.

So the steam generator is also important when we're considering entrainment rate phenomena at steady-state conditions.

CHAIRMAN WALLIS: How is this going to get fit into a code, the fact that the steam generator is important?

MR. BAJOREK: At this point we've got to be very careful on what and how we would apply this model. The problem in RELAP is that the horizontal stratified model was grossly underpredicted in the total entrainment.

I think what we see in the movies here is something that's more flow-regime dependent rather than something that's giving us entrainment off of a horizontal stratified. The flow regime is sitting there quiescent.

I think that at this point we should be taking the correlations, Maciaszek, Schrock, potentially the new one, and looking at the sensitivity of entrainment that we might be getting, but I don't know if we're far enough along that we would say that this is a great model and we should drop this in and replace what we've got there.

I think what we are seeing based on their work so far is that they are seeing higher rates of entrainment than the previous model that had been in RELAP.

And that puts it more in line with the no-reserve tests, some of the other -- I guess there was another one of the tests that was showing much higher entrainment than what they've been getting out of the existing correlation.

We're going to need something like that for AP1000, where the gas velocities coming out of the core are going to be substantially higher and we're going to expect more entrainment.

So I think it's headed in the direction of increasing the -- being able to predict higher entrainment. But I wouldn't say that this is a model that we can say is completely adequate for all situations.

CHAIRMAN WALLIS: I'm not sure yet that the model represents the physics. I'm sort of with Virgil. Perhaps we need to get to the model.

MR. SCHROCK: Well, I think this is the problem always with the codes, is that -- I said this in our private discussions -- you make comparisons of the code predictions against integral system performance. And you get an impression that the reason that the code doesn't predict the experimental data well is one of hundreds of correlations that are embedded in that code isn't right for that situation.

Now what you've just said focuses very clearly on what the difficulty in their thinking is.

It's not that the correlations were entrainment from a stratified region are the problem; it's that the code is telling you you have a stratified region when, indeed, it's not stratified. And, therefore, you're getting something altogether different.

The problem is in the characterization of the flow regimes, which is excessively simplistic in the codes and leads to all kinds of difficulties and confusions in interpreting these comparisons of integral test performance and code prediction.

And you're never going to improve that following the course that this is taking. You're dealing here with different phenomena than the references taken from the literature addressed.

MR. KRESS: It does -- it does --

MR. SCHROCK: You have to address the phenomena that are occurring in that system.

MR. KRESS: It does point you to where you need to work on your code, because basically the RELAP-type formulation won't predict this oscillatory behavior because of the way it's set up. And that's what you need.

You'll need something that predicts when you get this behavior, and then perhaps your results, or whatever correlation you put out of them, could be used if the code could predict that behavior.

MR. SCHROCK: Right.

MR. KRESS: But you need to work on that part of the RELAP.

MR. BESSETTE: Yeah. I think we agree -- I think -- you know, see, what we have in RELAP right now is -- simply invokes the off-take model when the code says you have stratified conditions at that node.

So if we have -- so you have to invoke the model at the right time. So if we have, you know, one particular model for slug flow, one for wavy, one for stratified, of course, as a starting condition, the code has to get flow regime right, you know, --

MR. SCHROCK: Right.

MR. BESSETTE: -- in order to invoke the model at the right time.

MR. SCHROCK: That's precisely my point.

MR. SHACK: The physics are different in each one of those regimes in what it does. And right now it just gravitates from regime to regime and makes it very simplistic.

CHAIRMAN WALLIS: I'm just wondering where you're going to go with this presentation. I see you've got what looks like three models that we sort of agree don't apply.

Are you going to just simply say here are three lousy models that don't apply and go on to the one that works that you developed, or are you going to spend a lot of time going through something which doesn't apply?

MR. WU: No. We want to say the two models we compare are the two asymptotical condition. And then we want to say bridge them together.

