

1 MR. BAJOREK: We have to partition it.
2 It's basically using model by -- and you come up with
3 a partition and then you also have to come up with a
4 model for the condensation in order to --

5 CHAIRMAN WALLIS: To get back to Professor
6 Schrock's question, I would think that Professor Dhir
7 would have the assignment of develop better
8 understanding of the physics and then tell us how to
9 put this into the code. It looks as if he's got an
10 assignment to understand the physics. And the way in
11 which this is related to what actually has to go into
12 TRAC seems to be a very important part of the problem.
13 Is he doing that?

14 MR. BAJOREK: No, that's going to be our
15 job.

16 CHAIRMAN WALLIS: I'm not sure you can.
17 I think he has to do it. I would assign him of making
18 the burdens, because then he knows what he's got to
19 measure and what he's got to model. If he just goes
20 off into an academic world and models everything he's
21 interested in, that's not the same thing as getting an
22 engineering model that goes into TRAC-M.

23 MR. BAJOREK: No, I don't --

24 MR. KRESS: You're presupposing that V.J.
25 doesn't know what the code meets?

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1 CHAIRMAN WALLIS: I don't know. I'm just
2 saying it should be part of his environment.

3 MR. BANERJEE: He may know, but he may not
4 want to do it.

5 MR. SCHROCK: I'd just like to say amen if
6 I do it.

7 DR. MOODY: Well, as I read this report,
8 I got knowing a little bit about the way V.J.
9 operates. I got the feeling that you were asking him
10 to do kind of a -- on a bottoms up study that you
11 could incorporate into a top down model. In other
12 words, a microscopic lab study that will give some
13 clue and I thought probably on his data that he
14 presented in correlations, that's what you were going
15 to use to incorporate into the TRAC code.

16 MR. BAJOREK: Yes.

17 DR. MOODY: Somehow.

18 MR. BAJOREK: We need to know the
19 individual mechanisms that dominate that split. It's
20 going to be up to us to make that we can take those
21 things, put in the variables, code those in such a
22 format that it can replicate the model that you might
23 come up with in a lab or, you know, in a more academic
24 setting. And we realize that there are always going
25 to be shortcomings in a two-fluid code that's not

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1 going to get us down to a CFD type of modeling of any
2 process. But at some point if we know the physics and
3 if we know models which are mechanistic and can be
4 faithfully used to represent what goes into a rod
5 bundle, whether it's, you know, a GE type or a
6 Westinghouse type over a range of subcoolings, then
7 we're going to have the confidence to put the models
8 in the code and get realistic results.

9 And I think, you know, in going back to
10 this there may be something physically real that's
11 going on, but we went additional steps in this to go
12 back and note when you had a large blip it was when a
13 ramp was being turned on and off in the subcooled
14 boiling model. So it wasn't just, you know, pointing
15 finger --

16 MR. RANSOM: Well, I would take issue with
17 that, too. What actually turns out interface drag is
18 very important to this kind of prediction. And if you
19 don't pay attention to that, you know, it doesn't
20 matter what you do in the heat transfer partition,
21 you're not going to get the right answer either. So,
22 this has to be looked at in that global way.

23 And, as a matter of fact, you know, in the
24 subcooled boiling experiment that we're going to talk
25 about I didn't see any real discussion or

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1 consideration of that. And that goes back to how are
2 you going to put this in the code. And I think there
3 are other issues, too, that we have to talk about.

4 CHAIRMAN WALLIS: Would you go back to
5 your first slide and do it properly, and you could say
6 that in order to predict the average boiling and I
7 have to know how many nucleation sites there are, at
8 what temperature they're activated. I need to know how
9 rapidly those bubbles grow attached to the wall. I need
10 to know when do they move away from the wall. Do they
11 grow some more when they leave the wall.

12 MR. BAJOREK: Right.

13 CHAIRMAN WALLIS: How do they move away
14 from the wall in a transverse direction. Are they
15 carried along in the axial direction. And then when do
16 they begin to condense and how rapidly do they
17 condense.

18 And what I see from his book is there's
19 some work on when they start to form and how many
20 nucleation sites are there. And there's some work on
21 isolated bubbles condensing. But where's all the rest
22 of what's going on that you need?

23 MR. BAJOREK: If we're concentrating on
24 the head transient, we haven't looked so much at the
25 interfacial drag at this point, no.

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1 CHAIRMAN WALLIS: And they've tracked this
2 interfacial drag, which has nothing to do with what
3 I've just talked about, how does it, you know,
4 influencing the result anyway because of the TRAC
5 model?

6 MR. BANERJEE: Well, interfacial drag will
7 surely influence the condensation rate. Because in a
8 way that's Reynold's analogy, right. So you have to
9 have an effect of the drag on the --

10 CHAIRMAN WALLIS: Well, it would probably
11 accelerate the bubbles to the same speed as the fluid
12 and there won't be any Reynolds --

13 MR. RANSOM: Well, in fact the nestled
14 number is the function of the relative Reynolds
15 number. The Reynolds number is based on relative
16 loss--

17 MR. BANERJEE: I guess the main point
18 here, Steve, that there should be framework laid out
19 to receive these results. And what is not clear is
20 what that framework is.

21 MR. BAJOREK: Okay.

22 MR. BANERJEE: So we don't have a set of
23 equation saying this is what's lacking in these
24 equations or this is where we need more information.
25 These the TRAC equations. These are the numbers that

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1 we're going to get out of -- whether that interfacial
2 area or whatever, heat transfer --

3 MR. BAJOREK: Yes.

4 MR. BANERJEE: It's not clear how that
5 data is getting fixed into TRAC. And that might not be
6 trivial to do. That's really the issue. It's sort of
7 difficult because you've got -- if you put
8 distribution coefficients in for the temperature or
9 something so you have subcooling at the wall,
10 something like that, you might get somewhere into that
11 regime. But it's not trivial to phrase this in, at
12 least I don't see it as trivial. You did this job.

13 CHAIRMAN WALLIS: You have to go to a
14 microphone. You have to say who you are.

15 MR. DHIR: I'm V. J. Dhir from UCLA.

16 The key difficulty when we started this
17 work was with the cores that they could not -- they
18 did not know what the repagination date was. What was
19 the source -- fraction. When you give a source term
20 you've got to give number density of bubbles, size of
21 bubbles and rate at which they're being injected into
22 the boil. So that information we're trying to
23 provide.

24 Then they also need to know what is the
25 local liquid temperature. That is effected not only by

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1 the heat transfer from the wall the liquid, but also
2 by condensation. So you need to know what rate the
3 bubbles will be condensing. So that's the problem
4 that we have looked at.

5 MR. RANSOM: In fact, that brings up an
6 interesting issue. It's not the local temperature that
7 you need to know in these codes, it's the bulk
8 temperature that you reference to. It's the bulk
9 liquid temperature which in the heat transfer
10 coefficient between the bubble and the bulk of the
11 liquid you must use.

12 And I know in a paper that I was reading
13 it went to great pains to measure the temperature at
14 the bubble, which of course is not the code variable.

15 MR. DHIR: Right. But if you look at it it
16 really depends on how much resolution you want to
17 have in the code. If there's only cell over the whole
18 -- you could have some average temperature. But what
19 you look at it, or we looked at it, there is a thermal
20 boundary layer which is, you know, temperature changes
21 very rapidly in that region. Beyond that it's like
22 bulk temperature.

23 MR. RANSOM: And that's quite a different
24 model than the model that you use in these one
25 dimensional codes. Maybe there needs to be some

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1 coming together.

2 MR. BAJOREK: Okay. I mean we aren't
3 finished with this. I mean, we still have to get
4 these models, understand them better, find a way to
5 put them in the code. But, you know, our looking at
6 what is in TRAC-M right now and similar codes leads us
7 to believe that the models and the way they're treated
8 now aren't acceptable. You do your best with the
9 available data to look --

10 MR. RANSOM: Steve, let me ask you a
11 question along that lines. There's quite a database
12 out there for subcooled boiling and internal
13 geometries. And did you ever -- and I'm sure that was
14 utilized in the development of these models. So what
15 is the explanation between, you know, those separate
16 effects assessment in all the models, then not giving
17 you good results in this case?

18 MR. BAJOREK: What is it? I'm sorry. I
19 couldn't hear you.

20 MR. RANSOM: I can't speak for the TRAC-M,
21 I guess, but I can speak for the RELAP-5 part. They
22 did use very -- they used Christian, they used St.
23 Pierre you, his experiments to validate the subcooled
24 boiling models. And you got reasonable results in
25 most cases. So I'm wondering why -- there should be

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1 some explanation, I guess, for why this --

2 MR. BAJOREK: Why? If that model's so
3 good, why couldn't it get things like bubble diameters
4 or interfacial drag in a newer test like McMasters?

5 MR. RANSOM: Well, the guess that I would
6 have is that's simply a critical number that's used to
7 decide the bubble size and --

8 MR. BANERJEE: Maybe I should interrupt
9 here. Because I think, you know, Dick Lahey did an
10 interpolation between Unal's experiments and some
11 other stuff. And he never actually broke it into
12 interfacial and heat transfer coefficient. He just
13 call it product of them.

14 MR. RANSOM: Yes, the multiplier.

15 MR. BANERJEE: Yes. And in fact what you
16 guys put into RELAP was Lahey's thing.

17 Now, what happens here this is -- Dave, I
18 don't know how they've separated it into bubble
19 diameter, but it looks like the -- in my opinion, the
20 interfacial area in that was roughly right. They got
21 the heat transfer coefficient completely wrong. So
22 it's the opposite problem to what you're seeing here.
23 So because of the getting the heat coefficient
24 completely wrong, they got the void fraction
25 completely wrong because --

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1 MR. RANSOM: In this case you mean?

2 MR. BANERJEE: In this case.

3 MR. RANSOM: Well, this is the Chen
4 correlation for the overall --

5 MR. BANERJEE: No, no. This is the
6 McMasters experiment where there were bubbles
7 condensing in a subcooled liquid. So the bubble
8 diameter was followed. This was not attached to the
9 wall.

10 MR. RANSOM: I see.

11 MR. BANERJEE: These were just steam
12 bubbles. So it's a condensation experiment basically.

13 MR. RANSOM: Who did that?

14 MR. BANERJEE: This was an old friend of
15 mine, a guy name Shukri or something.

16 And what happened was in these experiments
17 that they could measure of the diameter of the bubbles
18 as well as the rate of condensation. If remember
19 right, though, the reason these experiments are so
20 wrong compared to RELAP-5 is not the interfacial area.
21 It's the heat transfer coefficient.

22 MR. RANSOM: Between the bubble and the
23 bulk of the --

24 MR. BANERJEE: Yes, between the bulk. And
25 there's a very nice graph in the report by Joe Kelley

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1 which actually shows the incorrectness in the heat
2 transfer coefficient. So the problem has not been--
3 Lahey's coefficient was basically an interpolation.

4 MR. RANSOM: Well, Lahey's correlation
5 does not tell you what the heat transfer between the
6 bubble and the bulk is. It only divides between the
7 sensible heat and the heat of vaporization. So it
8 tells you how much vapor is being produced.

9 MR. DHIR: That's Lahey's model, but it
10 doesn't work.

11 MR. BANERJEE: It doesn't work.

12 MR. RANSOM: Well, it works rather well in
13 the codes of --

14 MR. BANERJEE: It works in certain regime,
15 but doesn't work.

16 MR. BAJOREK: That's the rollover term
17 that's in there.

18 MR. SCHROCK: These data are steam
19 injected into flowing subcooled liquid.

20 MR. BANERJEE: Yes, single bubbles. Well,
21 this area of bubbles.

22 MR. RANSOM: Oh, this is the McMasters --
23 I see.

24 MR. SCHROCK: Doesn't that depend on what
25 the diameter of the bubbles injection.

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1 MR. BANERJEE: Well, it was larger. It
2 went up, it condensed and they were followed with a
3 camera.

4 MR. SCHROCK: But single bubbles going up
5 the core --

6 MR. BANERJEE: Yes, single or multiple,
7 but they were in tubes. In fact, you get a very good
8 correlation of the heat transfer coefficient with the
9 interfacial drag which you can estimate very easily in
10 this problem. So when you correct the heat transfer
11 coefficient with a Reynolds analogy here, you get
12 almost a perfect correlation. That was the heat
13 transfer coefficient, you get that.

14 MR. SCHROCK: It seems to me that the
15 situation in the subcooled flow boiling channel is
16 different from that in the sense that there's a radial
17 distribution of liquid temperature which you don't
18 know.

19 MR. BANERJEE: No.

20 MR. SCHROCK: But it exists. And the
21 amount of vapor that's formed at the wall is in part
22 dependent upon that. So the amount that detaches from
23 the wall and is then part of the flow process is
24 different than in this kind of experiment.

25 MR. BANERJEE: It's a pure condensation

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1 experiment.

2 MR. SCHROCK: Both the growth and the
3 condensation occurred in the subcooled boiling flow
4 situation, but only condensation occurs here.

5 MR. BANERJEE: Correct.

6 MR. SCHROCK: And so you can't get the
7 right void fraction in subcooled boiling, shouldn't
8 expect to bring those two things into reconciliation--

9 MR. BANERJEE: Yes, we shouldn't give too
10 much credence to this other than knowing that the
11 condensation rate is wrong.

12 MR. BAJOREK: What's in TRAC-M right now
13 could have been used to compare to FRIGG, some other
14 experiments. Some comparisons look good, others
15 don't. It's based on the Saha-Zuber model. It's
16 shown graphically over here in Saha-Zuber to get that
17 total heat transfer where things are thermally
18 dominated. Assume it's a Nussett number of 455 when
19 it's hydrodynamically dominated, it comes to a
20 constant Stanton number of .0065. That's what was
21 used, that's what was in the --

22 CHAIRMAN WALLIS: How do you know if it's
23 .0065 and 01065. There are two different statements
24 there.

25 MR. BAJOREK: That's part of my point.

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1 This is what was used to correlate various water and
2 freon data in the original. That's not within TRAC-M,
3 which in some cases get good agreement, some cases
4 doesn't. Based on some work that was done at Savannah
5 River in a single tube and down flow, at some point
6 those were adjusted so that in a thermally dominated
7 region, which they defined as being a Peclet number
8 less than 7,000, not a Peclet number of 70,000 in the
9 original model. They say let it be a Nussett number
10 of 74.55. When you get to bubble liftoff, make it a
11 Stanton number of .0165.

12 I've taken this and plotted this versus
13 Saha-Zuber, which in the TRAC-M documentation is being
14 claimed as the basis, the foundation, for the
15 subcooled boiling model.

16 MR. SCHROCK: Where did the TRAC-M
17 modification come from?

18 MR. BAJOREK: It claims to have been based
19 on some Savannah River work that had been done for
20 looking at single tube flows and downflow. This is
21 what --

22 MR. SCHROCK: Another unnecessary
23 complication thrown into this. We're not interested in
24 downflow here.

25 MR. BAJOREK: Well, that's the point. I

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1 mean, if you have a good model, you should have been
2 able to match that subcooled data as well as this.

3 MR. SCHROCK: Why?

4 MR. BAJOREK: If your model is truly
5 mechanistic and you're getting the bubble size, the
6 condensation rates.

7 MR. RANSOM: Steve, a little further
8 comment. The results you show are using TRAC or
9 RELAP-5 and yet the correlation you're talking about
10 is TRAC-M. And so I'm wondering what is the
11 connection, you know, between the two

12 MR. BAJOREK: The connection is both of
13 those are attempting to base their models on something
14 that looks like the Saha-Zuber model.

15 MR. RANSOM: Well, do you have some TRAC-M
16 calculations that show that they don't behave
17 correctly then:?

18 MR. BAJOREK: Not today, but next time we
19 get together I'll try to get those.

20 MR. RANSOM: Well, you're blaming on this
21 correlation. And what I'm wondering was the basis for
22 criticizing the correlation if you have not actually
23 utilized it.

24 MR. BAJOREK: What is in TRAC-M is many
25 ways very similar to what is in RELAP.

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1 MR. RANSOM: I agree with -- well, RELAP
2 uses the 70,000 transition point.

3 MR. BAJOREK: Right. But it's using the
4 same -- overall the same type of scheme to come up and
5 do the splitting. Our bottom line is when we look at
6 those models and how either one of them as compared to
7 data, we're not comfortable with either one of those
8 models as an eventual subcooled boiling model in TRAC-
9 M. So the fact that we had oscillations in RELAP
10 which was the code that we needed to use for the
11 AP600, we weren't satisfied with what had been pointed
12 to as the subcooled boiling model there. When we look
13 at what had been put into TRAC-M, however it got
14 there, that's what's in there right now.

15 MR. RANSOM: And they used the Lahey model
16 for partitioning the energy between --

17 MR. BAJOREK: It's close. It's not the
18 same thing. I don't see the roe over roe term.

19 MR. SCHROCK: Who is "they"? Could I ask
20 it in this case?

21 MR. BAJOREK: They being -- I think this
22 was -- this was Los Alamos that had redone the heat
23 transfer several years ago.

24 MR. RANSOM: This TRAC-M modification was
25 done several years ago?

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1 MR. BAJOREK: Yes.

2 MR. RANSOM: As a part of the TRAC-M thing
3 or --

4 MR. BAJOREK: I don't know for sure.

5 MR. RANSOM: I mean, TRAC-M has been going
6 on for more than 4 years, but --

7 MR. BAJOREK: I don't know if this was
8 specifically put into TRAC-M to be TRAC-M or was
9 something that had been in one of the TRAC-P or TRAC-B
10 that had been grandfathered over into TRAC-M. I could
11 find that out, but I don't know.

12 MR. RANSOM: Okay.

13 CHAIRMAN WALLIS: You have a new slide
14 now?

15 MR. BAJOREK: Yes. This is a new slide to
16 show you what is in TRAC-M, not by way of saying this
17 is what we think is the right way of doing it, but to
18 show you that what TRAC-M does in a way of getting at
19 this partition is to put on a subcooled weighting
20 factor and another evaporation factor that it claims
21 goes back to Lahey to adjust the heat transfer
22 coefficient that you get out of this modified Saha-
23 Zubar.

24 Now, if you go to other codes they're
25 doing something similar, okay. Or they'll change this

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1 and they'll use a different model for this ramping,
2 and they'll change something over here with the
3 vaporization in order to try to get this split. In
4 some cases it works against the data. It other it
5 falls flat. And our argument is that the model no
6 longer has a basis, okay. If the one in TRAC-M has
7 been changed, some data, that we may not even care
8 about for reactor safety applications.

9 CHAIRMAN WALLIS: Professor Dhir is going
10 to come with a better alternative, you know, to this.

11 MR. BAJOREK: Yes.

12 CHAIRMAN WALLIS: He's going to have --

13 MR. BOEHNERT: He said that's right.

14 CHAIRMAN WALLIS: He's going to have a
15 different -- or whatever.

16 MR. BAJOREK: No. We're going to get away
17 from this taking a overall heat transfer coefficient
18 and slapping on a couple of ramps and at the very
19 least split this up into the individual mechanisms.
20 And if we understand those individual mechanisms, now
21 we an come up with better models that we could somehow
22 eventually put in the code and get the overall net
23 vapor generation that's going into the cell.

24 CHAIRMAN WALLIS: You mean the amount
25 which is formed by bubble growth minus bubble

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1 collapse?

2 MR. BAJOREK: Yes.

3 MR. BANERJEE: But it must depend on the
4 size of the cell, right?

5 MR. BAJOREK: Size of the cell --

6 MR. SCHROCK: I've got a question about
7 your equation 3 on the last slide.

8 CHAIRMAN WALLIS: Well, since it's going
9 to be replaced anyway.

10 MR. BAJOREK: Well, go ahead.

11 MR. SCHROCK: So what is H subscript WL?

12 MR. BAJOREK: That's the total heat
13 transfer -- that's the heat transfer or the total heat
14 transfer from the wall. And you get that out of the
15 Nussett number from the Saha-Zuber.

16 CHAIRMAN WALLIS: Which itself has more
17 correlating perimeters in it.

18 MR. BAJOREK: Yes.

19 MR. SCHROCK: But see, WSB is a pure
20 number and FE is a pure number.

21 MR. BAJOREK: That's a pure number. That's
22 dimensionless. Yes, those two are dimensionless.

23 MR. SCHROCK: And so the dimensions of H
24 gamma and WL are the same, those are the ordinary
25 dimensions of a heat transfer coefficient?