CHAIRMAN WALLIS: Well, we don't need to worry about Schrock's sink flows and things like that, do we, because it doesn't apply?

MR. WU: Well, --

CHAIRMAN WALLIS: Are you going to drag us through --

MR. WU: The case is for this project, we are trying to extend for small breaks. And Schrock's correlation obvious for small breaks should work for that. And then we want -- we don't want to abandon these --

CHAIRMAN WALLIS: For very small breaks.

MR. WU: Yes. So we say, well, we cannot develop a model say just for the larger break. We have to consider some model that already worked in the past. So we want -- so we figure out from the theoretical reasoning we found it is Maciaszek's and Schrock's work. It's actually two asymptotic conditions. And then we try to bridge them together.

So if you have a small break, it works. Basically it is approaching to Schrock's work. And then larger break approaches to Maciaszek's work. That's what our intention. We didn't try to abandon what is the previous work.

MR. WELTER: Thanks, sir.

I think that's my last slide in the test results section, determining the importance of the gas flow downstream, the gas flow direction.

In the onset tests we saw that there was a little bit of scattering compared to the entrainment rate tests. When I open or close a three-inch return line, there is a large difference in the liquid level in the hot leg.

CHAIRMAN WALLIS: Well, how are you going to use these data? Do you know the flow rate in the return line?

MR. WELTER: In terms of where -- we're installing a metered flow line.

CHAIRMAN WALLIS: Oh, you don't know it yet?

MR. WELTER: That's correct, sir.

CHAIRMAN WALLIS: So we're simply observing there's a difference, but --

MR. WELTER: That's correct.

CHAIRMAN WALLIS: So the data aren't usable yet until you've done some more measurement --

MR. WELTER: That's correct, sir.

CHAIRMAN WALLIS: -- to know what's really going on?

MR. WELTER: That's correct, sir.

This is showing just the effect.

CHAIRMAN WALLIS: But it's an effect which --

MR. WELTER: It's important.

CHAIRMAN WALLIS: -- can't be reflected in a theory because you don't know the flow rate split.

MR. WU: Not yet.

MR. WELTER: Not yet.

CHAIRMAN WALLIS: You don't know the flow rate split going in the two directions?

MR. WELTER: Yes, that's correct.

MR. WU: We know one is closed --

CHAIRMAN WALLIS: So you can't have finished -- you can't have finished the work.

MR. WU: The closed case, we know. That's -- that presented the real case of the loop seal case. That's the major, and --

CHAIRMAN WALLIS: It's a major effect, yes.

MR. WELTER: In this presentation we haven't presented an entrainment rate model. We've presented an onset model. The entrainment rate model is continuing work at this point.

CHAIRMAN WALLIS: Well, you've explored some things which influenced the entrainment.

MR. WELTER: That's correct.

And so this shows the effect of the return line or the flow direction.

Noticeably, with the three-inch line open there is no oscillatory behavior. So when the loop seal is filled and the three-inch line is closed, the oscillatory behavior occurs. When it's open, it's much more calm.

I'd like to take a few minutes because, like Dr. Wu said, the new model proposed is asymptotic conditions of Schrock and Maciaszek's work, so take a moment to look at those models.

That's Schrock and Smoglie using a potential flow formulation. The stream lines go to a sink. The break is modeled as a sink. The stream lines intersect the interface, so there's in effects of the interface, gas leak or interface on the potential. And h_b is far from the break, or the other way to say that is the break size is very small, can be considered a point sink.

For noise equate --

CHAIRMAN WALLIS: There's a flat ceiling, too, isn't there? There's no curvature to the pipe and all that.

MR. WELTER: That's correct. Exactly how strong it gets.

H_b again is considered as the gas chamber height at which entrainment begins.

CHAIRMAN WALLIS: What does he do with his interface then? He's got another sink reflecting an interface, or something? How does he --

MR. WELTER: In the model? Without improvement? I'm sorry, sir?

CHAIRMAN WALLIS: The stream lines come out of the interface like that?

MR. WELTER: The stream lines --

CHAIRMAN WALLIS: Magically come out of the interface?

MR. WELTER: That's correct. It's a sink.

MR. SCHROCK: I don't know why you've put my name on there, but --

MR. WELTER: Smoglie. I'm sorry, go ahead.

MR. SCHROCK: -- apart from the fact that it's misspelled.

(Laughter.)

MR. SCHROCK: The history here is that the program at KFK involved extensive experimentation under the direction of Dr. Reimann -- Reimann and Kahn, Reimann and some other people.

Smoglie was a student who did a theoretical thesis employing potential flow to make a prediction of the value of h_b for a stratified upstream condition.

I don't recall her having stream lines intersecting the interface, but it's been more than 10 years since I last looked at that. Maybe she did, but I kind of doubt that.

But, in any case, it's not something that I suggested or that any of my co-workers suggested.

MR. WU: We put Smoglie --

MR. SCHROCK: Also in your reporting of the KFK data you refer to that as Smoglie data. She had no data. I mean she -- in the sense that she did experimentation, she was not an experimentalist. She was a theoretician -- is a theoretician I presume now.

MR. WU: Thank you. We should represent it as KFK data later.

And for this Smoglie, they arrived at that. That's true. The interface, the stream line goes to the interface. I mean there is no interface there.

For your name put there is because your correlation. It's almost identical with that, except that the gas density --

MR. SCHROCK: Well, that's kind of a loose description. I mean --

MR. WU: So the two correlation basically the same, --

MR. SCHROCK: Yeah.

MR. WU: -- to the fifth power, so we didn't see this derivation is yours. We should have cleared it up before. And yours is based on the Froude number. And the Froude number is based on the branch velocity.

CHAIRMAN WALLIS: One of the units here, W is a flow rate?

MR. WU: Mass flow rate.

CHAIRMAN WALLIS: Mass flow rate. I don't understand how the units of the final correlation work out. It doesn't even make sense to me, but -- three in -- oh, well, maybe it does. Okay. Maybe it does.

MR. WELTER: So Bernoulli's equation can be written along the Z axis from the interface to the point sink. You take the derivative in terms of that with respect to the distance away, then you can develop a criterion based on the pressure gradient at the interface. If --

CHAIRMAN WALLIS: We're beginning to pick up the interface.

MR. WELTER: That's correct.

So at some condition if this pressure gradient is greater than or equal to the gravity potential, then entrainment begins. So it's an onset entrainment criterion.

CHAIRMAN WALLIS: So something happens.

MR. WELTER: Exactly. Something happens.

CHAIRMAN WALLIS: Is there any confirmation that this works?

MR. WELTER: Oh, yeah. The next slide will show data and how well this correlation -- yes.

H_b is then -- you can get that from this correlation. And h_b is a function of the gas mass flow rate to the one-fifth power or squared to the two-fifths power.

CHAIRMAN WALLIS: So the Smoglie data, compared with theory, spans about two orders of magnitude?

MR. WELTER: Yes, that's correct. But this -- the KFK data --

CHAIRMAN WALLIS: Worst case.

MR. WELTER: Yeah. The KFK data has large uncertainties in the determination. There are several -- you see several gas flow rates for the same liquid level.

This graph is a $W3_g$ squared, which is what's in the brackets. So this is raised to the one-fifth power.

CHAIRMAN WALLIS: So this is theory versus experiment; is that what it is you're saying?

MR. WELTER: That's correct. So it shows the degree of collapsing of the data, how well the -- so the exact -- the exact data would lie directly on this line. Left side versus right side.

This is the correlation by Smoglie, and it shows -- the red is ATLATS data for large -- or for small data. I'm sorry. And for Smoglie and Schrock data.

CHAIRMAN WALLIS: The only thing that works well is the Schrock data.