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1 MR. BAJOREK: Yes. And when you put it
2 all in here with B cell, which is the cell volume and
3 -- it does work out to be -- it's actually a
4 volumetric vapor generation.

5 MR. SCHROCK: So it's in the definitions
6 of these W and F that there's some physical sense to
7 this H gamma, is it?

8 CHAIRMAN WALLIS: We should move on. I
9 think we'll move on.

10 MR. RANSOM: Quickly, is this written up
11 in the TRAC-M manual?

12 MR. BAJOREK: Yes, it is. Appendix G.

13 MR. RANSOM: The new one that we got?

14 MR. BAJOREK: Yes. July 2000 I think is
15 the most recent one.

16 Okay. So just to quickly conclude. We
17 don't think what we see in there has an adequate
18 database. We don't have an adequate basis for it and
19 the ramps are essentially ad hoc. We wouldn't expect
20 that model to work over --

21 CHAIRMAN WALLIS: But you're going to
22 release this code before Professor Dhir is finished.

23 MR. BAJOREK: The beta version.

24 CHAIRMAN WALLIS: You going to leave it
25 the way it is?

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1 MR. BAJOREK: For the first release it's
2 probably going to have to be that way. But later
3 releases we hope we can change that.

4 And that's all I have.

5 CHAIRMAN WALLIS: Thank you.

6 MR. BAJOREK: Thank you.

7 CHAIRMAN WALLIS: Very reassuring
8 computation.

9 MR. ROSENTHAL: While V.J. is going up, we
10 had -- you know, at least from perspective we had some
11 separate effects experimental programs going on and we
12 had some code development programs going on. And I
13 didn't have some key staff, which I now have.

14 And we're working very hard now to play
15 catchup to glue the experimental programs and the code
16 development far better together.

17 Steve's been with us for about a year. Joe
18 Kelley has returned to the staff. And now we have the
19 staff to do it. And these guys are starting what
20 ideally would have taken place over the years.

21 MR. DHIR: Good afternoon.

22 You know, about 4½ years ago we started on
23 this project of subcooled flow boiling at low
24 pressures, so that was the specific topic. And there
25 we wanted to investigate subcooled boiling through

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1 experiments and model development. With me there is
2 one student, one post-doctorate fellow working and
3 they did most of the work.

4 In the last 4 years we have made several
5 presentations to NRC with respect to the progress we
6 have made. We have published some of the work in
7 various journals and present to conferences. And
8 today I think I appreciate the opportunity to discuss
9 with you what we have done and look forward to your
10 critique.

11 And it's also kind of interesting to stand
12 here rather than sit there.

13 The key objectives of this work were to
14 develop a mechanistic basis for subcooled boiling,
15 heat transfer for incorporation in advanced reactor
16 codes. And we had to support this development through
17 laboratory scale experiments on a 9-rod bundle,
18 although before going to 9-rod bundle, we did
19 experiments on a flat plate heater. That provides good
20 geometry for visualization and to do some detailed
21 studies.

22 A range of parameters of interests were
23 pressures from 1 to 5 bar, mass velocities from 100 to
24 1000 kilogram per meter square per second, and liquid
25 subcooling, that inlet from zero to 50 degrees

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1 celsius. That was the understanding we had when we
2 started the work.

3 The whole effort was divided into seven
4 tasks.

5 MR. SCHROCK: Does the at low pressures
6 imply that the interest in the model is just at low
7 pressure or is --

8 MR. DHIR: Low pressure. Okay. Our main
9 objective was to develop these models at low pressure
10 and validate them, but evidently I think that's doing
11 half the job. We got to extend these models to high
12 pressure and see if we can describe the whole pressure
13 regime. So what we are doing now while validating the
14 models, we are looking at high pressure data as well.
15 Hopefully, to describe the boiling process, if we
16 understand correctly for all pressure.

17 MR. SCHROCK: Okay.

18 MR. DHIR: So this total activity was
19 divided into seven tasks. The first task was to
20 conduct the literature search and see what was out
21 there, whether that was sufficient to develop models
22 or we needed more data as the development proceeded.

23 And from this literature review we
24 developed the database, and then the forming on task
25 was that we now have already what's out there, what we

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1 wanted to develop the test plan for the experiments.
2 And that first pre-task almost took the first year of
3 activity.

4 Thereafter we designed and fabricated a
5 test loop, and that test loop we used first a flat
6 plate geometry for the heater and subsequently we used
7 a 9-rod bundle.

8 And then the task 6 was to develop a
9 preliminary model.

10 And last task is to validate the model
11 with subcooled flow boiling heat transfer data at low
12 pressures and then eventually all pressures.

13 And currently we are in the last stages of
14 task 7. We are told that there's a sunset rule, so in
15 the next 3 or 4 months this activity will be stopped
16 and something new will start.

17 MR. BANERJEE: What's the sunset rule?

18 MR. DHIR: Namely the 5 year limit on
19 these activities. So 5 years will be over, I guess, in
20 a few months.

21 MR. BANERJEE: So at that point you can go
22 on to incorporating these into the codes, right?

23 MR. DHIR: I don't know.

24 MR. ROSENTHAL: We just have contracts,
25 commercial contracts that go five years and we'll be

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1 renewing contracts. There's no -- do the work as long
2 as you have to do it. But, of course, you like to
3 start work and conclude work which frees up monies so
4 you can do other work. But there's no rule.

5 MR. DHIR: Okay. I give you a little more
6 details of the tasks as we go along.

7 So we did a thorough search of the open
8 literature and found that there was a number of models
9 had lots of empiricism built into them and these
10 models were very often were inconsistent at subprocess
11 level.

12 MR. RANSOM: This may be a nitpick, but in
13 your literature review I didn't find any reference to
14 the current models that are used in the code or any
15 discussion of the deficiencies in those.

16 MR. DHIR: We looked at only mostly
17 published literature. We did not look at the code
18 themselves.

19 MR. RANSOM: Well, I think a lot of this
20 is in the published literature. You know, the
21 experiments which have been used for validation of the
22 models. I believe Lahey's work is in the literature.
23 The Saha-Zuber work is in the literature.

24 MR. DHIR: Yes.

25 MR. RANSOM: Why weren't they discussed?

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1 MR. DHIR: What do you mean discussed?

2 MR. RANSOM: Well, there was no reference
3 or discussion of the existing models.

4 MR. DHIR: Saha-Zuber --

5 MR. RANSOM: Is that to say that existing
6 models are inadequate, I guess.

7 MR. DHIR: Right. But in the report Saha-
8 Zuber was discussed.

9 MR. RANSOM: I don't believe it was. I
10 never found any mention of it.

11 MR. DHIR: Okay. But I think you will see
12 that I would mention to Saha-Zuber.

13 MR. RANSOM: In these two papers that we
14 received.

15 MR. DHIR: Okay. But we submitted the
16 reports, and it should be in the reports.

17 MR. RANSOM: You have delivered a report?

18 MR. DHIR: But I don't have it here.

19 MR. RANSOM: But it was given to the NRC?

20 MR. DHIR: Yes.

21 MR. RANSOM: Yes.

22 MR. SCHROCK: So there's a NUREG report
23 that has additional detail?

24 MR. DHIR: I don't think it's a NUREG
25 report. It was UCLA report which we submitted

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1 periodically to NRC.

2 MR. BAJOREK: We have a couple of progress
3 reports, but in preparation for this meeting we
4 thought a more concise way of looking at the models
5 were the technical papers.

6 CHAIRMAN WALLIS: It looks as if you're
7 going to cover a lot more than was sent to us.

8 MR. DHIR: Right. I have submitted
9 viewgraph. So that shows what was mostly summary of
10 what --

11 MR. BANERJEE: Wear us out, huh?

12 MR. DHIR: Right.

13 CHAIRMAN WALLIS: He's going to surprise
14 us.

15 MR. DHIR: So we found that application of
16 these models to low pressures are suspect. We did a
17 number of studies which have shown that. And there
18 was very limited low pressure experimental data
19 available. Most of the data were at high pressures.

20 So we compile all of the database, also
21 the experiment to conditions, test setup and so forth.
22 And that report which are titled Experimental and
23 Analytical Studies in Subcooled Flow Boiling and just
24 containing database was submitted to NRC.

25 Now, let's look quickly at what we are

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1 interested in. As you all know that initially in the
2 heated channel as subcooled liquid enters in and this
3 is first phase, first heat is removed by single phase
4 -- forced convection and if there's resulting flow --
5 then you have a resulting boundary layer so the heat
6 transfer coefficient will be -- in the actual
7 direction.

8 At some point on the heated surface you
9 see the nucleation start to occur, and that location
10 we call ONB, onset of nucleate boiling. If one is to
11 predict the complete physics of the processes
12 downstream, one should be first able to determine
13 where nucleation occurs.

14 This is followed a region where the
15 bubbles are detached to the surface, they're just
16 sitting there, vapor is produced and is condensed on
17 the surface but bubbles do not lift off from the wall
18 and migrate into the bulk liquid. And as we move
19 further downstream, downstream at some location the
20 bubbles start to leave the heater surface. Where this
21 process begins we call OSV, onset of significant
22 voids.

23 And beyond this point we are producing at
24 the wall some condensation is occurring as the bubbles
25 are attached to the wall or slide along the wall,

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1 thereafter the bubbles depart the heated surface and
2 move on to the bulk. Okay.

3 So the key items we need to discuss as
4 we're looking at the wall region, the physics of the
5 process, is that how the wall heat flux partitions.

6 CHAIRMAN WALLIS: What does that mean?

7 MR. DHIR: Partitioning means first just
8 as the wall, how the heat is transfer to, let's say,
9 the liquid. Separate the liquid. Then beyond that
10 how much of that energy goes into production of vapor
11 that goes into the bulk and how much is going on
12 condensation as the bubbles surface, and how much goes
13 directly into the liquid.

14 Q Is this very different from a model for
15 partitioning that may be in TRAC? Because TRAC
16 doesn't look at all these phenomena. Does the meaning
17 of all heat flux partitioning is something else in the
18 code.

19 MR. DHIR: No, code need -- what is your--
20 let's say I have a heat flux of -- what fraction of
21 that energy is going into the bulk as vapor, that's
22 what the core needs.

23 MR. RANSOM: Into the bulk or into --

24 MR. BANERJEE: Into just generating --

25 MR. DHIR: Into the liquid. What fraction

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1 is going into the liquid as vapor.

2 CHAIRMAN WALLIS: I don't understand.

3 MR. BANERJEE: The code is interested in
4 predicting the void fraction.

5 MR. DHIR: Correct. Right.

6 MR. BANERJEE: So there is partitioning--
7 used by Solbrig if I remember it correctly, of
8 partitioning this -- it was a fix at that time. Was
9 say how much went into generating vapor right at the
10 wall, which means to an attached model. That's where
11 it really --

12 MR. DHIR: That's a different concept.
13 I'm not going to talk about it. I'm just saying this.

14 MR. RANSOM: Well, let's say the Lahey
15 model is the same, it's how much energy goes into
16 producing vapor. So you can assume that energy is
17 divided by -- and produces vapor.

18 MR. DHIR: Right.

19 MR. RANSOM: The other part goes into the
20 bulk heating for the liquid. And I think that's the
21 same thing.

22 MR. DHIR: No. You will see that. Mine
23 are different. Okay. What I'm trying to say is this,
24 say you -- again, I will repeat myself.

25 You have a certain imposed heat flux on

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1 the wall.

2 MR. RANSOM: Right.

3 MR. DHIR: I draw an artificial boundary
4 here, okay. And I say how much of this energy from the
5 wall is going into this liquid as vapor.

6 MR. RANSOM: Right.

7 MR. DHIR: Okay. So that is that
8 fraction. How much went into the liquid either
9 because these bubbles moved or the liquid removed some
10 heat from the wall, plus how much came in through
11 condensation which occurred when the bubbles-- beyond
12 their boundary and that heat also went as a sensible
13 heat to the liquid. So the liquid got energy either
14 through condensation or directly from the wall, and
15 the vapor was added from the wall. So now you have
16 number density of these bubbles, the size of these
17 bubbles, so that gives you source term and it also
18 gives you what the LOCA and -- of the liquid is.

19 CHAIRMAN WALLIS: The void fraction is
20 also made it of the ones attached to the wall, which
21 you don't have in that description you just gave.

22 MR. DHIR: The void fraction of the wall?

23 CHAIRMAN WALLIS: Yes, that's a separate
24 model as the void fraction --

25 MR. DHIR: We could put it, but we have

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1 not addressed that. Yes.

2 MR. SCHROCK: I think there are two points
3 that need clarification on this description.

4 MR. DHIR: Okay.

5 MR. SCHROCK: And one is does the code
6 description include vapor generation in this first
7 region of attached bubbles? Bubbles grow and collapse
8 in that region, but don't detach from the wall. There
9 is no two phase flow problem in the sense that the
10 vapor is moving in the axial direction.

11 In the second region --

12 MR. DHIR: Right, in this region, that's
13 what we talk about.

14 MR. SCHROCK: No, the last comment
15 referred to the first region.

16 MR. DHIR: Right.

17 MR. SCHROCK: The lowest region.

18 MR. DHIR: Right.

19 MR. SCHROCK: Now in the upper region
20 there still is need to sharpen that description in
21 terms of whether this gamma vapor includes the volume
22 of bubbles growing at the wall before they detach or
23 does it account only for vapor which is detached and
24 moving with the stream.

25 MR. DHIR: I don't -- again, I'm not doing

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1 the code. But I think if I were to advise them, they
2 would not include this. They would be just looking at
3 what is leaving the wall.

4 MR. SCHROCK: Well, there's probably a
5 significant difference in the meaning.

6 MR. DHIR: Right. Yes.

7 MR. SCHROCK: I think there has to be a
8 convergence of what you're describing and what they're
9 trying to describe in the code.

10 But this implies that the void in the
11 attached bubble zone is insignificant.

12 MR. DHIR: No.

13 MR. SCHROCK: Yes, how do you find it
14 then?

15 MR. DHIR: What do you mean how do I find
16 it? Why do I need to know it?

17 MR. SCHROCK: There is no gamma --

18 MR. DHIR: Again, see, you're going --

19 MR. SCHROCK: There is no gamma vapor in
20 the attached region.

21 MR. DHIR: That's right. In this region.

22 MR. SCHROCK: Right.

23 MR. DHIR: Yes. There's no gamma vapor.

24 CHAIRMAN WALLIS: Well, how do the bubbles
25 get there?

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1 MR. DHIR: There's such a thing on the
2 wall.

3 CHAIRMAN WALLIS: Is there nucleate on the
4 wall?

5 MR. DHIR: They're -- on the wall.

6 CHAIRMAN WALLIS: They're just attached to
7 the wall in residence, they grow and collapse.

8 MR. DHIR: Beg pardon?

9 MR. BANERJEE: Those bubbles even before
10 detachment --

11 MR. DHIR: Right.

12 MR. BANERJEE: -- have a significant void
13 fraction.

14 MR. DHIR: Right. They have -- I don't
15 know how significant you call it, but it's maybe --

16 MR. BANERJEE: It depends on the size of
17 the channel.

18 MR. DHIR: Yes, right. But it's a -- it's
19 very low density bubble population on the surface.

20 MR. SCHROCK: Well, they're small compared
21 to the ground stream region.

22 MR. DHIR: Very small, yes.

23 MR. SCHROCK: But I'm just looking for
24 some more rigor in definition of terms linking the
25 experimental observation with the code. That's what

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1 I'm looking for.

2 MR. DHIR: Right. Again, we have not done
3 that part. Okay. We can speculate on it.

4 MR. SCHROCK: Well, that's a mistaken,
5 V.J. It's not your fault, but it's a mistake.

6 MR. BANERJEE: Bad boy.

7 MR. DHIR: What?

8 MR. BANERJEE: Bad boy.

9 MR. SCHROCK: Well, in the codes, for
10 example --

11 MR. DHIR: And that's why I came here to
12 listen to that.

13 MR. RANSOM: In terms of clarifying it a
14 little, there are no bubbles attached to the wall in
15 the code models, you know. So they sort of only begin
16 at OSV or somewhere around there.

17 MR. DHIR: Right. Exactly. They don't
18 look at this part. They only begin calculating from
19 here. And they don't know where OSV.

20 MR. RANSOM: Right. Is that the need? Is
21 the need only beyond OSV?

22 MR. DHIR: That's right. That's what I
23 would do.

24 MR. RANSOM: They always tell you the
25 other region.

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1 MR. BANERJEE: The code doesn't
2 distinguish to recommends this partitioned the heat
3 flux --

4 MR. RANSOM: Well, the beginning or onset
5 of significant voids is the first region, that's
6 considered the beginning of boiling, even subcooled
7 boiling.

8 DR. MOODY: You've got one part of your
9 study is -- bubbles, diameter --

10 MR. RANSOM: So it is not really -- that
11 are being attached to the wall.

12 DR. MOODY: -- so you could track the life
13 of a bubble, is that right?

14 MR. DHIR: Yes. You can go to -- detail as
15 you want to, but I think we are first discussing what
16 terms mean, what I'm trying to talk about.

17 This region the void fraction is very low.
18 We can tell you how much void fraction would be,
19 approximately. But it doesn't mean anything to the
20 code. Code are basically starts calculating void
21 fraction from --

22 MR. SCHROCK: So that's a separate
23 justification. There has to be a prediction of that
24 and a demonstration that --

25 MR. DHIR: Exactly.

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1 MR. SCHROCK: -- that amount of void is
2 insignificant in terms of whatever the code is
3 interested in.

4 But in the region of detached bubbles --

5 MR. DHIR: Right.

6 MR. SCHROCK: -- there remains the issue
7 of the volume of steam in attached bubbles.

8 MR. DHIR: Why are you interested in it?

9 MR. SCHROCK: Well, it's a part of the
10 total void fraction.

11 MR. DHIR: Right. The question is you're
12 looking at these bubbles are sitting in here and how
13 is that going to effect your -- if you say it will be
14 a secondary effect.

15 But key question you are wrestling with
16 it, how is this Y profile developing in actual
17 direction.

18 CHAIRMAN WALLIS: V.J, everything would be
19 helped tremendously if you had your picture here, and
20 you got a picture beside it which says this is what
21 the code says is happened. Code says you have two
22 fluids at different temperatures and so on, but you
23 have interactions between them.

24 MR. DHIR: Right.

25 CHAIRMAN WALLIS: Then you have to somehow

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1 go from this picture of reality to the idealized
2 picture in the code. It doesn't have anything on the
3 wall, as I understand it.

4 MR. DHIR: Yes, right.

5 CHAIRMAN WALLIS: But it -- injects vapor--
6 -

7 MR. DHIR: Injects vapor is right.
8 Exactly

9 CHAIRMAN WALLIS: Okay.

10 MR. DHIR: Then that, I'm going to provide
11 that information to them.

12 CHAIRMAN WALLIS: Okay.

13 MR. DHIR: You inject the vapor into that
14 and you inject the -- into the liquid, and you know
15 how much is coming out which way.

16 CHAIRMAN WALLIS: Then the liquid and
17 vapor then interact because they have different
18 temperatures.

19 MR. DHIR: Temperatures and that's how it
20 is.

21 CHAIRMAN WALLIS: There's more heat flux,
22 but this would mean a kind of code phenomena --

23 MR. BANERJEE: Well, it's not exactly what
24 the code does, that's the problem. What we're
25 wrestling with is the wall's partitioning is really --

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1 MR. DHIR: See, again --

2 MR. BANERJEE: --to the wall.

3 MR. DHIR: That's not done correctly.

4 Codes are not doing it correct. So why are we going
5 after that? I think they should rewrite that part
6 and, in fact, what I can give you my conclusion, what
7 I find, and Graham mentioned it correctly earlier. I
8 was surprised. That basically the heat going from the
9 wall, all of the energy goes to liquid. Then part of
10 that is converted into vapor and we track how much
11 vapor is leaving the heater surface and how much is
12 going just -- the rest of it is going just to the --

13 MR. SCHROCK: I'm glad you said that,
14 because I've written that for so many reports to the
15 ACRS I'm a little tired of saying it. The heat is all
16 transferred to the liquid first and then vaporization
17 occurs within that super heated liquid.

18 CHAIRMAN WALLIS: Were you surprised
19 because I said something correct?

20 MR. DHIR: Right.

21 CHAIRMAN WALLIS: Or were your surprised
22 because I gave you new knowledge which you didn't have
23 before?

24 MR. DHIR: No, I had the knowledge before.

25 But I was surprised because if you look at the codes,

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1 that's what we are talking about. And they keep
2 splitting right over from the wall.