MR. WELTER: Yes. That is right there. It's beautiful. It has --

CHAIRMAN WALLIS: You deny --

MR. SCHROCK: Absolutely amazing.

CHAIRMAN WALLIS: -- having created this data?

(Laughter.)

CHAIRMAN WALLIS: I thought you were denying having created anything.

MR. SCHROCK: No, no. I created a lot of data.

CHAIRMAN WALLIS: Oh, you created it, but you didn't have any theory.

MR. SCHROCK: Smoglie had the theory only.

MR. WELTER: But it has difficulty predicting where D over D is small.

CHAIRMAN WALLIS: Yeah.

MR. WELTER: The large breaks, that is.

Next we'll take a look at Maciaszek, who used a formulation by Wallis. Considering -- Wallis considered a branch or just basically a tube on top of a large pool with gas flowing over it so gas flows from all directions into an entrains liquid into the branch. It considers an interface condition with a two-bump sort of phenomenon, wave phenomenon, where the wave crest height is determined and defined as delta.

And you can write a simple continuative equation here, where velocity of the inlet or velocity from all sides in a virtual cylinder here, so it's rho v pi times number, which is diameter of the sphere --

of the cylinder.

And the cylinder is from h_b minus delta, so it's the cylinder right here (indicating). And that's show in this here. And that is --

MR. SCHROCK: Is this --

MR. WELTER: Yes.

MR. SCHROCK: -- a cylindrical off-take, or what --

MR. WELTER: Yes, this is a cylindrical off-take. So this is a cylindrical cylinder that the gas is flowing into.

MR. SCHROCK: And so it's in cylindrical geometry in that sense, and so these bumps represent a ring of --

MR. WELTER: A ring, that's correct.

MR. SCHROCK: Um-hum. Why does it do that?

CHAIRMAN WALLIS: I have no recollection whatsoever of any of this.

(Laughter.)

MR. SCHROCK: Why would the liquid deform in that way? It implies that the -- that there's a ring of low pressure lifting it into that format.

CHAIRMAN WALLIS: I guess there has to be a stagnation point in the middle, must be the argument.

MR. WELTER: That's correct. Velocity at this point is zero. There's a maximum velocity at the wave crest. Work done by Dr. Wu in the model improvement section I think delves a little bit deeper into that question.

CHAIRMAN WALLIS: This leads to a theory --

MR. WELTER: Yeah.

CHAIRMAN WALLIS: -- which compared on the next figure.

MR. WELTER: Yes. So this leads to a theory which is surrounded in this box here. The difference being it has a different experimentally-determined coefficient. And it uses the break size diameter d and it's different as to the one-third power inside of the one-fifth.

Here is how well the correlation -- it brings our data down well, but it's skewed, the Schrock and Smoglie data you can see, slightly skewed compared --

CHAIRMAN WALLIS: Now why are you calling it W^2 over d^5?

MR. WELTER: Okay.

MR. SCHROCK: That's this divided by h.

MR. WELTER: It's divided by d^5 for nondimensional. So the Maciaszek correlation, the horizontal axis is h_b over d.

MR. SCHROCK: What's on the axis of that?

MR. WELTER: I'm sorry. What?

MR. SCHROCK: What is being plotted on the --

MR. WELTER: Okay. Yeah, the Maciaszek correlation. So this is experiment -- this is experimental and this is your theoretical. So this is Maciaszek's correlation. It's the other --

MR. SCHROCK: No. What -- what quantity --

MR. WELTER: H_b is on --

MR. SCHROCK: -- is on -- is on the abscissa? It's unlabeled.

MR. WELTER: Okay. Yes. H_b over small d to, in this case, the third power.

MR. SCHROCK: We should never have to imagine that, you know.

CHAIRMAN WALLIS: Oh, is that what it is?

MR. SCHROCK: Even undergraduate students know that.

CHAIRMAN WALLIS: I didn't think that. I thought it was theory versus experiment. I guess in a sense it is, but --

MR. WELTER: It is.

CHAIRMAN WALLIS: -- it's essentially flow rate versus height, is what you're plotting. Flow rate squared versus height.

MR. WELTER: That's correct. Can I go on?

Okay. To summarize, the model --

MR. SCHROCK: I'd just --

MR. WELTER: Yes, sir. Please.

MR. SCHROCK: -- finally like to tell you that I saw this at close range many, many times and never did I see a ring of liquid pulled up, never. Always a symmetric --

MR. WELTER: Like this. Right here, yeah.

MR. SCHROCK: Right, yeah. Single little thing coming up and drops coming off the top of it.

CHAIRMAN WALLIS: This happened so often in two-phase flow.

MR. WU: Yeah. Maybe -- maybe --

CHAIRMAN WALLIS: The theory is based on the physics which is utterly different from reality and yet the correlation works.

MR. WU: Maybe the instability taken one point then break the other symmetric.

MR. WELTER: To summarize the evaluation

of the entrainment onset models, Smoglie's data is a large scattering with large uncertainties. The Smoglie model is effective. As we saw, it predicts that da- -- Schrock's data, and it's very effective for small break sizes or when the interface level is far from the break.

Maciaszek's model, which takes into account the break size, is valid for large breaks and -- which we saw why it pulled the ATLATS data down to that line, or when the liquid interface level is close to the break.

MR. SCHROCK: I guess you haven't shown us any data yet that would tell me that you ought to plot those on the same piece of graph paper. The data that you have is for conditions upstream that are not stratified for the most part, so far as I can tell.

MR. WELTER: Onset data -- the onset data is a calm surface. The entrainment rate is the oscillatory. Am I confusing that?

MR. SCHROCK: I just heard a lot of discussion about the fact that you don't even measure the onset of entrainment. What you measure is the cessation --

MR. WELTER: Cessation of entrainment.

MR. SCHROCK: -- of entrainment.

Cessation of entrainment in relationship to what kind of phase distribution you had upstream was left quite unclear. But you've not shown us any evidence of the fact that you have cleancut measurements of the onset of entrainment from stratified upstream conditions. I've not seen that. If you have it, show it to us.

MR. WELTER: Okay. Sir.

CHAIRMAN WALLIS: Well, presumably the bubbling in the reactor vessel sets up some sort of wave motion in the pipe.

MR. SCHROCK: Well, I'm not arguing that all these complications don't exist out there in the reactor systems. But what I'm saying is you're not going to improve your computer code by this kind of pursuit of what is wrong with what the code is currently doing.

What's wrong with what the code is currently doing is, predominantly, it has no idea what the upstream flow regime is.

CHAIRMAN WALLIS: Okay. We're getting close to the break, Jose, are we? We're supposed to go to 11:15 and then we're supposed to do a tour.

What would you like us to do?

MR. REYES: It would be valuable at this

point possibly to take a break and go look at the test facility.

CHAIRMAN WALLIS: We're going to come back and see this in the afternoon.

Then I think the interesting will be what you have done to get better agreement with data. As I understand, you have a better model, but it seems to be based on these somewhat iffy past models rather than a new model that really reflects what's actually happening; is that the case?

MR. REYES: I don't believe we've gotten to that point yet in the --

CHAIRMAN WALLIS: Can we discuss that after lunch when we feel happier?

MR. REYES: Quite likely.

CHAIRMAN WALLIS: Is that good? Okay.

Thank you very much. Very interesting subject.

So we're going to take a break now. We don't have a recorder at the inspection of the test facility. We don't --

MR. BOEHNERT: No.

CHAIRMAN WALLIS: So we're no longer in session. And when are we going to come back? When do we reassemble here?

MR. REYES: We would go to lunch from the demonstration and then --

CHAIRMAN WALLIS: And then we'll return to where we were here.

MR. REYES: At 1:30, I believe.

CHAIRMAN WALLIS: Shall we have a short lunch; can we try and get back early? How soon can we be back?