3 MR. BANERJEE: It's an idealization.

4 MR. DHIR: Not -- incorrect way of
5 counting.

6 MR. BANERJEE: Whichever way you think of
7 it. But what's happened is the region of the attached
8 bubbles you have to argue has a low void fraction and
9 therefore doesn't give you any significant void for
10 the reactor dynamics calculation.

11 MR. DHIR: If you want to interpret --
12 yes, that's the second issue.

13 MR. BANERJEE: That's what you have
14 clearly show that the void is --

15 MR. DHIR: No, no, no. No, no, no. This
16 is a different question you're asking.

17 MR. BANERJEE: But that is a significant--

18 MR. DHIR: Yes, that is a significant, we
19 will provide you. Because we know the number density
20 of bubbles. We know -- of the bubbles, so I can give
21 you what the void fraction is if that is needed. But
22 I think the recent question we were asked provided --

23 CHAIRMAN WALLIS: Okay. Presumably it also
24 increases the interfacial fiction fraction.

25 MR. DHIR: Right.

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1 CHAIRMAN WALLIS: The bubbles on the wall
2 are like a --

3 MR. DHIR: Right. It's improved heat
4 transfer, too. Basically we look at heat transfer
5 here, all the bubbles are sitting on the surface, the
6 heat transfer basically single phase, and it's higher
7 than would be without bubbles.

8 CHAIRMAN WALLIS: Okay. Can we move on to
9 the next linked slide.

10 MR. RANSOM: I would just like to make one
11 suggestion, and that is that you add interface drag or
12 relative velocity between the phases of significant
13 effect, at least in the work that I've done that seems
14 to be a factor.

15 MR. DHIR: Right.

16 CHAIRMAN WALLIS: That is part of how we
17 get the heat transfer coefficient between the phases.

18 MR. RANSOM: Well, so on that slide it
19 should be --

20 CHAIRMAN WALLIS: On the slide.

21 MR. RANSOM: -- a variable.

22 CHAIRMAN WALLIS: Okay. Ready for the next
23 one.

24 MR. DHIR: Good.

25 MR. BANERJEE: Is velocity of variable a

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1 net velocity in your --

2 MR. DHIR: Yes. In that velocity
3 subcooling.

4 Okay. So basically single phase, your heat
5 is removed by forced convection. The bubbles that are
6 attached to the heater surface, again although there's
7 some condensation going on at the surface, but some
8 heat is gone as a single phase heat transfer from the
9 wall, but there's no vapor production in terms of
10 vapor leaving and going into the bulk. So all of the
11 heat is basically -- as a forced convection heat
12 transfer into the liquid.

13 In the region beyond OSV we think from the
14 wall heat goes into the liquid either forced
15 convection or transient conduction. That's the key
16 contribution we're making as the bubbles detached or
17 slide along the surface, they break the thermal
18 boundary layer. It has to redevelop and that's the
19 period during which transient conduction occurs.
20 That's the key contribution, I think.

21 CHAIRMAN WALLIS: Well, we're not going to
22 talk about the middle region at all, so --

23 MR. DHIR: No. We are going to talk to
24 you a little bit, no, nothing much. Mostly we'll talk
25 about this region and maybe a little bit --

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1 CHAIRMAN WALLIS: So this QSP and QC,
2 you're some sort of drawing a control volume which
3 cuts out the region where you transfer heat to the
4 liquid and then it evaporates in vapor?

5 MR. DHIR: Right.

6 CHAIRMAN WALLIS: That's not allowed. So
7 you've joined their control volume beyond the place
8 where there's anymore evaporation occurring.

9 MR. DHIR: No.

10 CHAIRMAN WALLIS: Yes. For some of that
11 single phase from the -- we agree that all of the heat
12 transfer is single phase at the wall.

13 MR. DHIR: Right.

14 CHAIRMAN WALLIS: And then you've taken
15 out of that the bit which goes into evaporation and
16 then condensation?

17 MR. DHIR: Right.

18 CHAIRMAN WALLIS: And that's called
19 something else.

20 MR. BANERJEE: That's this force
21 convection.

22 MR. DHIR: Right. This is transient
23 conduction and force convection contributions. That's
24 the total heat from the wall. Okay.

25 CHAIRMAN WALLIS: I don't understand that.

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1 MR. DHIR: Because the region where there
2 are no bubbles, in this region, heat is still being
3 removed but that's basically by forced convection.

4 CHAIRMAN WALLIS: I don't understand the
5 subdivision between transient conduction and forced
6 convection.

7 MR. DHIR: Okay. Let me describe what
8 transient conduction. Transient conduction, let's say
9 bubble departed from this surface. Okay. It's going
10 to slide along the surface and then lift off from the
11 surface. The process is that a nucleation site above
12 it starts to grow, it grows to some diameter which we
13 call departure diameter, thereafter the bubbles start
14 to slide. And then it grows to a certain size and
15 lifts off from the surface.

16 As it is sliding along the surface it
17 disrupts the boundary layer and over that period or
18 over that region it is basically removed by transient
19 conduction. And I'll show you how graphically what we
20 mean by it, but for the time being we are saying that
21 the heat is removed over that portion over which the
22 bubbles slide is by transient conduction or if the
23 bubble detaches from the surface in a given location,
24 then the boundary layer has to redevelop around that
25 location and then heat will be removed by transient

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1 conduction. And the remainder of the area where
2 there's not much activity, heat will be removed by
3 forced convection.

4 MR. BANERJEE: But is the bubble that's
5 sliding you're always wiping the area.

6 CHAIRMAN WALLIS: You always force
7 convect, yes.

8 MR. BANERJEE: So you're always in
9 transient. It's like a surface renewal --

10 MR. DHIR: It's a question of the timing.
11 How much time is there? How much time it takes to
12 slide before it lifts off. And that time I'll show
13 you.

14 MR. BANERJEE: But it'll still be a
15 transient.

16 MR. DHIR: Right. It's a transient, but
17 maybe I'm really jumping ahead.

18 MR. BANERJEE: Your tunnel layer will be
19 developing and then destroyed and developing --

20 MR. DHIR: Right. Exactly. It will be keep
21 repeating that time period. Yes, sure.

22 MR. BANERJEE: It's always transient?

23 MR. DHIR: Yes, it's a transient.

24 MR. SCHROCK: Well, what's the force
25 convection for? What's the initial condition for that

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1 transient conduction problem, although that's the
2 problem, isn't it, V.J.?

3 MR. DHIR: Right. You see -- okay. Let's
4 look at this slide.

5 MR. SCHROCK: There's a surface renewal.

6 MR. DHIR: Surface renewal basically, yes.

7 MR. SCHROCK: Yes.

8 MR. DHIR: And so you see just once you
9 wipe it out, you start a time sequence to zero, your
10 transient conduction is -- and the heat will be --
11 heat flux will be dropping as inverse of square root
12 of time, and then forced convection has its own value.
13 We are saying that this transient time will be only up
14 to the point where the heat transfer by diffusion
15 equals the forced convection areas to --

16 MR. SCHROCK: But you didn't address the
17 point that I made that the initial condition for your
18 transient conduction problem is basically unknown. So
19 you have to put in some idealized initial condition
20 for that.

21 MR. DHIR: Right. We're saying zero. You
22 just wipe -- you have wiped out the thermal layer
23 completely and you're starting all over again.

24 MR. SCHROCK: But you cannot do that
25 because you've got a radial temperature distribution

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1 in that liquid that sort of overlays the whole thing.
2 The bubbles are disrupting that, but as a bubble goes
3 by it doesn't leave the uniform temperature field
4 behind it.

5 MR. DHIR: Right. Bubble is sliding on the
6 surface, heater surface.

7 MR. SCHROCK: Yes.

8 MR. BANERJEE: I guess that there is some
9 temperature gradient, it's not completely --

10 MR. SCHROCK: You don't know what it is is
11 what I'm arguing.

12 MR. DHIR: Right.

13 MR. SCHROCK: You have no basis for
14 claiming you know a -- a uniform temperature initial
15 condition --

16 MR. DHIR: But again, that's -- that's
17 assumption you make. You have to make some
18 assumptions. Right. And the key thing is that we say
19 that wipes out whatever the thermal layer existed,
20 therein --

21 MR. SCHROCK: And then subcooled liquid
22 comes in contact with the wall? The slightest
23 subcooled liquid comes in contact with the wall?

24 MR. DHIR: Right. That's what we're
25 saying.

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1 MR. BANERJEE: It's a typical surface
2 renewal theory.

3 MR. DHIR: Right.

4 MR. SCHROCK: If you bring in the mean
5 subcooling at that point, you're going to way
6 overestimate the heat transfer by this transient
7 process.

8 MR. DHIR: Right. And so that's true. It
9 depends on how subcooled the liquid is. But basically
10 heat flux it would be calculated to the total whatever
11 you're subcooling is.

12 MR. BANERJEE: What's delta Tw?

13 MR. DHIR: Delta Tw is T wall minus T set,
14 and this is the liquid subcooling you have. So this is
15 the -- so the liquid slug of the slab which is coming
16 in has a bulk temperature -- the liquid.

17 MR. BANERJEE: So it's the full bulk
18 temperature of the wall is --

19 MR. DHIR: Into a slab which is initially
20 a temperature T liquid.

21 CHAIRMAN WALLIS: I don't understand this
22 at all. I thought these bubbles were attached to the
23 wall and then they sort of came off --

24 MR. DHIR: Look, what we see is this. This
25 bubble starts to grow on the surface. It grows to a

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1 certain size and then it will slide on the surface.

2 CHAIRMAN WALLIS: Yes.

3 MR. DHIR: And as it is sliding, we are
4 saying it's wiping out the thermal layer which is --

5 CHAIRMAN WALLIS: Which is dragging the
6 same thermal layer along behind it.

7 MR. DHIR: And then it leans back, goes
8 away. And the new bubble starts, it will start the
9 process all over again.

10 CHAIRMAN WALLIS: It's like a kind of
11 Reynolds analogy. When the bubbles goes, it brings in
12 some stuff from the cool. It's like Bankoff's sort of,
13 whatever he called it.

14 MR. SCHROCK: I think Graham just said it,
15 it drags along some temperature structure from the
16 upstream region behind the bubble as it goes. And
17 that upstream region is your region one where the
18 bubbles grew and collapsed in -- and they give you a
19 considerable superheat at the wall. Not a subcooling
20 at the wall.

21 CHAIRMAN WALLIS: Well, I guess we have to
22 move along. I can see we're probably going to have to
23 discuss --

24 MR. DHIR: Again, I don't know why that
25 region has an effect. That region brought in thermal--

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1 developed. But we are calling this process as you move
2 downstream and the bubbles are at every location, the
3 bubbles are going, forming and then sliding along the
4 surface and then lifting off. Then merging between
5 with some of the bubbles along the way. And the only
6 function you can argue with me is that when the
7 bubbles slide they disrupt the total thermal layer or
8 not and when the liquid comes in it's at what
9 temperature it is. And the assumptions we are making
10 it wipes out the thermal layer and the new thermal
11 layer starts by the -- or if you consider the -- slab
12 and the initial temperature is this.

13 MR. SCHROCK: Well, it's not like it has
14 to move radially in and out. It goes around the
15 bubble. The bubble slides through the liquid and
16 liquid is moving around the bubble, not just over the
17 top of it.

18 MR. DHIR: I'm not saying it -- you're
19 talking about the wall.

20 MR. SCHROCK: I'm talking about how the
21 liquid is displaced by the sliding bubble.

22 MR. DHIR: Right.

23 MR. SCHROCK: Okay. It's not as though
24 the bubble is a ring around the tube and all -- and it
25 has to slide through the liquid in that way, in which

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1 case liquid from a region far away from the wall would
2 be induced into that zone.

3 MR. DHIR: Right. Right.

4 MR. SCHROCK: And go around the bubble.
5 What you're doing is more akin to what Graham Wallis
6 said. It's like dragging along behind it whatever is
7 upstream of the bubble, it's begun to slide.

8 MR. BANERJEE: The liquid can't slip onto
9 the wall. The bubbles can slip but the liquid can't
10 in some sense.

11 MR. SCHROCK: We got on this discussion by
12 my point that the initial condition in a transient
13 conduction modeling of the heat transferred directly
14 from the wall to the liquid is a major problem because
15 the initial condition for that transient conduction
16 model is essentially unknown.

17 You've chosen to model it as though the
18 mean subcooling comes to the wall instantly as the
19 bubble goes by.

20 CHAIRMAN WALLIS: It seems upper bound.

21 MR. SCHROCK: And I think that is a great
22 extreme. I mean, it's --

23 MR. DHIR: Okay. You have the --

24 MR. SCHROCK: The temperature of the
25 liquid at the wall is going to be much higher than

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1 that and your transient conduction to the liquid is
2 going to be way overestimated with that assumption.

3 MR. DHIR: Okay. Now I will give you --
4 we have the numerical simulations also of this
5 process.

6 MR. SCHROCK: Okay.

7 MR. DHIR: And if you look at it the
8 liquid that is coming onto the surface after the
9 bubble has gone out is very close to the bulk
10 temperature. I'm not on subcooled case, but the
11 saturated case, numerical simulation. It's close to
12 the saturation temperature, the temperature of the
13 wall almost drops to the saturation value before it
14 picks up, actually.

15 MR. BANERJEE: In the numerical simulation
16 did you have the liquid laminar or --

17 MR. DHIR: Laminar.

18 MR. BANERJEE: -- is giving you next
19 mixing effect to --

20 MR. DHIR: Right, exactly. And the
21 question now -- you know, we can belabor this point,
22 but it's extremely difficult to see what exact the
23 temperature will be and how much the region is. And
24 when you develop the model you're going to have
25 certain assumptions and now it's questionable

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1 assumptions, one can validate them, but those
2 assumptions are based on what we can --

3 CHAIRMAN WALLIS: I think if you move a
4 bubble through a liquid and allowing the flow of the
5 streamline, it's coming back to about where they
6 started. So you haven't done any mixing at all.

7 MR. BANERJEE: Well, you have a wake.

8 MR. DHIR: The wake of --

9 CHAIRMAN WALLIS: But not in the very low-
10 -

11 MR. BANERJEE: It is not?

12 CHAIRMAN WALLIS: No. If there's a wake,
13 then they -- okay.

14 MR. BANERJEE: There will be a wake.

15 CHAIRMAN WALLIS: It's a wake relative to
16 what? Because the bubble's presumably moving because
17 the liquid's pushing it to the wakes on the other side
18 of it.

19 MR. BANERJEE: You have to look at it as
20 something --

21 CHAIRMAN WALLIS: Okay. Okay.

22 MR. DHIR: Anyway, we've gone farther --

23 MR. BANERJEE: So did you submit that CFD
24 for review yet?

25 MR. DHIR: We have done full boiling and

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1 flow boiling as yet.

2 So basically, you know, from the wall we
3 said energy is going by full convect not transient
4 conduction. Then it split, some goes into the liquid
5 to sensibly heat the liquid and some goes into
6 evaporation, that is how much vapor bubbles -- how
7 many vapor bubbles and what size are leaving the
8 surface. And that's your -- leaving the surface as
9 they were.

10 Whatever the condensation that occur at
11 the surfaces will be counted in --

12 CHAIRMAN WALLIS: Those were two different
13 layers. There's a Qfc and Qand a Qtc. It's happening
14 at the wall.

15 MR. DHIR: Qtc is basically showing what
16 is happening as the bubble has slided and --

17 CHAIRMAN WALLIS: At the wall. And Ql and
18 Qev are happening somewhere further out.

19 MR. DHIR: Right. Qev can be happening as
20 the bubble is -- from energy what you dumped in as the
21 transient conduction goes back into evaporation. But
22 we don't know how much that is. We are just looking at
23 how many bubbles are leaving and at what sequence.

24 CHAIRMAN WALLIS: I think Ql and Qev are
25 what you need to put in the two fluid model for the

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1 code. Code's never been to model things like Qtc.

2 MR. DHIR: The code won't. This is for our
3 purpose.

4 CHAIRMAN WALLIS: That's it. So they were
5 at two levels?

6 MR. DHIR: Right.

7 CHAIRMAN WALLIS: One is for the physics
8 and one is what you need for the code.

9 MR. DHIR: Right. Exactly. Code doesn't
10 need that first part. And I'll show you both
11 calculations if we get to it.

12 MR. BANERJEE: As long as the void at the
13 wall is negligible, what you're saying is the case.

14 MR. DHIR: Okay. What happens if void is
15 not negligible?

16 MR. BANERJEE: Than you have to make an
17 estimate of that.

18 MR. DHIR: Estimate of what?

19 MR. BANERJEE: The void fraction at the
20 wall, not -- void fraction at the wall. What you're
21 doing is you've set up the way to handle the situation
22 for all the detached bubbles. So, see, the way you've
23 got it there is the bubbles are detaching from the
24 wall and you've got a split between vapor generation
25 because it's detached bubbles --

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1 MR. DHIR: Right.

2 MR. BANERJEE: And, of course --

3 MR. DHIR: The remainder wasn't liquid.

4 MR. BANERJEE: And how much goes into the
5 liquid.

6 MR. DHIR: Right.

7 MR. BANERJEE: There were a layer of
8 bubbles sitting at the wall --

9 MR. DHIR: Right.

10 MR. BANERJEE: Just sliding along or doing
11 whatever the hell they're doing --

12 MR. DHIR: Right.

13 MR. BANERJEE: Depending on the size of
14 the channel --

15 MR. DHIR: Right.

16 MR. BANERJEE: -- you know, they may or
17 may not be significant part of void fraction. How big
18 are these bubbles?

19 MR. DHIR: It depends on the pressure and
20 velocity, whatever.

21 MR. BANERJEE: Well, it was a size --

22 MR. DHIR: It's about a millimeter or
23 less.

24 MR. BANERJEE: Okay. Millimeter or less.
25 So if you have, say, tubes or rods in some areas that

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1 they -- what is the typical flow of area?

2 MR. DHIR: Three millimeters.

3 MR. BANERJEE: Three millimeters. So the
4 gap itself would be almost -- completely by the -- it
5 would have a significant --

6 MR. DHIR: Right. Right.

7 MR. BANERJEE: I mean I haven't done the
8 sums.

9 MR. DHIR: Right. But, again, that void
10 fraction we can give that value.

11 MR. BANERJEE: Right.

12 MR. DHIR: Because we know the number and
13 sizes of the bubble and so forth, and how much packing
14 is there. So one can get an estimate.

15 So basically an isolated bubble, you're
16 saying that as a bubble slides along your thermal
17 layer is developing and that's the transient
18 conduction is occurring. The region where there's no
19 activity we're saying the heat is removed by forced
20 convection.

21 MR. SCHROCK: Do your data show that the
22 bubble always begins to slide before it reaches OSV?

23 MR. DHIR: OSV they're all stationary,
24 OSV. They don't -- they're sizes below what is needed
25 to slide. They never get to that size.

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1 MR. SCHROCK: Your picture shows it's
2 sliding before it gets there.

3 MR. DHIR: OSV starts here.

4 MR. SCHROCK: And, see, you got a bubble
5 below that that appears to be sliding.

6 MR. DHIR: I think that should not be
7 shown, actually. But anyways, there should be no
8 arrow there. This bubble is just sitting there. Beyond
9 that point the bubble start to slide.

10 MR. SCHROCK: So does that mean that the
11 sliding phenomenon is akin to bubble departure from
12 the standpoint of OSV?

13 MR. DHIR: Yes. Bubbles have to grow to
14 a certain size before they can slide.

15 MR. SCHROCK: That I understand.

16 MR. DHIR: Okay.

17 MR. SCHROCK: But the question is whether
18 or not OSV is defined in such a way that it means any
19 axial movement of the vapor, any axial movement of the
20 bubble whether it's attached to the wall or detached?

21 MR. DHIR: That's correct. But the bubble
22 has to --

23 MR. SCHROCK: I mean, it can be one way or
24 the other.

25 MR. DHIR: No. Once it's start to slide --

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1 with other bubbles it will lift off when getting the
2 lift off side. So our definition is the moment the
3 bubble start to slide, we say OSV begins.

4 CHAIRMAN WALLIS: Do the forces from the
5 fluid make it both slide and lift off and is there a
6 lift force on it lifting it off?

7 MR. DHIR: Yes, that's correct. There is
8 definitely a lift force.

9 CHAIRMAN WALLIS: What's important is that
10 you break the contact with the nucleation center, and
11 after that figure out what its trajectory is.

12 MR. DHIR: Right. Yes, and that's a very
13 important thing. But the lift has been ignored in the
14 past and bubbles -- to the surface. And if you make
15 the fourth balance you cannot describe it.

16 MR. BANERJEE: In fact, if you inject
17 bubbles -- with tiny holes, you see exactly this; that
18 they grow to a certain size and then they slide --

19 MR. DHIR: Right. Right.

20 MR. RANSOM: Well, this model is similar
21 I think to -- the other one is the critical enthalpy
22 model which predicts enthalpy the liquid has to reach
23 before a bubble can survive. And that's considered the
24 point of onset of significant void --

25 MR. DHIR: That's what people have done

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1 mostly.

2 MR. RANSOM: Right. But this one is quite
3 similar. And I'm not criticizing it necessarily. I
4 mean, because I think you're also trying to predict
5 when will a bubble depart from the wall and can
6 survive in the bowl.

7 MR. DHIR: Right.

8 MR. RANSOM: Without immediately
9 condensing.

10 MR. DHIR: Right. And we are basically
11 saying what is this point. I'm not -- I will show you
12 the data what we got with respect to this point and
13 what old correlations are and so forth, and show you
14 later comparisons. But I am not focusing my attention
15 to just theoretically or mathematically predicting
16 this mark, this location. There's a correlation. But
17 the key issue what we are trying to resolve -- which
18 means beyond this location.

19 And this is a balance here. How long the
20 bubble sitting here is the balance on how much
21 evaporation is occurring and how much condensation is
22 occurring can you have -- to create bubbles that are
23 large enough to slide. Bubbles have to grow to
24 certain size before they can slide. Smaller bubbles
25 will just sit there.

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1 MR. SCHROCK: Part of the detachment
2 process, I think, has to do with the radial thickness
3 of the liquid superheat. And when the bubble extends
4 a certain distance from the wall, if it's still
5 surrounded over all of its surface by liquid superheat
6 to some degree, certainly a variation over its
7 surface, then where it's superheated, it can --
8 there's no question it can still grow.

9 MR. DHIR: Right.

10 MR. SCHROCK: Whether or not it can still
11 grow goes beyond that --

12 MR. DHIR: Right.

13 MR. SCHROCK: And that's the balance
14 between the rate of --

15 MR. DHIR: Evaporation and condensation.

16 MR. SCHROCK: -- and the rate of
17 condensation.

18 MR. DHIR: Exactly. That's what
19 determines its location.

20 MR. BANERJEE: But the lift off --

21 MR. DHIR: Lift off is a separate issue.
22 Lift off is a separate issue.

23 MR. BANERJEE: Because even with air
24 bubbles they will slide for a while and then they left
25 off.

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1 MR. DHIR: Lift off, right.

2 MR. BANERJEE: Which they're not growing
3 anymore. They stop growing at that time.

4 MR. DHIR: Exactly. That's lift force.
5 Definitely.

6 MR. SCHROCK: I guess the point I was
7 trying to make is that there's a thermal condition
8 that's a part of the attachment process. It's not just
9 the flow conditions.

10 MR. DHIR: Right. But thermal condition
11 gives you -- right. Thermal condition is going to
12 give to you how big the bubble is going to grow at
13 that site. If the bubble does not grow to that size,
14 it's going to sit there. So it's -- thermal conditions
15 basically what size it gets to. And then the forces
16 are the -- how much forces are acting to slide. It
17 can push it out --

18 CHAIRMAN WALLIS: It can be still growing
19 while it's sliding --

20 MR. DHIR: Yes, sure it does grow. Yes.

21 CHAIRMAN WALLIS: So that it may -- it's
22 sense of gravity may detach, but it's --

23 MR. DHIR: No. Yes, it's still growing.
24 The substantial growth occurs during that.

25 CHAIRMAN WALLIS: I don't want to take a

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1 break too early, because I want to make more progress.

2 I think we may have to accept that you got
3 a model here and then go ahead and then sort of see --

4 MR. DHIR: I just -- right.

5 CHAIRMAN WALLIS: -- see your experiments.

6 MR. DHIR: Right. But only thing -- one
7 more thing I would show you that when the bubbles
8 start to merge on the heater surface, are your
9 superheat goes up -- so at least have your criticism
10 on this part. As the bubbles grow nucleation sites
11 become very large. The spacing S can be smaller than
12 the lift off diameter you need or smaller than even
13 the bubble diameter departure. So in this situation
14 the bubbles while they're growing, they're -- and then
15 once they get to that size, they will lift off.

16 CHAIRMAN WALLIS: They merge together in
17 two dimensions, why don't they produce --

18 MR. DHIR: What do you mean?

19 CHAIRMAN WALLIS: This is a one
20 dimensional picture, but presumably they're merging --

21 MR. DHIR: Right. In that area. But
22 there's always liquid so it's not -- they form like a
23 bridge, like a mushroom, so the bubble mushroom is
24 there and then there are several stems, but the liquid
25 is still there. It's not only that area.

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1 CHAIRMAN WALLIS: -- then you get a raft
2 of bubbles attached to each other, not just a chain.

3 MR. DHIR: No, no. This is one dimensional
4 picture here. But if you look the other direction --

5 CHAIRMAN WALLIS: Yes, but in the other
6 direction you've also gotten an S.

7 MR. DHIR: Right, it's a square grid.

8 CHAIRMAN WALLIS: So they will touch in
9 the other direction.

10 MR. DHIR: Right. They will touch like--

11 CHAIRMAN WALLIS: So you get a complete
12 layer of bubbles coming up.

13 MR. DHIR: In this model, right. That's
14 correct. The bubbles are coming out just in unison.

15 CHAIRMAN WALLIS: That's probably what you
16 need for TRAC?

17 MR. DHIR: This is how we calculate our
18 transient conduction for this case; that all the
19 bubbles lift and then form the thermal layer again and
20 then calculate the -- so this will be at high heat
21 fluxes.

22 So, you know, I'm skipping these slides.
23 It's just on the conduction calculation, at different
24 times and so forth.

25 MR. RANSOM: Well, in your TRAC model do

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1 you envision this being a transient effect -- a
2 periodic effect, I guess, right in which bubbles form
3 on the wall and then depart?

4 MR. DHIR: No. TRAC will just get the
5 source term, how much --

6 MR. RANSOM: You somehow merge it all
7 together so it's a uniform thing with time more or
8 less.

9 MR. KRESS: If the -- conditions -- if the
10 -- conditions change then --

11 CHAIRMAN WALLIS: You still have to split
12 these into the Q1 and the Qevs.

13 MR. DHIR: Right.

14 CHAIRMAN WALLIS: How do you do that?

15 MR. DHIR: Q1 and Qev -- Qev we calculate
16 from our -- you know, I will show you how we calculate
17 Qev.

18 CHAIRMAN WALLIS: So you take the total
19 and then --

20 MR. DHIR: And then subtract Qev.

21 CHAIRMAN WALLIS: And then you take away
22 Qev?

23 MR. DHIR: Right. Exactly.

24 CHAIRMAN WALLIS: Well, how do you know d?

25 MR. DHIR: You measured.

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1 CHAIRMAN WALLIS: Well, how do you predict
2 it?

3 MR. DHIR: Correlation. We measured, we
4 got the data and from that we recorded --

5 CHAIRMAN WALLIS: -- how do you predict
6 Qev -- you need to know frequency in a d cubed and Na.

7 MR. DHIR: Right, right.

8 CHAIRMAN WALLIS: And you know all those
9 things?

10 MR. DHIR: That's exactly what you need to
11 know to predict Qev. That's a key point. That's what
12 I'm leading to. I discuss the model -- right, exactly.

13 CHAIRMAN WALLIS: Okay.

14 MR. DHIR: That's the whole point of this
15 present -- but the key point I was trying to make
16 showing you early on this modeling effort that what
17 detail we have to make measurements to get all the
18 ingredients which we need to put into the model. This
19 requires you need to know frequency, number of
20 density, bubble size and so forth.

21 MR. BANERJEE: How do you measure the rod
22 bundles?

23 MR. DHIR: We measured most of them on the
24 flat plate. And then on the rod bundle we -- there's
25 some there but just to verify it, but not too much

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1 data. The rod bundle becomes very difficult because
2 very quickly the liquid becomes saturated and after
3 that you can't see much. And so rod bundle we got
4 some data, but not whole lot.

5 Okay. So when we do the experiment
6 basically from the preliminary model, what we see that
7 there are a number of variables which need to be
8 measured in the experiment and here in this table I
9 give you which quantity we are measuring and what
10 measurement that we are using to measure that
11 quantity.

12 Wall heat flux for the flat plate heater,
13 we measure from the thermocouples that are imbedded in
14 the copper block. And for the rod we measure just
15 from the power that is input to the rod. We have
16 thermocouple embedded in the copper block and so we
17 get the temperature profile and then from that we get
18 the surface temperature. For the rods we have a
19 thermocouple attached to the -- wall and those
20 thermocouples are calibrated and from those
21 thermocouples you measure the wall.

22 MR. RANSOM: Can I ask a question about
23 that. That I didn't quite understand from the
24 writeup, but you have cartilage heaters and then
25 you're also measuring the temperature gradient using

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1 the temperature gradients to extrapolate to the
2 surface and determine the heat flux

3 MR. DHIR: In the copper block, yes.

4 MR. RANSOM: I wasn't clear how you
5 separate the effect of the heaters on the surface.
6 Are the heaters on the backside of this copper block
7 or -- so you're only looking at conduction through the
8 copper?

9 MR. DHIR: Just wait.

10 MR. RANSOM: I was wondering how you
11 separate the effect of the cooling, you know, from the
12 boiling process from the heating of the cartilage
13 heaters and --

14 MR. DHIR: Okay.

15 MR. RANSOM: So where is the heat transfer
16 surface actually?

17 MR. DHIR: This is the surface.

18 MR. RANSOM: Okay.

19 MR. DHIR: And this is a larger area so
20 the heaters are going this way.

21 MR. RANSOM: Yes.

22 MR. DHIR: And they're going up to this
23 portion here.

24 MR. RANSOM: Up to that shoulder?

25 MR. DHIR: That shoulder or even below

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1 actually.

2 MR. RANSOM: So do they generate heat over
3 their length?

4 MR. DHIR: Yes, right.

5 MR. RANSOM: So there's uniform heat
6 generation --

7 MR. DHIR: Right. And then we have this
8 section where the heat even if there were some
9 nonuniformities in this portion the heat flux will be
10 mostly --

11 MR. RANSOM: And that's where you're
12 measuring the gradient --

13 MR. DHIR: Gradients, right.

14 MR. RANSOM: -- of the temperature?

15 MR. DHIR: Right. This is the portion that
16 you see -- we're jumping ahead. This is about 3
17 centimeters wide for test purpose and about 30
18 centimeters tall. Okay. And we have 7 axial locations
19 where we put thermocouples. And we -- this is a cross
20 section and this is a treated surface. We have three
21 for thermocouples in the middle, three on the side,
22 three on this side to see if this heat flux is uniform

23 MR. BANERJEE: It's copper, right?

24 MR. DHIR: Copper.

25 MR. RANSOM: Okay. I understand what

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1 you're doing now.

2 MR. DHIR: Okay.

3 MR. RANSOM: And then flow is along this
4 block, right?

5 MR. DHIR: Right.

6 MR. RANSOM: And it's vertical, is that
7 correct?

8 MR. DHIR: Vertical.

9 MR. RANSOM: Okay.

10 MR. DHIR: Liquid temperature we use a
11 microthermocouple so that we could get temperature
12 profiles in the liquid, at least in the single phase
13 case already close to partial nucleate boiling region.
14 And then ONB we measure for -- of the boiling surface
15 as released from thermocouple outward. Number density
16 of nucleation sites, we took pictures of the heating
17 surface and then counted the number that were active
18 per unit. And, again, the temperature at which we
19 measured the nucleation inside was obtained from
20 extrapolation of the temperature -- temperature
21 profiled in the solid.

22 MR. BANERJEE: How close to the surface do
23 you have the thermocouples?

24 MR. DHIR: About 3 millimeters, 2 to 3
25 millimeters.

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1 MR. BANERJEE: And you can actually see--
2 do you see any temperature fluctuations or it's too
3 far.

4 MR. DHIR: No, it's too far.

5 MR. RANSOM: There's one other perimeter
6 that appears -- yes, the Fourier number there, which
7 has a timed perimeter in it. And I don't see that on
8 here. But I presume that's time from the bubble
9 initiation or --

10 MR. DHIR: No. That Fourier number is for
11 the -- heat transfer of the condensation when the
12 bubbles leave the heater surface and is moving into
13 the bulk, for the moment it leaves the heater surface,
14 that is the time you start counting.

15 MR. RANSOM: Okay. So it's the history of
16 the bubble?

17 MR. DHIR: Bubbles, right.

18 MR. RANSOM: How do you measure that or
19 how do you determine that?

20 MR. DHIR: You'll be jumping ahead again.

21 MR. RANSOM: I am?

22 MR. DHIR: Yes.

23 CHAIRMAN WALLIS: He measures time and
24 then calculates --

25 MR. RANSOM: Time for what? It's time

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1 from when the bubble has departed the wall and --

2 MR. DHIR: It starts to go into the -- so
3 your condensation starts. Now there's only -- there's
4 no heating from the wall. All the energy what the
5 bubble has is being lost to the condensation at the
6 surface. Bubble is shrinking, so we are tracking
7 bubble trajectory and what the location is from then
8 knowing every point release happens, you know where
9 the position of the bubble is.

10 MR. BANERJEE: This is like the McMaster
11 experiment?

12 MR. DHIR: Right, but it's on a heater
13 surface. No, we're not getting -- it's on a boiling
14 surface. The bubbles are creating on the boiling
15 surface of different sizes and so forth. I show you
16 some -- but we are jumping ahead so I have to change
17 the whole thing.

18 The bubble departure and lift off that --
19 and location of OSV from visual observation.

20 MR. RANSOM: Is that how you get the time,
21 you see it lift off and then you follow the bubbles?

22 MR. DHIR: Actually we do. Let me show
23 you.

24 MR. RANSOM: Yes.

25 MR. DHIR: Just wait one second.

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1 CHAIRMAN WALLIS: But the collapse of the
2 bubbles in superheat liquid seems to be the most
3 straight forward part of this --

4 MR. DHIR: Right, exactly. That was the
5 easy thing to do.

6 MR. BANERJEE: To measure.

7 MR. DHIR: Beg pardon?

8 MR. BANERJEE: To measure.

9 MR. DHIR: Right. Bubble release
10 frequency in high-speed films and count the number of
11 bubbles at least for a unit of time.

12 Condensation heat transfer coefficient for
13 attached bubbles, in this case one needs to have a
14 liquid temperature profile and bubble growth rate in
15 the vicinity of the solid surface. And by noting the
16 difference in bubble growth rate for saturated and
17 subcooled liquid, one can determine that how much
18 energy is going to support condensation on attached
19 bubbles.

20 This exercise requires auxiliary
21 experiments and we have done some for another study,
22 but for this case that portion is lacking. For the
23 time being we are using Ranz and Marshall correlation
24 basically to calculate the condensation heat
25 coefficient.

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1 Condensation heat transfer coefficient for
2 detached bubbles, that we measured and I'll show you
3 some results. Again, from films.

4 Bubble number density, high-speed films
5 counting the number of bubbles per unit of time. And
6 then the void fraction, we use gamma densitometer.

7 MR. RANSOM: How do you establish the
8 bubble relative velocity?

9 MR. DHIR: You look at the bubble
10 velocity.

11 MR. RANSOM: You know the bubble velocity,
12 what's the liquid velocity?

13 MR. DHIR: Liquid we are using the bulk as
14 axial to flow.

15 MR. BANERJEE: No, no, he's measuring the
16 void fraction.

17 MR. DHIR: Resolution in terms of what?

18 MR. SCHROCK: Spacial?

19 MR. DHIR: Spacial resolution. I think
20 it's close to 2 to 3 millimeters closest to the wall
21 we can go -- is about 3 millimeter in size. So we
22 can't go close --

23 MR. SCHROCK: And the channel thickness is
24 what?

25 MR. DHIR: Channel is 3 centimeters.

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1 MR. SCHROCK: Three centimeters. So you
2 look at a tenth of the cross section --

3 MR. DHIR: Average at a given time.

4 MR. SCHROCK: And do the profile.

5 MR. DHIR: Profile.

6 MR. KRESS: Do the bubbles condense so
7 fast that they don't have time to interact with each
8 other? You're looking at individual bubbles.

9 MR. DHIR: Right. Yes, they don't
10 interact.

11 MR. KRESS: They don't interact.

12 MR. DHIR: Different bubbles we are
13 talking.

14 CHAIRMAN WALLIS: All this is happening in
15 a time scale of milliseconds?

16 MR. DHIR: Milliseconds, right.

17 CHAIRMAN WALLIS: So you don't have any
18 time to average the turbulence in the flow. So I
19 think you get a lot of fluctuations because the
20 environment around the bubble depends on the
21 instantaneous contact

22 MR. DHIR: Right, you see --

23 CHAIRMAN WALLIS: Average that through the
24 whole --

25 MR. DHIR: But we have measured the

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1 temperature profile --

2 CHAIRMAN WALLIS: But it's only an
3 average.

4 MR. DHIR: Exactly.

5 CHAIRMAN WALLIS: You get a lot of
6 variation depending upon what the turbulence --

7 MR. DHIR: That's true, but -- and the
8 question is what level of detail do you want.

9 CHAIRMAN WALLIS: Well, I'm just saying
10 when you make these measurements --

11 MR. DHIR: Right.

12 CHAIRMAN WALLIS: -- you're going to get
13 a fluctuation, get a lot of difference in the results
14 because your instantaneous fluid conditions depend on
15 --

16 MR. DHIR: Mixing, yes.

17 CHAIRMAN WALLIS: So there's no time to
18 average them out.

19 MR. BANERJEE: But you're ensemble
20 averaging --

21 MR. DHIR: Exactly. We take many of the
22 cases --

23 CHAIRMAN WALLIS: Your average will be
24 okay, but there'll be a big spread around that
25 average.

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1 MR. DHIR: Even thermocouple when we put,
2 we are looking at liquid temperate -- quite a bit.

3 MR. SCHROCK: Now in your rod bundles you
4 can't get these gamma densitometer measurements?

5 MR. DHIR: Right. We look at only mid-
6 plane. We cannot go close to the wall because
7 uncertainty becomes very large.

8 MR. SCHROCK: So what do they mean?

9 MR. DHIR: What do you mean what they
10 mean? We are giving -- rod bundles are --

11 MR. SCHROCK: So I guess I should repeat
12 the question. How do you -- what kind of resolution do
13 you get on your void in the rod bundle measurements?

14 MR. DHIR: Well, in the rod bundle we have
15 only measured at the mid-plane. We have not done
16 radial profile. We have gotten it because uncertainty
17 is too much.

18 MR. SCHROCK: What does mid-plane mean?
19 It's a rectangular bundle and you've --

20 MR. DHIR: Right. In the middle channel,
21 we look at the center channel.

22 MR. SCHROCK: You make a measurement
23 midway between the rods?

24 MR. DHIR: Right.

25 MR. SCHROCK: But the rods are closer than

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1 the walls in the flat plate experiment, so how does
2 the --

3 MR. DHIR: We are focusing the beam
4 through this passage and we are aiming at the mid-
5 plane here.

6 MR. BANERJEE: How can you focus a gamma
7 beam?

8 MR. DHIR: What do you mean focus?

9 MR. BANERJEE: You just said you're
10 focusing --

11 MR. DHIR: Focusing means you remove the
12 gamma beam, you could be hitting the wall and then you
13 can --

14 MR. SCHROCK: So you've collumnated to a
15 smaller beam --

16 MR. BANERJEE: So you go at -- beam?

17 MR. SCHROCK: You've collumnated the gamma
18 densitometer to a small beam.

19 MR. DHIR: Right.

20 MR. SCHROCK: I understood that. But what
21 I don't understand is how the size of that beam
22 compares with the gap between the rods here.

23 MR. DHIR: The rod gap is 3 millimeters
24 here.

25 MR. SCHROCK: But you didn't tell me what

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1 the collumnated gamma densitometer beam is.

2 MR. DHIR: I said that initially we had 3
3 millimeter beam. Then we use a plug to reduce it to
4 about 1.5 millimeter size.