MR. REYES: I think a short lunch would be --

CHAIRMAN WALLIS: Can we have a quick tour and get back at 1:00?

MR. REYES: Let's do that.

CHAIRMAN WALLIS: Let's meet here at one o'clock. We'll meet here again at one o'clock.

(Tour and luncheon recess taken from 11:15 a.m. to 12:58 p.m.)

CHAIRMAN WALLIS: And we'll continue with the presentations by OSU.

MR. WELTER: I hope you enjoyed a good lunch at West Cafeteria. I know I'm ready to fall asleep now, but I don't get to do that.

We left off, I finished summarizing the onset of entrainment model evaluation. I wanted to then step into and discuss entrainment rate models that we're evaluating also, the first one being the Schrock correlation. It's based on a curve fit of entrainment rate data based on your actual gas chamber level, h, and then divided by your onset gas chamber level, h_b. That determined the quality or the rate to your branch.

CHAIRMAN WALLIS: X is a mass flow rate? There's nothing here about third properties at all?

MR. WELTER: It's predicting the quality, which gives you a --

CHAIRMAN WALLIS: It's called a mass fraction.

MR. WELTER: Exactly. It gives you the fraction of liquid.

CHAIRMAN WALLIS: There's nothing about densities or anything when -- if they were both water, that wouldn't make any difference.

MR. WELTER: H_b.

CHAIRMAN WALLIS: It's remarkedly substantive.

MR. WELTER: Smoglie also developed a correlation based on the dimensionless h over h_b.

CHAIRMAN WALLIS: She has densities, though, so...

MR. WELTER: And there is a rho f and rho g in this model. It's based on the right-hand term. One minus that term is based on a vapor pull-through through a down branch.

And then she went and said that for upward is one minus the down, and then she modified the experimental coefficient 2 over h_b to match the data.

Yonomoto developed the correlation model for determining x3. It has A and B, which are experimentally-determined constants based on the void fraction in your main line.

CHAIRMAN WALLIS: In the main line. It says on branch void fraction.

MR. WELTER: Oh, I'm sorry. Branch.

CHAIRMAN WALLIS: Do you mean the main line --

MR. WELTER: Thank you. Branch void fraction.

CHAIRMAN WALLIS: So it's kind of funny because x3 is a submeasure of the void fraction, isn't it, indirectly.

MR. WELTER: Quality, yes. You can relate quality in void fraction.

CHAIRMAN WALLIS: So it depends on itself --

MR. WELTER: Yes.

CHAIRMAN WALLIS: -- in a sense. You have to know the void fraction to predict the quality. You might be in a little bit of trouble.

MR. WELTER: They ran a -- we ran experiments to determine the void fraction in relation to that.

The correlation is based on determining a sphere of influence and within that sphere of influence all of the liquid in the hot leg will then be sucked up the branch.

CHAIRMAN WALLIS: If you plot these three curves as versus h over h_b, you're doing that somewhere?

MR. WELTER: Yeah.

CHAIRMAN WALLIS: They're actually -- on the same piece of paper?

MR. WELTER: That's correct. Smoglie is not plotted on this one. H average, when we consider, when we look at our data, we have oscillatory behavior. So we have to have some way of placing that on this graph. We use h average, which is the average between the reactor side and the steam generator side, liquid levels in the hot leg.

CHAIRMAN WALLIS: What shall I conclude from this figure?

MR. WELTER: You can conclude from this figure that the data -- that we ran ATLATS predicts significantly higher entrainment rates than the correlation. Higher h, yeah.

CHAIRMAN WALLIS: It's lower, isn't it? X3 is lower?

MR. WELTER: Oh, I'm sorry.

MR. WU: Yeah, lower rate -- well, higher, higher rate.

MR. WELTER: Well, the quality is lower, so there's more liquid going in for the same -- for the same level -- I'm sorry -- for the same level, if you have the same level here, our data is a quality --

CHAIRMAN WALLIS: Oh, quality, okay.