5 MR. SCHROCK: So for the rod bundles it's
6 1.5 millimeters.

7 MR. DHIR: 1.5 millimeter size.

8 MR. SCHROCK: Compared to?

9 MR. DHIR: Three millimeter gap.

10 MR. SCHROCK: Three millimeter gaps. So
11 it's -- and then it's shining through --

12 MR. DHIR: Shining through here a sequence
13 of two phased fluid which is at one point only one --
14 only 3 millimeters thick and then essentially is
15 unlimited halfway to the next row of rods.

16 MR. DHIR: Right.

17 MR. SCHROCK: So you're averaging kind of
18 in --

19 MR. DHIR: In this cross section.

20 MR. SCHROCK: Yes. How do you interpret
21 what it means I guess is the question I'm trying to
22 get at, V.J.? It's an average longitudinally and
23 axially with respect to the beam.

24 MR. DHIR: The question I would ask you
25 that was raised, this is how distance -- here and

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1 here. And the question you would ask is how accurate
2 it is. And --

3 MR. SCHROCK: No, not a question of
4 accuracy, but just how do you interpret it? What does
5 it mean after you've got the number?

6 MR. DHIR: Now, suppose I had a code
7 model? Let's say that I had -- I was modeling this in
8 a code and if I gave somebody this information, they
9 should be at least validated to the --

10 CHAIRMAN WALLIS: This isn't the volume
11 average in the rod bundle, because you're just taking
12 a point --

13 MR. SCHROCK: That's my point I'm making.
14 It's the volume average in a little one and half
15 millimeter diameter tube running between the rod.

16 MR. DHIR: Exactly.

17 CHAIRMAN WALLIS: And that's not the same
18 as the average to the bundle because you haven't
19 counted the bit you couldn't see that's shelter by the
20 rods.

21 MR. DHIR: That's right.

22 CHAIRMAN WALLIS: So it's not the average
23 void fraction in the whole section.

24 MR. DHIR: Yes. But if you're going to
25 validate some code which can do this kind

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1 configuration, you can test it --

2 CHAIRMAN WALLIS: Well, it isn't validate
3 -- it isn't calculating void fraction in a strip.
4 It's calculating an average void fraction for the
5 whole works?

6 MR. DHIR: No, but if I had 3-D code, why
7 I couldn't do it?

8 MR. BANERJEE: But you don't have a 3-D
9 code.

10 MR. DHIR: But they have some 3-D code.

11 CHAIRMAN WALLIS: But the question is how
12 does this related to what TRAC needs now? What it
13 needs now is an average over everything.

14 MR. BAJOREK: You don't have it there, but
15 you will have it in your flat plate.

16 MR. DHIR: Flat plate we have.

17 MR. BAJOREK: In that case we would be
18 able to get --

19 MR. DHIR: But if you want to test the
20 flat plate.

21 MR. BANERJEE: Well, I guess it's history
22 now. But this geometry gamma densitometer is not
23 ideal.

24 MR. DHIR: Yes.

25 MR. BANERJEE: Because we made rod bundle

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1 void fraction measurements about 25 years ago in
2 neutrons capturing and --

3 MR. DHIR: But, again, how many things you
4 want to do?

5 MR. BANERJEE: Right.

6 MR. DHIR: It's not only we --

7 CHAIRMAN WALLIS: What do you need to do
8 to get the answers required?

9 MR. DHIR: WE didn't need --

10 CHAIRMAN WALLIS: What you want, and you
11 may want all kinds of things.

12 MR. DHIR: Right. But we don't need -- we
13 are just providing this additional information
14 basically.

15 CHAIRMAN WALLIS: I think actually we both
16 want and need to take a break fairly soon. Is this a
17 good point to do it?

18 MR. DHIR: That's fine, yes.

19 CHAIRMAN WALLIS: We going to move on to
20 a different topic?

21 MR. DHIR: Yes, right.

22 (Whereupon, at 3:39 p.m. off the record
23 3:53).

24 CHAIRMAN WALLIS: We're now on the record.
25 Get ready to proceed.

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1 Can you start to give us results, or did
2 you not finish --

3 MR. DHIR: No, I just want to describe the
4 flow loop a little bit, quickly.

5 CHAIRMAN WALLIS: Because we do want to
6 finish up before 6:00, so we're going to have to move
7 along here I think.

8 MR. DHIR: Okay.

9 CHAIRMAN WALLIS: If there's no argument
10 about modeling concepts, it might move along much
11 quicker.

12 MR. DHIR: Right. Okay. First, our
13 graphic -- flat plate and this was followed by a 9-rod
14 bundle and we did fabricate two 9-rod bundle. The
15 first rod bundle got destroyed during the
16 experimentation or got degraded in some sense, so we
17 had to rebuild another one.

18 MR. KRESS: But you joined the nucleus --
19 your departure --

20 MR. DHIR: No. No. It was degraded --
21 instrumentation. Thermocouple failed and so forth.

22 And on the flat plat we carried out 125
23 flow boiling experiments. The pressure in our
24 experiments was with one bar, Marked velocity was
25 varied from about 124 to 898 kilograms per meter

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1 squared, liquids are cooling on t to 50, wall heat
2 flux around 2 to 113, wall plus centimeter square and
3 contact angle from 30 to 90 degrees.

4 MR. KRESS: A question about those. Do
5 those correspond decay heat levels?

6 MR. DHIR: Those correspond to the
7 operation levels, right. From 2 to 113.

8 MR. KRESS: And the flows are what's
9 calculated to exist during the -- level --

10 MR. DHIR: Right. Right.

11 MR. KRESS: Okay.

12 MR. DHIR: This a schematic of the
13 facility flow loop, so forth. We have two tanks of
14 each one 1.25 cube in volume and the liquid is stored
15 in one of these tanks and its conditioned to bring it
16 desired temperature and then it's pumped through a
17 preheating section so that we can correctly control
18 the temperature of the liquid that enters the first
19 section. And after that it is dumped into another
20 second tank.

21 Now, this is a photograph of the facility.
22 Basically you see those two tanks and preheater. And
23 this is -- where the test section is placed, either
24 rod bundle or the flat plate. And this is our power
25 supply, and this power supply is rated at 40 volts and

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1 2.225 amps, so it give you 100 kilowatts of power. And
2 this we have gotten through our grants, and not NRC.

3 This is how the test chamber for the flat
4 plate tests. A converging nozzle was followed by a
5 flow technique section about 61 centimeters upstream
6 of the trail section. Then 30 centimeters downstream
7 there was a rectangular section and followed by a --
8 nozzle.

9 CHAIRMAN WALLIS: That's a --

10 MR. DHIR: Beg pardon? Centimeters.

11 CHAIRMAN WALLIS: The dimension are really
12 in -- 30.5 is

13 MR. DHIR: One feet.

14 CHAIRMAN WALLIS: 61 is 2 feet.

15 MR. DHIR: Two feet, right.

16 CHAIRMAN WALLIS: Okay.

17 MR. DHIR: And the cross section -- it's
18 a square cross section 4.2 centimeters each side and
19 copper block faces the one side and three sides you
20 have glass windows.

21 MR. SCHROCK: And at these low
22 temperatures you have no problems with glass windows?

23 MR. DHIR: No.

24 MR. SCHROCK: No itching of the windows?

25 MR. DHIR: No. You have -- still using a

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1 -- not different, but rod bundle up to 3.5 baud.

2 This is -- you are seeing the best block.

3 MR. RANSOM: Just out of curiosity, why
4 didn't they use a transition region --

5 MR. DHIR: What do you mean transition?

6 MR. RANSOM: Well, normally you'd use like
7 triangular section or something to minimize the
8 distortion, you know --

9 MR. DHIR: Right. But this length was
10 sufficiently long enough. This region was
11 sufficiently long enough to give us --

12 MR. RANSOM: Well, you're measuring the
13 gradient through that nose more region, right?

14 MR. DHIR: Right, this region.

15 MR. RANSOM: Well, didn't you tell me the
16 cartilage heaters extend all the way through the
17 block?

18 MR. DHIR: They go up through here, up to
19 this length.

20 MR. RANSOM: Yes, that's what I thought.

21 MR. DHIR: And beyond that, then the heat
22 has to flow through this section.

23 CHAIRMAN WALLIS: It's not a very one
24 dimensional looking -- when you think of solving the
25 conduction equation. Maybe all the differences -- the

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1 differences are small anyone.

2 MR. DHIR: Very small difference. You'll
3 see that in a minute.

4 And this is for the rod bundle. Rod
5 bundle, the rod tubing is Zircalloy-4 and the rod is
6 only is 1.1 centimeter, the sheet thickness is 1.5
7 millimeter. And we arrange in a 3 x 3 grid. A total
8 of 140 subcooled flow boiling experiments were
9 performed. These experiments have been performed at
10 1 bar, 2 and 3 bar. And in the 1 bar case, we varied
11 the marked velocity from 186 to 2800 which is 20
12 centimeters to 2.8 meters per second. So quite large
13 range.

14 Subcooling from 2.7 to 69 degrees at
15 inlet. Heat flux 1.6 to 25 bar per centimeters.
16 Current contact angle was about 57, hydraulic -- was
17 1.23

18 CHAIRMAN WALLIS: You say P was 1.03 just
19 because of the elevation of your lab or something?

20 MR. DHIR: Elevation of the lab and the
21 pump is in -- you know, the well was there, so
22 there's--

23 CHAIRMAN WALLIS: Is that sort of
24 pressure?

25 MR. DHIR: Yes.

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1 CHAIRMAN WALLIS: Because atmospheric
2 pressure varies by ten percent or something anyway.

3 MR. DHIR: Right.

4 CHAIRMAN WALLIS: So did you adjust for
5 variations in atmospheric pressure?

6 MR. DHIR: No. This is the pressure --

7 CHAIRMAN WALLIS: Oh, so this gauge
8 pressure?

9 MR. DHIR: No, no, no. Absolute pressure,
10 but the pressure constance is calibrated.

11 CHAIRMAN WALLIS: Absolute pressure?

12 MR. DHIR: Right.

13 CHAIRMAN WALLIS: And you adjust something
14 to make it 103 when the outside pressure is 105?

15 MR. DHIR: We not have 105. I don't think
16 we got 105.

17 CHAIRMAN WALLIS: You don't?

18 MR. DHIR: I don't think so. Usually it's
19 below what it must be at most of the time. We are
20 close to the ocean.

21 CHAIRMAN WALLIS: Yes, but the barometric
22 pressure when storms come by varies by plus or minus
23 5 percent.

24 MR. DHIR: Right. Most cases it was 1.03
25 but again we can -- this is a trivial item.

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1 MR. SCHROCK: Not on experimental days.

2 MR. DHIR: No, this is the measurement
3 from the pressure -- I'm giving you 1.03, not all
4 experiments would have 1.03.

5 CHAIRMAN WALLIS: Oh, okay. Okay.

6 MR. DHIR: So it's not --

7 CHAIRMAN WALLIS: It's a nominal pressure.

8 MR. DHIR: Right, nominal.

9 And this is how the rod bundle looks like.
10 And I thought the rod bundle is 91 centimeters.
11 Again, we have a -- flow welding section and this is
12 the photograph, you can see how it looks like. And
13 all four sides of the -- are glass windows.

14 CHAIRMAN WALLIS: It's prestressed. It
15 looks like a prestressed thing with tables holding it
16 together.

17 MR. DHIR: Right.

18 MR. DHIR: Yes, you have pins loaded
19 actually, pins holding it together.

20 CHAIRMAN WALLIS: Bungee cords.

21 MR. DHIR: After you heat there is some
22 expansion.

23 MR. KRESS: Where does the power come in
24 at? Through the bottom?

25 MR. DHIR: Through the top and bottom.

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1 MR. KRESS: Through the top and the
2 bottom.

3 MR. DHIR: And in the rod bundle we have
4 placed thermocouples about 18 centimeters apart and is
5 about 6, 7 locations. And the filler material we used
6 in two bundles. First one was lava and the second one
7 we used G-10 insert and there was a slot cut in the G-
8 10 on lava and the thermocouples were carried through
9 to the slots. And this was filled with high
10 thermoconductivity poxy and kind of pushed it to the
11 surface.

12 MR. RANSOM: Were these fresh ZR-4 tubes?

13 MR. DHIR: ZR-4.

14 MR. RANSOM: You expect a high oxidation
15 level to change the nucleation density or --

16 MR. DHIR: We had no change. But in --
17 water we did not see degradation. Copper it's much
18 more.

19 MR. RANSOM: I was concerned about the
20 reactor case where you probably have a high --

21 MR. DHIR: I'll show you something with
22 boron.

23 MR. RANSOM: Oh, okay.

24 MR. DHIR: Boron does more than just --

25 MR. RANSOM: V.J., what is lava? Is that

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1 the lava I know or --

2 MR. DHIR: Yes, that's the lava.

3 MR. RANSOM: Is that lava rock?

4 MR. DHIR: Right. You can get lava rock
5 pieces. And it's a --

6 MR. SCHROCK: Isn't that a commercial
7 product you --

8 MR. DHIR: Yes.

9 MR. SCHROCK: -- you make. It's sort of
10 a ceramic after you cook it.

11 MR. DHIR: Cook it, right. A similar
12 tool, you know.

13 MR. SCHROCK: But it's machineable.

14 MR. DHIR: Yes. You can get rod bundles
15 and rods --

16 MR. RANSOM: A manmade product --

17 MR. DHIR: Yes. Okay. First with the
18 flat plate, we looked at how uniform the heat flux was
19 along the axial direction. And, as you can see, for
20 this case about 42 -- this is at those several
21 locations how the heat flux varied on the
22 thermocouple.

23 CHAIRMAN WALLIS: Oh, you did the measures
24 across the plane?

25 MR. DHIR: Across the plane. I don't have

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1 it here, but does not vary more than 5 percent. There
2 was some drop on the edges, but it's fairly uniform.

3 CHAIRMAN WALLIS: Heat loss?

4 MR. DHIR: Heat loss, although it's
5 insulated, but still there is a heat loss.

6 CHAIRMAN WALLIS: You think it'd be higher
7 at the edges.

8 MR. DHIR: No, no. Temperature drops but
9 the heat flux is higher. So if you look at the
10 temperature uniform to along the surface, the
11 temperature is lower on the outer side.

12 This is the wall temperature as a function
13 of distance for one case. And you can see initially
14 it's a subcooled flow, forced convection and then
15 boiling starts somewhere around here. There's some
16 temperature drop and then it stays fairly constant
17 flow.

18 This is the temperature profile in the
19 liquid with the thermocouple which -- outward. And
20 most of the drop occurs very close to the wall, the
21 laminar sublayer. And as we go farther downstream and
22 the outer region of the thermal layer expands and you
23 can see the thermal layer becomes quite thick.

24 CHAIRMAN WALLIS: The top one of this with
25 the pinky triangle there.

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1 MR. DHIR: 24?

2 CHAIRMAN WALLIS: What TRAC is doing is
3 taking some average which you would say would be 88 or
4 something, or is TRAC taking 85, or what does TRAC
5 take as the temperature of the liquid.

6 MR. DHIR: Bulk 35.

7 CHAIRMAN WALLIS: No, that's not. The
8 average is 87 or something.

9 MR. DHIR: Average if you look at over the
10 whole cross section is close to 85.

11 CHAIRMAN WALLIS: Isn't that what TRAC
12 uses, the average over the whole cross section?

13 MR. BAJOREK: It would know the 85 degrees
14 in this point.

15 CHAIRMAN WALLIS: It wouldn't know that --
16 no, 85 at all. It would just know the average. TRAC
17 doesn't calculate the peak or minimum. It just takes
18 the average.

19 MR. RANSOM: Yes, it's the bulk --

20 MR. DHIR: The -- it would be 85.

21 CHAIRMAN WALLIS: No. The average is
22 above 85.

23 MR. RANSOM: Well, it's got to increase as
24 you flow down the --

25 MR. DHIR: Right. But how much -- you

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1 know, if you integrate those over there, how much
2 increase is going to --

3 CHAIRMAN WALLIS: But TRAC would say that
4 the top, the average bulk temperature is 85, although
5 there is water -- 85 --

6 MR. DHIR: Higher than --

7 CHAIRMAN WALLIS: Say the bulk temperature
8 was 87. Now there is water 85 in the middle.

9 MR. BAJOREK: Yes, but most heat transfer
10 correlations are using that bulk temperature, not an
11 average temperature.

12 CHAIRMAN WALLIS: That's right. So it --
13 what's the difference? What's the difference?

14 MR. BAJOREK: Barring what little bit you
15 have in the boundary layer.

16 CHAIRMAN WALLIS: What do you mean by
17 bulk?

18 You mean -- is wider than that.

19 MR. DHIR: No, channel is -- channel is
20 the 4 centimeters wide.

21 CHAIRMAN WALLIS: So the bulk temperature
22 is something like 87 when you average over the whole
23 thing. It's not 85, although there is liquid at 85 in
24 the middle.

25 MR. DHIR: Right.

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1 CHAIRMAN WALLIS: When you're doing your
2 condensation on these bubbles --

3 MR. DHIR: Right.

4 CHAIRMAN WALLIS: -- you're something
5 average. If they go out in the middle, they
6 disappear.

7 MR. DHIR: No. Bubbles were declining only
8 up to about here.

9 CHAIRMAN WALLIS: Only up to about there?

10 MR. DHIR: Right. So I'm making the
11 local--

12 CHAIRMAN WALLIS: What you see is the --
13 temperature than the bulk?

14 MR. DHIR: Right.

15 CHAIRMAN WALLIS: Of course, these
16 transverse things are not modeled in TRAC at all.

17 MR. SCHROCK: Now, M.J., this acts as a
18 single phase set of measurements.

19 MR. DHIR: This is single phase.

20 MR. SCHROCK: Yes. So there's no --

21 MR. DHIR: Right.

22 MR. SCHROCK: Once you start getting two
23 phase, this gets all changed.

24 MR. DHIR: Changed, but still outer
25 regions you'll have still some cooling.

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1 MR. RANSOM: I think you had some
2 arguments in the paper that it's still measuring the
3 liquid temperature or approximately the liquid
4 temperature?

5 MR. DHIR: Right.

6 MR. RANSOM: But you do use that data to
7 establish the temperature of the liquid where the
8 bubble is at, right?

9 MR. DHIR: Exactly. That's what we do.
10 And the first the exercise we made it was kind of a
11 test how good experiments you're doing, we calculated
12 from the wall side and if we take this gradient does
13 it match. And this gradient we have much more
14 uncertainty because its profile is so steep. But we
15 didn't -- about 20 percent it matched with what we
16 were putting in from the other side.

17 This is how the heat transfer coefficient
18 looks along the copper block -- single phase flow. So
19 you can see it's just developing flow. It's like --
20 flat plate and the -- is decreasing. In this case the
21 narrow number at the end about -- less than the what
22 we need for transition -- to turbulent flow.

23 MR. RANSOM: What did you say the Reynolds
24 number is?

25 MR. DHIR: Based on the length.

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1 MR. RANSOM: Yes, is what?

2 MR. DHIR: It's about close to 10 above 5.

3 MR. RANSOM: Ten to the 5th, right?

4 MR. DHIR: Right.

5 MR. BANERJEE: Based on the length.

6 MR. DHIR: Length. Right.

7 MR. RANSOM: Distance. REL?

8 MR. BANERJEE: Right.

9 MR. RANSOM: Is that a curve a model?

10 MR. DHIR: No, just to the data.

11 MR. RANSOM: It would have been helpful to

12 -- how did it compare with --

13 MR. DHIR: This is a laminar -- flow -- we

14 can apply, but you see I don't have it here. I think

15 that it is one of the reports that was discussed, what

16 difference. But we find the -- value is about 20

17 percent higher than what you'll get for laminar flow.

18 MR. RANSOM: Which is 20 percent higher?

19 MR. DHIR: This value here.

20 MR. RANSOM: Is 20 percent higher than

21 what we would --

22 MR. DHIR: Then you'll get for -- profile

23 for example is you calculate what --

24 MR. BANERJEE: So you should be able to

25 trace the --

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1 MR. DHIR: Oh, yes, right. We did that. I
2 think it's in one of the reports. But the key point
3 here was it looked --

4 CHAIRMAN WALLIS: In a square geometry.

5 MR. DHIR: Right, so there will be some
6 difference. And also we have not taken any precaution
7 to make the flow laminar exchange, so there will be
8 some difference.