MR. WELTER: -- less than .2.

CHAIRMAN WALLIS: Quality means --

MR. WELTER: And then theirs would be all the way over here --

CHAIRMAN WALLIS: Okay. Sorry, that's right. That's right.

MR. WELTER: -- up to 9, so there would be entrainment rate, --

CHAIRMAN WALLIS: That's right.

MR. WELTER: -- higher entrainment rate.

CHAIRMAN WALLIS: X is a measure of vapor fraction, not liquid fraction.

MR. WELTER: That's correct, sir.

CHAIRMAN WALLIS: Yeah. That's right.

MR. WELTER: I need to go back here. I pressed the wrong button. Okay. So the different graphs, Yonomoto is the higher one. Schrock's correlation is the one in the center.

CHAIRMAN WALLIS: H ab over h break? Why -- what's the --

MR. WELTER: H_b is the inception. H over h_b. This is the real h_b that we find in our experiments. So this is the h_b from our new model.

CHAIRMAN WALLIS: So there the correlations never go beyond 1 for h over h_b, but yours does?

MR. WELTER: Exactly.

CHAIRMAN WALLIS: Is that some physical --

MR. WELTER: Yes, there's a significance in that, --

CHAIRMAN WALLIS: -- peculiarity?

MR. WELTER: -- in that our level in the hot leg is below the onset level.

CHAIRMAN WALLIS: You get more entrainment below the level which gives you the onset?

MR. WELTER: Yes.

CHAIRMAN WALLIS: It doesn't make sense.

MR. WELTER: Exactly.

CHAIRMAN WALLIS: When you're actually entraining you have a lower level than at the onset?

MR. WELTER: Yup. That's what we see in our data.

CHAIRMAN WALLIS: It seems to be backwards.

MR. WELTER: Yeah. Because what happens -- well, a physical meaning, when the oscillatory behavior is set up, the level in the inlet side is actually being -- I'd like to draw it. Can I draw that? A better illustration.

If you look at the mixture level in the reactor vessel, during steady-state entrainment it's actually higher than the hot leg. So what's happening is it's pushing down the level on the inlet. Then the oscillatory behavior begins there.

CHAIRMAN WALLIS: So how does --

MR. WELTER: So this level is actually being pushed --

CHAIRMAN WALLIS: So how does the gas get out of the -- squeezes through out of the hole --

MR. WELTER: It squeezes through there and it pushes this level down lower below the onset.

That's what our data is saying.

CHAIRMAN WALLIS: Okay. That's a huge difference. I mean if you've got this factor of two and a half. It's --

MR. WELTER: Yes.

CHAIRMAN WALLIS: There's very high data points there.

MR. WELTER: Yes.

MR. SCHROCK: I didn't understand what h average means.

MR. WELTER: H average is the average -- because we have the oscillatory behavior, we have this step. There's two levels between -- we have these two different levels. Average is the average between these two different levels over time. So if this was h2, this is h1, h average. H1 plus h2.

MR. SCHROCK: That presumes pretty detailed knowledge of the shape of that interface in a horizontal pipe. That's a complicated thing to come by. How did you get that number?

MR. WELTER: Sir, h average?

MR. SCHROCK: Yeah.

MR. WELTER: Oh, the measurement. We measure the liquid level here. We have a ring probe that can measure this liquid level, and we have a ring probe that can measure this liquid level.

MR. SCHROCK: You mean at -- at --

MR. WELTER: The inlet and the outlet. We have a measurement --

MR. SCHROCK: Certain axial locations, both of which are away from --

MR. WU: About 2D.

MR. WELTER: Oh, okay.

MR. WU: But 2D downstream and upstream.

MR. SCHROCK: But why would you think there would be a correlation of what's happening for two-phase flow going into the vertical off-take pipe that depends on the average of those two. It depends on the local conditions where it comes off.

MR. WELTER: We're not necessarily presuming that there is a relation between those. We want to evaluate the model with our data. And this is the only way to determine some sort of an h, is to use what we consider an average --

CHAIRMAN WALLIS: What happens if you --

MR. WELTER: What happens if.

MR. SCHROCK: Well, I don't see how it relates to the correlation that we proposed or to our experimental data. Our experimental data --

MR. WELTER: That's true.

MR. SCHROCK: -- were for a level h which is seen visually at -- at the axis of the take-off pipe, --

MR. WELTER: Correct.

MR. SCHROCK: -- not upstream, downstream.

MR. WU: So when you --

MR. SCHROCK: So how can you plot your data against --

MR. WELTER: Your level is right here; am I correct?

MR. SCHROCK: -- our correlation, on the one hand, or how can you compare your data with our data when the --

DR. WU: My question --

MR. SCHROCK: -- data-reporting scheme is totally different?

MR. WU: My question is when entrainment occurs, you see the liquid level jumping under there. How can you observe by research just a crack in it to determine the right under the off-take is a liquid level. Your visualization window is both downstream and upstream. And there are small windows there, two windows.

MR. SCHROCK: Yes, you're right. That's true. That's true.

MR. WU: So it's not right under -- well, right under the off-take you cannot get it, that level.

MR. SCHROCK: Yeah.

MR. WU: So we tried the different ways. We use the --

MR. SCHROCK: But, on the other hand, never was there a situation such as is depicted here.

MR. WU: You don't have the jump.

MR. SCHROCK: No.

MR. WU: You don't have the different -- difference. That's a difference of our data -- of your -- under your data. Your levels, both the inside and the outside, is the same -- are the same. So --

MR. SCHROCK: But you're comparing apples and oranges, is what it amounts to.

MR. WELTER: Okay. The purpose of this slide, I think, is not to necessarily show that the correlation does not predict our data, but shows the inappropriate application. The correlation is fine for predicting the data of your case.

MR. KRESS: How do you determine the quality? Is that the ratio or the average flows --

MR. WELTER: Yes.

MR. KRESS: -- averaged over the --

MR. WELTER: That's correct.

MR. KRESS: -- time period?

MR. WELTER: That's correct, sir.

MR. KRESS: Okay.

MR. WELTER: That it would be liquid mass flow rate over the total.

MR. KRESS: Yeah. You know, --

MR. WELTER: And that's injection. So basically our flow meter is what we inject from the water pump, what we inject from the air compressor; we use that.

MR. KRESS: So that's a -- um-hum.

That thing varies with time, but it would -- as an average it averages out.

MR. WELTER: The quality for the steady state is quite, quite steady, because we have a steady injection flow, steady air flow, and they're both pretty steady over time.

MR. KRESS: Yeah, but there's capicitants in the system that would mess that up.

MR. WELTER: Okay. We do take an average.

MR. KRESS: Yeah.

MR. WELTER: Yeah, a time average.

CHAIRMAN WALLIS: Well, the Schrock theory looks pretty lousy compared with the Schrock data, too. I mean it doesn't predict the trends. And have you had a --

MR. SCHROCK: Well, I don't understand that. I mean our data didn't look like that against our correlation, but --

MR. KRESS: Because you just fitted it to your correlation, hum? I mean you code-fitted it, right?

MR. SCHROCK: That's what they're saying it did, but I --

CHAIRMAN WALLIS: It doesn't look like a code fit at all, especially in low x3s.

MR. SCHROCK: It doesn't ring any bells for me.

CHAIRMAN WALLIS: Anyway, we should probably move on. This just shows that nothing works very well so far.

MR. WU: That's right.

And also we tried to use the different levels. The front level and back level, it doesn't work.

MR. WELTER: At this point I'd like to turn the model development and conclusion, Section 5 and 6 of your presentation, over to Dr. Wu.

Thank you very much.