9 And this is on the rod bundle, single
10 phase heat transfer coefficient.

11 CHAIRMAN WALLIS: That's length the axis
12 there?

13 MR. DHIR: Axis? Yes, it's not missing
14 here. It's these, distance from inlet.

15 CHAIRMAN WALLIS: It's also showing a big
16 entrance length effect.

17 MR. DHIR: Yes. You see almost 50
18 hydraulic damages.

19 CHAIRMAN WALLIS: So how come it
20 correlates so well on the right hand side?

21 MR. DHIR: Just one thing. I'll come to
22 that.

23 This is -- flow and you see out 50 --
24 damage it becomes almost fully developed and the
25 colored symbols are for the central rod. And the open

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1 symbols are for the rod which is at the corner and
2 facing -- thermocouple is facing outside, outward
3 direction. So it's in the quadrant. And that
4 thermocouple -- reduced from that thermocouple is
5 about 15 to 20 percent lower than the central rod.

6 MR. SCHROCK: So would you say again
7 whether those numbers are X over D or just X?

8 MR. DHIR: This is rod bundle, this is
9 just Z centimeters.

10 MR. SCHROCK: Z?

11 MR. DHIR: Z, centimeters.

12 MR. BANERJEE: And the hydraulic damage is
13 about

14 MR. DHIR: 1.2

15 MR. BANERJEE: So this is in turbulent
16 zone?

17 MR. DHIR: Yes, 11,000 yes.

18 CHAIRMAN WALLIS: So it's developing
19 pretty slowly?

20 MR. DHIR: Yes.

21 CHAIRMAN WALLIS: It is, yes.

22 MR. SCHROCK: It should go faster than
23 that for Reynolds of 11,000 I think.

24 MR. DHIR: 11,000 I don't know.

25 CHAIRMAN WALLIS: Anyway, what's the right

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1 hand side?

2 MR. DHIR: Okay. And the right hand side
3 is we take these values here and we develop a case and
4 we are plotting them for the Weisman number based on
5 this fully heat transfer coefficient normalized the --
6 number to the .4 power we are plotting against -- to
7 the .8 power. And these are all of our data covering
8 a range of 8,000 to about 95,000

9 MR. RANSOM: Just a little bit of
10 clarification. The heater rods continue on in unheated
11 party? I mean --

12 MR. DHIR: No.

13 MR. RANSOM: What is the zero to 100,
14 that's only the heated section?

15 MR. DHIR: Heated section ends here.

16 MR. RANSOM: And where does it begin?

17 MR. DHIR: Middle.

18 MR. RANSOM: And the leads and the other
19 parts of the rods --

20 MR. DHIR: They're still longer -- so much
21 longer, but our measurement start at --

22 MR. RANSOM: Okay. But what I'm wondering
23 about, where does the viscous layer begin? You know,
24 you have a viscous boundary layer and you have a
25 thermal boundary layer.

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1 MR. DHIR: Right.

2 MR. RANSOM: Obviously the thermal
3 boundary layer begins at zero in this case at the
4 heated point.

5 MR. DHIR: Right. Right.

6 MR. RANSOM: But presumably you must have
7 a fully developed viscous layer.

8 MR. DHIR: No I've seen the other kind of
9 grid to which these rods were sitting. So the floor
10 is coming through holes.

11 MR. RANSOM: Through spaces?

12 MR. DHIR: Kind of spaces, but it's like
13 a grid plate where the rod was sitting in.

14 MR. RANSOM: Where do the grid space start
15 then?

16 MR. DHIR: Just above zero. You know,
17 they're just sitting here.

18 MR. RANSOM: So you mean the flow comes in
19 like jets?

20 MR. DHIR: That's right. The flow is
21 coming in like through those holes, passages.

22 MR. RANSOM: So it's not a fully developed
23 turbulent situation at the beginning of the heated
24 section?

25 MR. DHIR: It's not fully developed flow,

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1 yes.

2 MR. RANSOM: It may be one reason the heat
3 transfer coefficient is bigger at the beginning. It
4 actually generates some extra -- with these jets.

5 MR. DHIR: Possible.

6 So what we find is the fully developed
7 values for this range of -- number are about 16
8 percent higher than Dittus Boelter correlation. And
9 the chain line is the Weisman correlation for a square
10 grid type of arrangement and the rod bundle --
11 somewhat smaller than what we have, and his real
12 number range was on the higher end. It was about from
13 30,000 to about 700,000 and yet on the low end about
14 8,000 to 95,000 but we are predicting lower heat
15 transfers then will be predicted from Weisman's
16 correlation.

17 MR. RANSOM: I'm back to Professor Sanjoy
18 Banerjee's question, why do they agree down at the
19 lower end, because they seem to be in quite a bit of
20 disagreement, at least that is bolder on the left hand
21 one, and yet the low Reynolds number on the right hand
22 plot they seem to be in quite good agreement.

23 CHAIRMAN WALLIS: Well, it's actually
24 quite close because there's a false origin on the left
25 hand side.

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1 MR. DHIR: Right.

2 MR. RANSOM: It's what?

3 CHAIRMAN WALLIS: It's a false origin.
4 You know 2500 is the base and the left hand side the
5 percent disagreement is not very big. Because go all
6 the way down to zero.

7 MR. DHIR: Because zero is --

8 MR. SCHROCK: They're everywhere within 30
9 percent.

10 CHAIRMAN WALLIS: Anyway, the interesting
11 problem is the two phrase, isn't it?

12 MR. DHIR: Right. But at least it gives
13 you -- this range was not available in the literature
14 and there's some interest in that range.

15 CHAIRMAN WALLIS: All right.

16 MR. DHIR: Because of application to --
17 and then we go to ONB. So now these are not -- if you
18 see this 4, it's a 4 item which I showed you on the
19 table, what phenomena we were trying to model or
20 understand or measure and what the instrumentation
21 was.

22 MR. BANERJEE: Claussius Clapeyron.

23 MR. DHIR: Yes.

24 MR. KRESS: I had a question about this,
25 V.J.

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1 MR. DHIR: Yes.

2 MR. KRESS: It seemed to me like that psia
3 ought to be proper from the Claussius Clapeyron
4 equation, the one on the right hand side of the first
5 equation.

6 MR. DHIR: They put it at saturation
7 temperature corresponding to the pressure in the
8 vapor.

9 CHAIRMAN WALLIS: Which is the same as --

10 MR. DHIR: No. Liquid pressure is less.
11 So the liquid is at saturation temperature. Pressure
12 in the vapor bubble is higher than the pressure
13 outside. And the temperature of the vapor has to be
14 cooled to or at least the saturation temperature cause
15 under the pressure in the bubble. So the temperature
16 of the vapor is higher than the liquid, and that's the
17 reasoning you made that the vapor bubble has to be
18 surrounded by superheated liquid for it to go.

19 MR. SCHROCK: But the difference is small
20 through bubbles of this size.

21 MR. DHIR: What size?

22 MR. SCHROCK: The average size they have
23 when they're detached from the wall. There's not
24 much--

25 MR. DHIR: Right.

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1 MR. SCHROCK: Not much delta P involved
2 once they've detached.

3 MR. DHIR: Well, how did we jump to
4 detached bubbles. First I'm talking about onset of
5 nucleate boiling.

6 MR. SCHROCK: Oh, yes. You're right.
7 You're right. I'm not paying attention.

8 MR. DHIR: So we're talking about bubbles
9 forming on the cavities --

10 MR. SCHROCK: Right, right.

11 MR. DHIR: -- which is a very, very small
12 number.

13 MR. BANERJEE: So this is really right in
14 the cavities?

15 MR. DHIR: Cavities, right. You know, as
16 I said, initially we want to predict where the boiling
17 starts. And if you're not going to predict that right
18 and then you keep on adding the arrows you move
19 downstream. So there are a number of correlations
20 models that have been proposed since '60s. You all
21 know them, know about them, I don't need to repeat
22 them. But basically HSU it was proposed in '62, very
23 simply matched or said the minimum superheat will be
24 the case when temperature profile in the liquid is
25 simply tangent to the superheat you need to -- because

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1 of the evaporation in the bubble.

2 And then Bergles & Rohsenow, Rohsenow
3 followed that same idea, but they placed the
4 properties of the fluid in terms of the pressure. And
5 Sato and Matsumara again did a similar thing. Davis
6 and Anderson added a constant C_1 to account for
7 different contact angles.

8 MR. SCHROCK: Actually, the vapor inside
9 the bubble is slightly superheated, but it's
10 negligible importance.

11 MR. DHIR: Yes.

12 MR. SCHROCK: Rohsenow worked that out
13 from a free energy argument years ago. And there's a
14 physical model --

15 CHAIRMAN WALLIS: I think Maxwell did it,
16 somebody like that.

17 MR. DHIR: It's higher than --

18 MR. SCHROCK: It's Helmholtz.

19 CHAIRMAN WALLIS: Helmholtz, somebody.

20 MR. DHIR: Right.

21 MR. SCHROCK: On a physical model.

22 MR. DHIR: Yes, Kandlikar.

23 And see those kind of correlations are
24 modeled work when the liquids are partially breaking
25 the surface. And Hahne, Spindler and Shen in 1990

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1 looked at freons which -- the surface well and they
2 found those correlations really under predicted the
3 wall superheat at nucleation. And from experiments
4 they found that -- could be written empirically like
5 this, and if you use that corrective style you can
6 calculate the 1B superheat and then you substitute
7 that into the -- balance and this is a superheat and
8 the liquid subcooling is there, multiple by heat
9 transfer coefficient, that gives the heat flux and
10 ONB. So you get delta to ONB and heat flux ONB both.

11 This is what -- see how our data looks
12 like on the flat plate for different heat fluxes. This
13 is the cover I show you earlier. This is a single
14 phase heat transfer. And these are the plots we see
15 as increase --

16 CHAIRMAN WALLIS: I didn't understand your
17 little vertical things where you said this is where
18 the two meet. I couldn't see. Either the numbers in
19 the text don't agree with the position of those little
20 vertical lines, and also I don't understand how they
21 related to the curves.

22 MR. DHIR: Okay. Let me explain what
23 we're blocking here.

24 Let's take this curve. Higher heat flux,
25 okay. The heat transfer coefficient, it decreases and

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1 then increases and increases and then finally becomes
2 almost constant. So we are plotting here is where we
3 saw ONB and bubbles start to form on the surface.
4 Visually and by noting the minimum in the curve.

5 CHAIRMAN WALLIS: Oh, the minimum.

6 MR. DHIR: Right.

7 CHAIRMAN WALLIS: I thought you said it
8 was where there was departure from single phase, which
9 would have put it way over to the left.

10 MR. DHIR: Right. That will be left. But
11 minimum --

12 CHAIRMAN WALLIS: When you say minimum in
13 the text, it says --

14 MR. DHIR: Minimum is the heat transfer
15 improves after the bubbles start to form.

16 CHAIRMAN WALLIS: But it's really where it
17 departs from single phase that's something's happened.

18 MR. DHIR: Right, but single phase it
19 departed, visually we see single phase, and this is
20 the two phased region.

21 CHAIRMAN WALLIS: I didn't understand this
22 minimum idea at all. Because I was looking for where
23 the one curve leaves the other one, which is actually
24 further to the left. Okay. Now I think I understand
25 it. No, I understand what you've done with the

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1 minimum part.

2 MR. DHIR: Right. But these are different
3 heat flux curves.

4 CHAIRMAN WALLIS: Yes, but minimum wasn't
5 clear to me that minimum meant anything.

6 MR. DHIR: What we find, if I set the heat
7 flux and measure the heat transfer coefficient along
8 the length of the plate, you will see heat transfer
9 coefficient would decrease, a minimum value and then
10 increase.

11 CHAIRMAN WALLIS: Okay.

12 MR. DHIR: And the minimum point almost
13 coincided where the nucleation starts.

14 CHAIRMAN WALLIS: Well, why does it leave
15 the single phase flow curve before that?

16 MR. DHIR: What do you mean before that?

17 CHAIRMAN WALLIS: Well, you dashed -- your
18 colored red curves leaves the black curve way up at
19 the left hand corner of the picture.

20 MR. DHIR: This one?

21 CHAIRMAN WALLIS: No, the curve.

22 MR. DHIR: This curve? This is single
23 phase.

24 CHAIRMAN WALLIS: The red curve leaves the
25 black curve at a point which is almost on the left

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1 hand corner up there at 6,000.

2 MR. DHIR: Right.

3 CHAIRMAN WALLIS: So really you shouldn't-

4 -

5 MR. DHIR: All these points should be one
6 point.

7 CHAIRMAN WALLIS: No, no, the right curve.
8 You put a curve in there. You've only really got red
9 points, right? If you'd shown a straight line through
10 the red points hitting the black line, then I would
11 have believed something. But you fared in a curve.
12 And the red curve leaves the black curve at about 2 in
13 terms of Z. You see what I mean?

14 MR. DHIR: Right. This -- okay. The key
15 point you want to make here is that you increase the
16 heat flux, you leave this curve either later or
17 earlier.

18 CHAIRMAN WALLIS: Come down the black
19 curve.

20 MR. DHIR: Okay.

21 CHAIRMAN WALLIS: And then when you get
22 into the right curve -- you're on the Metro, right?

23 MR. SCHROCK: Right.

24 CHAIRMAN WALLIS: When do you get onto the
25 red curve?

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1 MR. DHIR: That's true.

2 CHAIRMAN WALLIS: When does your finger go
3 from the black curve to the red curve?

4 MR. DHIR: Okay. The question is here
5 this represents some of uncertainty of measurement for
6 each experiment. Actually this should be one curve.

7 MR. BANERJEE: Yes, the heat flux
8 shouldn't have an effect.

9 MR. DHIR: Effect on the single phase heat
10 transfer coefficient.

11 CHAIRMAN WALLIS: Okay. But you come down
12 the black curve.

13 MR. DHIR: Yes.

14 CHAIRMAN WALLIS: Now put your finger on
15 the black curve.

16 MR. DHIR: Right.

17 CHAIRMAN WALLIS: Come down there -- don't
18 -- don't go so far.

19 MR. DHIR: Okay.

20 CHAIRMAN WALLIS: Now go up some more.

21 MR. DHIR: Okay.

22 CHAIRMAN WALLIS: Go up some more. Go up.

23 MR. DHIR: Okay.

24 CHAIRMAN WALLIS: And you still haven't
25 met where the red line comes in.

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1 MR. DHIR: Right.

2 CHAIRMAN WALLIS: The right line comes in
3 up there somewhere.

4 MR. DHIR: This red line and this solid
5 should be the same curve.

6 CHAIRMAN WALLIS: Well, then you should
7 draw them the same.

8 MR. DHIR: Again, I have my data. The
9 data says each time I take the experiment I have data
10 difference. I'm not treating it.

11 MR. BANERJEE: --down there which is much
12 closer.

13 MR. DHIR: Right. So that's what I'm
14 saying --

15 MR. BANERJEE: So why do you draw it --

16 MR. DHIR: Oh, you could draw it here and
17 then --

18 CHAIRMAN WALLIS: Then it would be clear
19 where it left. You see, the thing is where do you
20 leave one and hit the other? And you curved it like
21 that, it looks as if it leaves at 6,000.

22 MR. BANERJEE: But there's no logic for
23 you to miss that red point.

24 MR. DHIR: Again, it's just the line fell
25 through the data. It's not specific. The key question

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1 is the idea we should be talking about does the
2 minimum represent onset of nucleate boiling.

3 CHAIRMAN WALLIS: You see your text
4 doesn't say anything about minimum. Your text says
5 where the volume departs from the other line, and that
6 is way up where I was trying to get you to go, and
7 that's very misleading to the reader.

8 MR. SCHROCK: What is that inset ONB
9 location, what's that legend mean?

10 MR. DHIR: ONB location, this is visual
11 observation. Visually we see on the -- on the plate,
12 you know the location --

13 MR. SCHROCK: So it's a vertical line not
14 a horizontal line, but there's a solid one and a
15 dashed one.

16 MR. BANERJEE: The first one is the
17 minimum.

18 MR. DHIR: Dashed one represents the
19 minimum, the heat transfer coefficient curve.

20 CHAIRMAN WALLIS: And the minimum should
21 be ONB. But, anyway, we should probably move on.
22 It's confusing to the reader when he sees these
23 things.

24 MR. RANSOM: I can't even tell which one's
25 dashed and which one's not because the dash is much

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1 different.

2 CHAIRMAN WALLIS: Which goes with which
3 curve is also a question.

4 MR. DHIR: No, all these four curves
5 should be one.

6 CHAIRMAN WALLIS: Up to some point

7 MR. DHIR: Up to some point. Because then
8 they should diverge on each case.

9 CHAIRMAN WALLIS: Right.

10 MR. DHIR: But we are being honest to our
11 data that what -- I plotted. So I could have plotted
12 an average of these and then draw it, and then it will
13 be clear, there'll be -- in that main curve.

14 MR. SCHROCK: So the visual and the
15 observation from the HZ plot are sometimes one way in
16 relationship, sometimes the other way.

17 MR. DHIR: Right. Because thermocouples
18 are made indiscreetly so you're not exactly locating
19 that -- from the plot you cannot exactly locate that.

20 MR. SCHROCK: Okay.

21 MR. KRESS: For the blue line the visual
22 and the HZ are on top of each other?

23 MR. RANSOM: There's only one vertical
24 line on that one.

25 MR. KRESS: Yes, it must be on top.

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1 CHAIRMAN WALLIS: Anyway, you just have to
2 clarify it.

3 MR. DHIR: Right.

4 MR. BANERJEE: What is the other one?

5 MR. DHIR: What? The other one is simply
6 locating where the ONB occurs, how it's influenced by
7 flow velocity and there are two different flow
8 velocities, liquid subcooling and contact angle.
9 Because the boiling has shifted. Superheat has
10 shifted depending on the contact angle or your flow
11 boiling -- flow velocity.

12 So basically this plot is telling you that
13 if ONB to occur at this location, then $\Delta T_{w,ONB}$
14 would be higher if I have a high flow rate.

15 MR. SCHROCK: When they use this in their
16 interpretation in the code evaluation, they're going
17 to have to do something about the contact angle as a
18 function of pressure. Are you providing those data
19 for them or --

20 MR. DHIR: No, not as yet. Not as yet.

21 MR. SCHROCK: Has that come up in your
22 discussion with the sponsor?

23 MR. DHIR: No.

24 CHAIRMAN WALLIS: It's a function --

25 MR. SCHROCK: But you agree, it depends on

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1 surface tension, which depends on temperature --

2 MR. DHIR: Surface tension is one really.
3 It depends, you know, solid liquid also surface
4 tension.

5 CHAIRMAN WALLIS: It depends on the age of
6 the fuel.

7 MR. SCHROCK: It depends on a lot of
8 stuff.

9 MR. DHIR: Lots of stuff.

10 MR. BANERJEE: So the contact angle has a
11 larger effect than the flow velocity?

12 MR. DHIR: On what?

13 MR. BANERJEE: On the ONB.

14 MR. DHIR: That's true. In this situation
15 you can see onset of nucleate boiling contact angle
16 has more effect.

17 MR. BANERJEE: Lots more. I mean, the
18 major effect.

19 MR. DHIR: Right.

20 MR. SCHROCK: See, at the outset I was a
21 little puzzled by why the emphasis on low pressure for
22 your experiment. In the TRAC code it seems to me they
23 need the ability to solve this problem for any
24 pressure that may occur during an accident transient
25 or transient of any kind. And that would seem to cover

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1 a substantial range of pressure, not just low
2 pressure.

3 MR. DHIR: Right.

4 MR. BANERJEE: But during the AP600 runs
5 the low pressure behavior in the subcooled region, at
6 least of RELAP-5 was --

7 MR. SCHROCK: That's what led them to
8 think they had a problem.

9 MR. BANERJEE: Yes.

10 MR. DHIR: Right.

11 MR. BANERJEE: That's really what happened
12 historically. We had a lot of trouble trying to
13 interpret this result. Whether they are true or not,
14 we don't know. Because maybe the -- for all we know.
15 But that was the reason.

16 MR. DHIR: But at that time thinking was
17 that these codes do well for at high pressures, but
18 not at a low pressure.

19 CHAIRMAN WALLIS: We've got to five slides
20 out of 83 in about --

21 MR. SCHROCK: How do we know? I mean,
22 you've identified what the real dependence is here.
23 And it's contact angle.

24 MR. DHIR: Right, it's quite important.

25 CHAIRMAN WALLIS: A elusive problem.

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1 MR. SCHROCK: That means the code needs
2 good contact angle information, and I don't think it
3 has it.

4 MR. DHIR: You know, at least it's 30
5 points of whatever the key variable you need to know.

6 MR. SCHROCK: Right.

7 MR. DHIR: And then we come back and say
8 rather what we want to do in the code.

9 MR. SCHROCK: Yes.

10 MR. BANERJEE: How did you vary the
11 contact angle?

12 MR. DHIR: How did I vary the contact
13 angle? For copper block we polished the surface and
14 when you polish the copper block and use water, you
15 get contact angle close to 90 degree.

16 Then we follow the standardized procedure
17 where we put the copper block in the air and heat it
18 so it gets oxidized. But controlling the oxidization,
19 we can change the contact angle. And so we went down
20 to about 30 degrees.

21 And generally when you like polished
22 copper, after you're done with the experiment contact
23 angle changes. And then we had to have some sort of
24 an average for that run. But when you're at 30
25 degrees still same, for example, after you are done --

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1 MR. SCHROCK: And for your Zircalloy you
2 did it on a piece of flat Zircalloy with drops --

3 MR. DHIR: Right. Flat. And then we also
4 put on the rod very small droplet and see what the
5 contact angle was. And as you'll see in there, the
6 contact angle is given for the --

7 MR. BANERJEE: 37 or something.

8 MR. DHIR: 57.

9 MR. BANERJEE: 57.

10 MR. SCHROCK: It's hard to measure well
11 with little drops.

12 MR. DHIR: With the plates, yes, you can
13 do that. Yes. But, again, the question is are you --
14 you know, we can spend all of our time on contact
15 angles.

16 CHAIRMAN WALLIS: With little drops
17 because the contact angle then varies over the
18 surface?

19 MR. SCHROCK: Well, it's just very hard to
20 see where the contact line is.

21 MR. DHIR: Again, then you can get in
22 discussion of whether it's microscopic contact --

23 MR. SCHROCK: And you measure the --

24 MR. DHIR: So, but at least it gives you
25 a perimeter which you can measure.

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1 MR. SCHROCK: Yes.

2 CHAIRMAN WALLIS: That's an elusive
3 perimeter. I remember going back to Burnstein's
4 experiments and change the surface and a lot of things
5 change.

6 MR. DHIR: But the question you ask
7 yourself if it's elusive perimeter, it is an important
8 perimeter. If it's not important, let's forget about
9 it.

10 CHAIRMAN WALLIS: But it is important.

11 MR. DHIR: That's what I'm saying.

12 MR. BANERJEE: Well, your experiments show
13 that it's --

14 MR. DHIR: It's extremely important.

15 MR. BANERJEE: -- the main perimeter.

16 MR. DHIR: That's right.

17 MR. BANERJEE: One of them.

18 MR. DHIR: In the past we have -- you
19 know, somehow ignored it whenever the problem occurred
20 or it's elusive problem and let's --

21 MR. SCHROCK: Because it's hard to measure
22 and it's inconsistent.

23 MR. DHIR: Right.

24 MR. SCHROCK: We'd never get agreement.

25 MR. DHIR: But if you think of, again --

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1 MR. SCHROCK: Subtle operational
2 conditions.

3 MR. DHIR: That's true. But let's say I
4 give you 57, you may come out at 52 or somebody comes
5 with 62, it's not going to be 5 degrees.

6 MR. SCHROCK: Yes. That's right.

7 MR. DHIR: So that's what we should shoot
8 for.

9 MR. SCHROCK: But the difference between
10 60 and 30 is big.

11 CHAIRMAN WALLIS: We need to move on.

12 MR. DHIR: So we have proposed our own
13 correlation for predicting the onset of nucleate
14 boiling. What we are saying is that the corrected size
15 of the cavity is given by -- through the analysis, but
16 the probability of finding this cavity diminishes as
17 the contact angle decreases. This cavity may not be
18 available to nucleate as at first it becomes more
19 ready. So that's the --and this function F which
20 corrects the cavity size we get empirically by
21 correlating all the data that is available in the
22 literature. And varying from the contact angle of one
23 degree to almost 90 degree.

24 MR. BANERJEE: What is ϕ ?

25 MR. DHIR: ϕ contact angle.

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1 MR. KRESS: And how are they supposed to
2 know what that is in the code?

3 MR. DHIR: Code? If they're working with
4 Zircalloy -- what's stated is they would know about 57
5 degrees.

6 MR. KRESS: That's the unoxidized state?

7 MR. DHIR: Right.

8 MR. KRESS: Okay.

9 MR. DHIR: So that's all I can say at the
10 moment. But with the lowest thing it does effect --
11 it does depend on pressure as well.

12 CHAIRMAN WALLIS: -- contact angle is in
13 the cavity, isn't this different? How do you measure
14 that? It's not the same as on the surface.

15 MR. DHIR: I don't know. That's the
16 proposal I have for research.

17 CHAIRMAN WALLIS: The cavities may be
18 there because they are different.

19 MR. DHIR: Yes. We have looked at again,
20 now we're going back to study. We did about 12 -- 12,
21 15 years ago and we looked at the shape of the
22 cavities microscopically. And then for my polishing
23 the surface and see what kind of cavity it really
24 nucleated. And we were able to relate the trapment of
25 gas in the cavity to a contact angle.

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1 CHAIRMAN WALLIS: What I'm saying is
2 suppose you have a clean surface, a clean line.

3 MR. DHIR: Yes.

4 CHAIRMAN WALLIS: And after a while it may
5 develop cavities because of erosion and corrosion
6 phenomenon.

7 MR. DHIR: Yes.

8 CHAIRMAN WALLIS: And because of this
9 corrosive phenomenon what's in the cavity isn't the
10 same as what's on the surface.

11 MR. DHIR: Yes.

12 CHAIRMAN WALLIS: And therefore what
13 contact --

14 MR. DHIR: That's possible, yes. But
15 again, that's possible but it's going to be -- first
16 order of effect to second order effect.

17 MR. BANERJEE: I mean, BWI is adding zinc
18 and its cobalt and all sorts of stuff was on the --

19 MR. DHIR: You know, again, we just did
20 this -- now I'm jumping, but maybe -- Zircalloy, fresh
21 Zircalloy and water we found contact angle was about
22 57. Then we did some experiments with boron and water.
23 We put 7,000 ppm of boron in the water. And that water
24 we used to measure the contact angle. It was about the
25 same. Because the number's different with boron. And

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1 then we also, you know as you run that experiment,
2 boron deposits from this cladding. And then we
3 measured the contact angle again, it was not much
4 different than 57. So that is what evidence we have.
5 However, nucleation sites and then boron crust was on
6 the surface, but much more, because you formed the
7 porous structure --

8 CHAIRMAN WALLIS: Well, close around --

9 MR. DHIR: Right. So that increase the
10 number.

11 CHAIRMAN WALLIS: You distill. You distill
12 the water away and leave the crud behind.

13 MR. DHIR: Right. And then that crud is
14 porous.

15 CHAIRMAN WALLIS: Yes.

16 MR. DHIR: And you form -- there. And in
17 fact we found -- I'm giving -- with boron your
18 nucleate boiling heat transfer was higher but single
19 phase heat transfer was lower after the crud was
20 formed.

21 So this is all of the data we have and
22 which we put together in the literature. And you can
23 see data varies from contact angle of 1 degree FC72 to
24 about 90 degrees with copper, maybe 35 degrees with
25 copper.

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1 CHAIRMAN WALLIS: What's the pressure
2 range?

3 MR. DHIR: Most of the data it's at -- of
4 pressure but some is at high pressures as well. There
5 the contact angle was given. I'll show you later on.
6 I think it's -- it's Bergles & Rohsenow high pressure
7 data.

8 MR. BANERJEE: And this is for flat
9 plates, or does it also have rod bundles?

10 MR. DHIR: Rod bundles are there. It's
11 the 57 8 points 2 bar, 6 points at 3 bar and about 7
12 points of water. With boron and about 19 points with
13 rod bundle. So you have several data points.

14 MR. SCHROCK: These are all calculated
15 from the equation on 34, the previous page?

16 MR. DHIR: The previous page, right.

17 CHAIRMAN WALLIS: This all assumes you
18 have enough nucleation sites that you're not limited
19 by the numbers, by Hsu criteria.

20 MR. DHIR: Hsu criteria gives us the --
21 sites. Then we are saying.

22 CHAIRMAN WALLIS: If they don't exist,
23 then you won't get --

24 MR. DHIR: That's what -- nonexistence we
25 call the F function. That's what accounts for

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1 nonexistence.

2 MR. SCHROCK: There's a note on that slide
3 that says for small superheats. What's the one --

4 MR. DHIR: Oh, because we expanded the
5 pressure difference to saturation temperature
6 difference due to Clausius Clapeyron. And if you go
7 to high superheats that doesn't work, you know. You
8 can't expand like that.

9 MR. DHIR: Because of the Clausius
10 Clapeyron?

11 MR. DHIR: Clausius Clapeyron, right.

12 MR. BANERJEE: But you could use it on
13 Hahne's --

14 MR. DHIR: Right. On Hahne's equation you
15 can use it. Go to steam table --

16 CHAIRMAN WALLIS: If you had a surface
17 with no cavities in it and everything would be
18 different?

19 MR. DHIR: Right.

20 CHAIRMAN WALLIS: Like boiling on mercury
21 or something?

22 MR. DHIR: Mercury or, you know, again,
23 but in the limit if you say contact angle goes to zero
24 --

25 CHAIRMAN WALLIS: Well, no, just contact

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1 angle. It's also a crunch of -- you have to have
2 enough cavities for this --

3 MR. DHIR: That's true. You know, it's
4 like glass. You can have one crystal, you won't get
5 anything.

6 MR. KRESS: Why does the Hayes's alloy
7 look different than all the others. It's those little
8 crosses up to the top.

9 MR. DHIR: Cross, yes. That's the -- this
10 that R11 which --

11 MR. KRESS: Freon.

12 MR. DHIR: Freon. Freon, and you know
13 that was the number we got, but then we don't know
14 what the reason is. Somebody's -- let's put all the
15 data we have.

16 MR. SCHROCK: What is the largest
17 superheat you had in your test tube?

18 MR. DHIR: My test the highest is about 15
19 degrees C.

20 MR. SCHROCK: 15C?

21 MR. DHIR: 15 to 20C, yes. That's how
22 high we have gone. But there are others who have gone
23 quite high. See, our data is mostly here, you can
24 see. ONB's low superheat, but doing the experiments
25 we have gone higher.

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1 MR. SCHROCK: Okay.

2 CHAIRMAN WALLIS: Okay. The next one.

3 MR. DHIR: Okay. So we not able to only
4 put it to ONB -- but also Q_{ONB} because it's a no single
5 phase heat transfer coefficient --

6 CHAIRMAN WALLIS: If you don't put the --
7 effect in you get far more scatter?

8 MR. DHIR: That's right. But here you can
9 see Q_{OMB} , we have gone about 4 orders of magnitude.
10 Okay. This has all the high pressure data as well.

11 MR. BANERJEE: Which is the high pressure
12 data.

13 MR. DHIR: That is this one, water and
14 nickel. That -- high heat influx.

15 MR. KRESS: How is the contact angle
16 determined in all these experiments?

17 MR. DHIR: Some are reported, but we have
18 measured this to a droplet. We place a microdroplet --

19 MR. KRESS: Drop a droplet on there and as
20 it --

21 MR. DHIR: Then take a photograph.

22 MR. KRESS: Okay.

23 MR. SCHROCK: Graham, how did you see the
24 contact angle effect on his graphs? I didn't
25 understand your point.

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1 CHAIRMAN WALLIS: About what?

2 MR. BANERJEE: Well, it's collapsed
3 through the --

4 CHAIRMAN WALLIS: I assume that if you
5 don't put contact angle in -- they have a formula for
6 using contact angle, f equals minus 6. But if you
7 simply puts f equals 1 you get presumably much more
8 scatter. It will be useful to show that, I think.

9 MR. DHIR: You should show that.

10 MR. BANERJEE: What happens if you put f --

11 MR. DHIR: You'll certainly underput.

12 MR. BANERJEE: Yes. If you take the
13 exponential term out --

14 MR. DHIR: Right.

15 MR. BANERJEE: Φ is in radiance, right?

16 MR. DHIR: Right.

17 CHAIRMAN WALLIS: How much does f vary?

18 MR. DHIR: Oh, varies quite a bit. I'll
19 show you next slide.

20 CHAIRMAN WALLIS: How much is quite a bit?

21 MR. DHIR: How you can go to -- you can go
22 to as close as zero.

23 CHAIRMAN WALLIS: You said it varies. Does
24 it vary --

25 MR. DHIR: Close to zero.

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1 CHAIRMAN WALLIS: No, but isn't it from 4
2 degrees to 70 degrees?

3 MR. DHIR: Let me show you next group.

4 MR. BANERJEE: Well, if 5 goes to zero,
5 then f is equal to zero?

6 MR. DHIR: Right.

7 CHAIRMAN WALLIS: But it is off the graph?

8 MR. DHIR: Right. You got to -- nucleation
9 temperature, that's what we say.

10 This is one example how that f does it.
11 They assume the correct size is 5 micron and then you
12 see how -- when we would change. If I just kept 1, T_{ONB}
13 would be only what you have here. ΔT_{ONB} over ΔT
14 be homogeneous nucleus and we're plotting here. And
15 you're close to .03 or .02. And because of the f
16 function and eventually when this goes to zero, you're
17 going to homogeneous nucleation temperature. That's
18 how we effect the whole curve.

19 MR. BANERJEE: How well does Davis and
20 Anderson correlation true?

21 MR. DHIR: It doesn't -- you know, if we
22 account for their pressure -- it works okay. Not
23 Davis and Anderson, but that was --

24 CHAIRMAN WALLIS: What happens if you use
25 π ?

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1 MR. DHIR: Beg pardon? Just one second.

2 CHAIRMAN WALLIS: You won't wet the
3 surface at all?

4 MR. DHIR: Your question was -- Davis and
5 Anderson doesn't do it that well with just pi.

6 Yes, what was the question?

7 CHAIRMAN WALLIS: If pi is pie, the liquid
8 doesn't wet the surface at all?

9 MR. DHIR: Right. We have gone up to 9
10 degree even, now you can go on further. You go to
11 zero.

12 CHAIRMAN WALLIS: Well, it goes to 1 and
13 your correlation doesn't go to zero.

14 MR. DHIR: Right. One is just normalized.
15 You know, with homogeneous nucleation. So your cluster
16 size would determine.

17 MR. RANSOM: Isn't value T home?

18 MR. DHIR: Homogeneous nucleation.

19 MR. RANSOM: Oh, homogeneous nucleation.

20 CHAIRMAN WALLIS: So the water boiling on
21 mercury or the contact angle is pi? It also has no
22 nucleation centers.

23 MR. DHIR: Right. Right.

24 CHAIRMAN WALLIS: All right. We need to
25 move along then.

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1 MR. DHIR: Okay. Then we look at
2 nucleation site density.

3 MR. KRESS: Now I want you to pronounce
4 that. I want you to pronounce that name.

5 MR. DHIR: I can pronounce it.
6 Kocamustafaogullari.

7 CHAIRMAN WALLIS: Yes, it's easy. Can you
8 do it?

9 MR. KRESS: No.

10 MR. DHIR: Okay. Oh, maybe 18, 20 years
11 ago these guys predicted that nucleation site density
12 would correlate like this or the number density was
13 normalized -- which was taken from FRIGG correlation.
14 And now you can see FRIGG correlation is for pool
15 boiling, not for flow boiling and the characteristic
16 site would differ anyway.

17 So that is their model.

18 Wang at UCLA did theirs about 7, 8 years
19 ago. We looked at pool boiling and we came up with
20 number density like this. It depends on contact angle.
21 And again, contact angle was very important variable,
22 that's what we found.

23 CHAIRMAN WALLIS: What is D_c ?

24 MR. DHIR: D_c is the captured --

25 CHAIRMAN WALLIS: Oh, that one. Okay.

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1 MR. DHIR: And it's mostly proportionate
2 to superheat.

3 CHAIRMAN WALLIS: It's surface perimeter.

4 MR. DHIR: And so the superheat, you see
5 the power is 6 and very highly nonlinear. If you're
6 now going to put it nucleation site, then see how do
7 you hope to predict heat flux.

8 CHAIRMAN WALLIS: This is a very
9 dimensional correlation.

10 MR. DHIR: Yes, it is dimensional. The
11 cavity sizes and micron, and so forth.

12 So this is a picture we see, same surface,
13 copper and two different contact angles. Same
14 superheat. And left hand side 30 degree contact
15 angles, right inside is 90 degrees.

16 CHAIRMAN WALLIS: Same history, too.

17 MR. KRESS: How did you vary the contact
18 angle on it?

19 MR. DHIR: We discussed earlier, but what
20 we have is the copper surface, we oxidize it.

21 MR. KRESS: You oxidize. Okay.

22 MR. BANERJEE: But nucleation site then
23 simply is changed, too.

24 MR. DHIR: Yes, that's what I'm saying.
25 Site density is strongly dependent on contact angle.

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1 CHAIRMAN WALLIS: This is with all the
2 cavities active because you know you can -- you know,
3 snuff them out by boiling and then cooling down and
4 pushing the liquid into the holes.

5 MR. DHIR: Yes. But when you go to higher
6 superheat that effect is gone. But clearly you can
7 see the difference. You know, I have refuted this
8 with different number of students. So I may --
9 personally to ask them, give them a test score and
10 then do it. And every time we see this --

11 CHAIRMAN WALLIS: You can do this snuffing
12 experiment easily in there.

13 MR. DHIR: Yes, you can do it.

14 CHAIRMAN WALLIS: But there's no gas
15 involved in the cavities. It's all just pure liquid?

16 MR. DHIR: There is always some trapped
17 gas to start with, yes. And you can -- play games
18 like that, you can have the cavities, then pressurize
19 it or some you could subcool and then kill them. They
20 will not come --

21 CHAIRMAN WALLIS: Right.

22 MR. SCHROCK: These equation that's per
23 square centimeter from your graphs --

24 MR. DHIR: Right.

25 MR. SCHROCK: Per square centimeter.

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1 MR. DHIR: In the literature you will see
2 there are lots of -- and information with respect to
3 flow boiling, especially in nucleation site density.
4 Many people believe that all nucleation site density
5 is effected by flow rate, it's effected by subcooling.
6 But we find none of those effect it. The key variable
7 is while superheat then contact angle. Okay.

8 And these are the data you see for our two
9 flow velocities and fixed contact angle. And I can see
10 there's hardly any effect of flow velocity.

11 MR. BANERJEE: And you just counted the
12 sites?

13 MR. DHIR: Yes, photograph like I showed
14 you and you can know the area and you can see how many
15 are there.

16 MR. SCHROCK: You take multiple
17 photographs and get the average then.

18 MR. DHIR: Repeat them.

19 MR. SCHROCK: Right. Yes.

20 MR. DHIR: It's a tedious job. And this
21 is now flat plate, but two different subcoolings. So
22 there's no, you know, there's a clear distinction on
23 two subcoolings and we don't see any effect as long as
24 your contact angle is fixed and -- so that will simply
25 life some ways that you have only two variables.

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1 And this is what we see from our
2 experiments which we have done. And this is all of
3 the data we got.

4 CHAIRMAN WALLIS: It's really four bounds,
5 though.

6 MR. DHIR: Beg pardon?

7 CHAIRMAN WALLIS: Five. It's five groups.

8 MR. DHIR: Right. Five different contact
9 angles.

10 MR. DHIR: Okay. This line and this dotted
11 line is the correlation developed currently here from
12 pool boiling data. And that correlation was for --
13 superheat greater than about 15 degrees corresponding
14 to cavity size of about 5 --

15 CHAIRMAN WALLIS: So if you didn't control
16 contact, you could go for a factor of thousands or so?

17 MR. DHIR: Yes, sure. That's why boiling
18 curve shift all over the plate. That's the key
19 ingredient. Although -- cavity size of cavities, side
20 density doesn't play any role.

21 CHAIRMAN WALLIS: We should have both of
22 you together.

23 MR. DHIR: We have. We were there in
24 Illinois in May. We were there and there were -- so
25 we had good discussion argument.

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1 CHAIRMAN WALLIS: Was it a refereed
2 discussion?

3 MR. DHIR: It will be published.

4 CHAIRMAN WALLIS: Okay. Let's move on.

5 MR. DHIR: Yes. Okay. So even you see
6 there's a big variation in the number density with
7 contact angle. And we would look at
8 Kocamustafaogullari data and predict that, that's what
9 he find.

10 So for all the data we have developed a
11 correlation and -- less than 15 degrees number density
12 varies as delta T to the square. But superheats it's
13 delta T to the 5.3 power. Okay.

14 CHAIRMAN WALLIS: Next one shows the
15 correlation.

16 MR. DHIR: And then the --

17 MR. SCHROCK: What happens to them at 15
18 degrees?

19 MR. DHIR: What 15 degrees.

20 MR. BANERJEE: They would discontinuous.

21 MR. SCHROCK: They're discontinuous.

22 MR. DHIR: Yes, they're the discontinuous.
23 Because it depends on the -- you know, the surface.
24 The superheat becomes large and then they just take
25 off.

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1 So you can see it's lots of data, lots of
2 time was spent on this. And this is all the data we
3 have and it's easy to get an error in this, especially
4 when you're -- say over 1 centimeter square area, you
5 have one cavity or two, you're a factor of 2 off. And
6 so your densities and you see some scatter out here.
7 And then high heat flux as the bubbles start to -- is
8 very difficult to delineate how many cavities are
9 there. So you see scatter out there.

10 This scatter is puzzling. This is the
11 data we took very early and we found many more
12 cavities than you will suspect from all the other
13 data. And that's when we were just starting to
14 experiment. My guess is that we had too much gas in
15 the water, we had not aerated the water. We have not
16 gone back and reproduced this data, so it's still
17 there.

18 MR. BANERJEE: This is all your own data?

19 MR. DHIR: This is all our own data, but
20 we -- as I showed you earlier, the data of Klausner --
21 we got.

22 See, most people don't give you contact
23 angle or superheat. And if you don't have it, you can
24 put it wherever you want to. And so we tried to void
25 it.

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1 CHAIRMAN WALLIS: Right. Right.

2 MR. DHIR: Next we go to bubble diameter
3 and departure and lift off. And so what we find, here
4 we plot bubble diameter departure. Departure means the
5 bubbles start to slide on a nucleation site. Lift off
6 is when it takes off, now going to the surface. Okay.

7 And here this typical data. We have more
8 sets of data, but this for flat plate with velocity of
9 about 35 centimeters per second and three different
10 subcoolings.

11 As we increase the subcooling you can see
12 the bubble diameter departure. As we increase the
13 wall superheat it increases. We relate this to the
14 inertia as bubble goes faster, there's more liquid
15 inertia to be encountered. Bubble go to slow down
16 with condensation, inertia is less.

17 And similar -- so we find bubble diameter
18 departure going about square root of wall superheat
19 and that's lift off diameter, which is larger than the
20 departure diameter. So the bubbles grow as they move
21 along the surface.

22 MR. BANERJEE: Why is this vertical line,
23 like vertical scatter?

24 MR. DHIR: It's a measurement arrow you
25 see once sometimes bubbles munch.

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1 MR. BANERJEE: I see. It's not just the
2 distribution of the --

3 MR. DHIR: Right. No, no. And this is
4 from flat plate.

5 MR. BANERJEE: Right.

6 MR. DHIR: Now you could do some cavity
7 experiments which you are doing also, you can get very
8 clean data, the scatter won't be there.

9 CHAIRMAN WALLIS: Well, this next one you
10 have a characteristic link which depends on G?

11 MR. DHIR: Yes.

12 CHAIRMAN WALLIS: Why is that?

13 MR. DHIR: Because even in the wall the
14 bubble is attached there is a buoyancy actually.

15 CHAIRMAN WALLIS: So this is only for
16 vertical upflow?

17 MR. DHIR: Vertical upflow.

18 CHAIRMAN WALLIS: If you have vertical
19 downflow, it would be quite different.

20 MR. DHIR: Different, right.

21 CHAIRMAN WALLIS: Horizontal flow would be
22 quite different?

23 MR. DHIR: That's right.

24 CHAIRMAN WALLIS: And we have done
25 separate study which shows those things.

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1 MR. BANERJEE: The microgravity?

2 MR. DHIR: Yes, different.

3 CHAIRMAN WALLIS: Yes. If you go to --
4 well, microgravity everything goes off scale here.

5 MR. DHIR: This one would go off scale,
6 but you see that lift becomes extremely important,
7 microgravity.

8 CHAIRMAN WALLIS: So this is a big
9 correlation without much mechanism behind it?

10 MR. DHIR: That's right.

11 CHAIRMAN WALLIS: Right.

12 MR. DHIR: We have -- I'm not showing
13 here. Where we're doing the medical simulations and
14 data from that, we can do the correlation. But this is
15 just from this work.

16 Basic physics is that superheat is
17 important, subcooling is important and that's all I
18 can say.

19 MR. BANERJEE: The length scale is surface
20 tension to some sort of --

21 MR. DHIR: Buoyancy, yes. Typical end
22 scale in boiling.

23 MR. BANERJEE: But if G is zero then you
24 have a problem.

25 MR. DHIR: As I was saying again, it's

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1 very specific to upflow, 1G.

2 CHAIRMAN WALLIS: And this surface tension
3 comes in because the bubble is hanging onto the
4 surface.

5 MR. DHIR: Hanging on to the surface and
6 that's what is --

7 CHAIRMAN WALLIS: I think it would depend
8 on the contact angle then.

9 MR. DHIR: Yes, this is -- again, this is
10 a 30 degree contact angle. Contact angle is a
11 variable.

12 CHAIRMAN WALLIS: Oh, you have a
13 correlation involving --

14 MR. DHIR: Not as yet.

15 CHAIRMAN WALLIS: Okay.

16 MR. DHIR: We're not done with that. So
17 this is only for 30 degree, one contact angle,
18 although it should be stated there.

19 Now we just said okay, let's go to the --
20 and see what's out there, and this is what we find.
21 This is the velocity we got from our previous graph
22 which I showed you --

23 CHAIRMAN WALLIS: The curve is yours?

24 MR. DHIR: Yes. And this is all the data.
25 You know, some people don't give you again, superheat,

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1 whole subcooling, local values and just see how much
2 scatter is off all the data, but it seems like the
3 velocity effect we're getting seems to be okay.

4 But to put all this data in perspective,
5 we need to have, you know, information about what the
6 superheat, local superheat was, subcooling was,
7 contact angle was.

8 MR. BANERJEE: So this Unal's data is the
9 one that Lahey used?

10 MR. DHIR: Right. Unal went to high
11 pressures, too, you see. It's a larger angle
12 pressure. And Unal's data is here.

13 CHAIRMAN WALLIS: It works best a high
14 pressure.

15 MR. DHIR: Yes. But we don't know what
16 the contact angle is for that case. Okay.

17 MR. SCHROCK: You probably could get a
18 reasonable handle on it knowing the materials, huh, in
19 Unal's data?

20 MR. DHIR: Approximate, yes. Contact
21 angle, but not superheat.

22 MR. SCHROCK: Yes, not superheat.

23 MR. DHIR: Yes, and subcooling.

24 MR. BANERJEE: What is that curve you just
25 fitted it?

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1 MR. DHIR: We just plotted our curve, that
2 velocity effect I got from the previous viewgraph, and
3 that's just --

4 MR. BANERJEE: I see.

5 MR. DHIR: Without subcooling effect or
6 superheat or contact angle. Just to see. If I had
7 just done this, how far I could be off. And it also
8 shows you that the velocity set probably is taken
9 into--

10 CHAIRMAN WALLIS: Okay. I think we have
11 to move on. There's a fantastic amount of information
12 here.

13 MR. DHIR: So next is OSV. There's number
14 of correlations starting with Bowring, '62 and it's
15 kind of dimensional correlation. This delta _{OSV} means
16 that what is the liquid subcooling when the bubbles
17 start to migrate into the bulk. So -- and they're
18 relating -- flux and velocities.

19 And Levy did -- he accounted for the
20 turbulent profile in the thermal boundary layer.

21 Dix correlated again delta _{OSV}, heat flux,
22 single heat transfer coefficient.

23 Saha & Zuber which we were talking about
24 earlier, this was basically telling you when OSV was
25 not correct, but heat flux. It doesn't tell you heat

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1 transfer coefficient. People are using it.

2 And Zeitoun recently came up with a
3 different correlation.

4 But you can see all of them somehow form
5 a -- number which is --

6 CHAIRMAN WALLIS: D.J. I need to replace
7 your battery. That's why it's clicking.

8 (Whereupon, at 5:01 p.m. off the record
9 until 5:02 p.m.)

10 MR. DHIR: We are only halfway through.

11 MR. BANERJEE: But you've still got an
12 hour.

13 CHAIRMAN WALLIS: You've got an hour.

14 MR. DHIR: Okay. I'll move quickly. But
15 this is --

16 CHAIRMAN WALLIS: What we found is we
17 didn't see this before. We saw some stuff, but most of
18 this wasn't in it.

19 MR. DHIR: So we have looked at -- you
20 know, from our data where the OSV occurs initially and
21 those are the data you see here. And -- given
22 location, this increase the flow rate, you need to
23 have high heat flux. That's what it does.

24 And if you increase the subcooling, then
25 also you need higher heat flux.

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1 MR. BANERJEE: How are you defining onset
2 of significant void here?

3 MR. DHIR: When the bubbles start to
4 migrate.

5 MR. BANERJEE: Okay.

6 MR. DHIR: And some people have defined
7 very differently, so there's always that struggle we
8 had what did they mean. Some people may have the void
9 fraction when they see some increase in void fraction,
10 that's what -- they would call. But then that's way
11 downstream you see.

12 MR. BANERJEE: Even if you have a
13 millimeter bubble on a 1 centimeter diameter pipe on
14 the wall, then you've got a void fraction of about 10
15 percent that's due to the millimeter bubble?

16 MR. DHIR: Right.

17 MR. BANERJEE: It's not trivial.

18 CHAIRMAN WALLIS: Because the ones on the
19 wall are more significant?

20 MR. BANERJEE: Well, they appear --

21 CHAIRMAN WALLIS: That's right, so they're
22 a lot --

23 MR. DHIR: So our proposal is based on
24 this, that if the bubbles just before departure is
25 smaller than the thermal layer thickness, then

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1 presumably the bubble will start to slide and
2 eventually detach at high subcoolings. If on the
3 other hand bubble is larger, then condensation
4 occurring, then the liquid subcooling has to be less
5 for bubble to grow to its desired size.

6 CHAIRMAN WALLIS: There's no further
7 mechanics in this?

8 MR. DHIR: No. At the moment it's just--

9 CHAIRMAN WALLIS: I would think that
10 motion of a bubble would depend on the mechanics.

11 MR. DHIR: Right. See, that's again --
12 it'll take some time. And we are looking at numerical
13 simulation and then single bubble experiments. But
14 that's funded through NASA. And that gives us this
15 information. But right now it's amazing hypothesis.
16 But we tested this hypothesis by taking all the data,
17 Dix's data, we have all the water data and flat plate
18 and rod bundle. And we found that this DD over Δ
19 correlated with the constant -- empirical constant C
20 like this. So our correlation is very simple
21 correlation, it's like dimension less wall superheat
22 if we could do a constant, then OSV occurs.

23 And that constant we have gotten
24 empirically. And it includes Dix's data, all data with
25 freon and we have Bowring's data you'll see in the

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1 next viewgraph, and it seems to do for all of those
2 data more reasonably well.

3 Bowring's data at high pressures and Dix's
4 for the freon, and our data.

5 So up to now this is simply empirical.

6 Bubble release frequency, how do we get
7 it. Here I think you can see what happens to the
8 bubbles as they grow. I mark here this arrow. And
9 here the bubble is growing, start to grow. This is the
10 bubble which is growing. And now you see clearly this
11 bubble is --

12 CHAIRMAN WALLIS: It looks like 2 bubbles.

13 MR. DHIR: Well, this a reflection.

14 CHAIRMAN WALLIS: Oh.

15 MR. DHIR: And growing, growing. You see
16 the arrow is almost wanted -- cavity is. And now it
17 start to slide. This is where the bubble was
18 initially, now it's moved over. It continues to
19 slide, slide and at that point it lifts off. And now
20 after waiting --

21 CHAIRMAN WALLIS: And another one starts?

22 MR. DHIR: Beg pardon?

23 CHAIRMAN WALLIS: Then another one starts?

24 MR. DHIR: Another one starts.

25 MR. BANERJEE: But actually, you know as

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1 soon as it slides it seems to be within the second
2 slide already slightly lifted off if you look at the
3 reflection.

4 MR. DHIR: Right. You know, that is a key
5 question. Is there a layer underneath so create a
6 liquid layer. And I don't know. That's a question I
7 have myself. That is a bubble sliding on a thin film
8 of liquid or is still in contact with the solid
9 direct.

10 MR. BANERJEE: Well, if it is, then it's
11 violating a no slide boundary condition.

12 MR. DHIR: Right.

13 MR. BANERJEE: Unless it's rolling.

14 MR. DHIR: Right. That's what Steve --

15 MR. BANERJEE: Steve Davis.

16 MR. DHIR: Steve Davis, he said that maybe
17 the bubble is rolling, but it's very hard to --

18 MR. KRESS: It didn't look like the bubble
19 changed sides much during the slide period.

20 MR. DHIR: Oh, it grows.

21 MR. KRESS: You think -- it didn't look
22 like it grew.

23 MR. DHIR: No, it grows. And if you look
24 at -- maybe it's not growing. It's bigger than the
25 previous and then eventually --

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1 MR. KRESS: It just maybe from here --

2 MR. DHIR: Yes, it grows. And I show you
3 those lift off diameters, they're bigger. About 50
4 percent.

5 CHAIRMAN WALLIS: Okay. Okay. So you can
6 get a frequency from this?

7 MR. DHIR: Yes, right.

8 MR. SCHROCK: You're comparing with Dix
9 and Bowring, and as I remember both of them, they
10 extrapolate the axial void profile to zero void and
11 say that's the point.

12 MR. DHIR: Right.

13 MR. SCHROCK: So it's a little different
14 meaning than yours.

15 MR. DHIR: Right, there is some
16 difference. Right. That's the key issue we have.

17 And the waiting time at least you can see
18 here. That is important because in some situations
19 waiting time, transient conduction may have -- waiting
20 time. And this is based on the data we got for
21 different subcoolings and superheats.

22 Again, these -- what I'm going to show you
23 here is not finalized. This is the stage where we are.

24 MR. BANERJEE: What do you mean by the
25 waiting time here?

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1 MR. DHIR: Once the bubble leaves the
2 nucleation site, another bubble doesn't form right
3 away.

4 MR. BANERJEE: Okay.

5 MR. DHIR: You wait for a while --

6 CHAIRMAN WALLIS: What's BG?

7 MR. DHIR: BG is the growth period of the
8 bubble at the nucleation site.

9 CHAIRMAN WALLIS: Before it slides?

10 MR. DHIR: Slides, right.

11 So key thing we are saying is that with
12 subcooling -- subcooling increases at a given
13 superheat, you see the waiting times become longer.
14 And at high superheats subcooling plays little role,
15 waiting times become quite small in comparison to the
16 growth time.

17 CHAIRMAN WALLIS: I presume where there's
18 an intercept at one here where the waiting time is
19 everything, that it's always waiting and there's this
20 very occasional flip.

21 MR. DHIR: Right.

22 CHAIRMAN WALLIS: That's when there's a
23 certain critical delta T for something to happen on
24 the top there.

25 MR. DHIR: Top, right. That's what would

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1 happen. I was hoping that this will go out to our OSV.

2 CHAIRMAN WALLIS: It doesn't?

3 MR. DHIR: I don't know. We have to test
4 it. I asked them to test it. See if it goes to OSV
5 condition. It should go to, you know, 1.

6 And this is the growth period -- growth
7 period with -- subcooling and that's what the
8 correlation we have so far. Again, one contact angle,
9 30 degrees.

10 You know, generally the bubbles slide --
11 can slide quite a while if you did not have any
12 nucleation site on their part. This is a separate
13 experiments we did where we had just a single bubble
14 sliding over a surface, no other nucleation site. And-
15 -

16 CHAIRMAN WALLIS: This is still boiling,
17 this isn't an air bubble or something like that?

18 MR. DHIR: No, no, no boiling. One on a
19 single nucleation site.

20 And this bubble, as you can see, for 30
21 centimeter velocity has slide almost 18 millimeters
22 before it lifted off.

23 MR. BANERJEE: How is the velocity defined
24 here?

25 MR. DHIR: The distance the bubble travels

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1 from the nucleation site.

2 MR. BANERJEE: Is the velocity of the
3 bubble?

4 MR. DHIR: Bubble.

5 MR. BANERJEE: Not the velocity of the
6 fluid?

7 MR. DHIR: No, no. Velocity of the fluid
8 is the parameter here. This is fluid velocity.

9 MR. BANERJEE: For which?

10 MR. DHIR: This is the fluid velocity.

11 MR. BANERJEE: Ah, so that's what I was
12 asking.

13 MR. DHIR: No, no, this is liquid
14 velocity.

15 MR. BANERJEE: How is that defined? What
16 velocity is it? Is it bulk velocity?

17 MR. DHIR: Bulk velocity of the liquid.
18 And I'm plotting the distance it slides as a function
19 of the bulk velocity. But we can get the --

20 MR. BANERJEE: Is this for a specific
21 bubble size, right?

22 MR. DHIR: Right, for these conditions.
23 Single bubble -- liquid is saturated.

24 MR. BANERJEE: How big was the bubble?

25 MR. DHIR: To start with it's about 1.5

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1 millimeter or so.

2 CHAIRMAN WALLIS: Well, now we get to a
3 bit that we got a report on, the bubble collapsing.

4 MR. DHIR: Right.

5 CHAIRMAN WALLIS: That looks like a
6 relative straight forward.

7 MR. DHIR: Straight forward, right.
8 Should I go over it? No.

9 CHAIRMAN WALLIS: Quickly.

10 MR. DHIR: Everything is quick.

11 This is another picture of the bubbles are
12 formed on the heater surface. You look at this bubble
13 and this bubble detaching from the surface. It has
14 detached. And now we are looking at its size and its
15 position. And these are .8 milliseconds apart, these
16 photographs.

17 And knowing the position we can calculate
18 its velocity, local velocity and we also know from the
19 photograph what the size of the bubble is.

20 CHAIRMAN WALLIS: So you know how far it
21 is from the surface?

22 MR. DHIR: Oh, maybe a few millimeters, 2
23 or 3 millimeters.

24 CHAIRMAN WALLIS: You don't measure that,
25 although the reflection probably tells you.

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1 MR. DHIR: Reflection tells us where you
2 start with.

3 CHAIRMAN WALLIS: It does tell you how far
4 it is from the surface?

5 MR. DHIR: Yes, right, exactly. And
6 that's how you calculate the distance.

7 CHAIRMAN WALLIS: Yes.

8 MR. DHIR: And knowing the bubble size as
9 a function of time, you can deduce what the heat
10 transfer coefficient should be.

11 And these are some of the correlations
12 which are --

13 MR. BANERJEE: Provided you know the --

14 MR. DHIR: Liquid subcooling.

15 MR. BANERJEE: Yes, at that point.

16 MR. DHIR: At that point. But we have
17 measured that liquid subcooling with a thermocouple.
18 Not during that experiment, but with the same
19 conditions we have measured what the temperature.

20 MR. BANERJEE: So the average?

21 MR. DHIR: Average.

22 MR. RANSOM: These are the overall heat
23 transfer coefficient I guess. Now you could
24 envisualize it as having a heat transfer coefficient
25 on the interior of the bubble and, you know, heat

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1 transfer coefficient on the exterior, and some
2 condition at the interface on interfacial temperature.
3 And I gather this is from saturation temperature to
4 whatever liquid temperature surrounds the bubble?

5 MR. DHIR: Right.

6 MR. RANSOM: Yes.

7 MR. DHIR: But the pressure in the bubble
8 is, you know, not much different than outside. It's
9 large bubble relatively, unless it becomes extremely
10 small. But by that time we call it zero size.

11 MR. RANSOM: Are most of these limited by,
12 say, the conduction in the liquid.

13 MR. DHIR: Yes, of course.

14 MR. RANSOM: Pretty much, I guess. What's
15 the mechanism inside the bubble?

16 MR. BANERJEE: It's all pure steam, right?

17 MR. DHIR: Steam bubble.

18 MR. RANSOM: And rushing to the interface.

19 CHAIRMAN WALLIS: Rushing to the
20 interface.

21 MR. DHIR: Right. So there is assumption
22 there.

23 MR. SCHROCK: The heat transfer
24 coefficient in the initial number has a delta T. I
25 guess you've already responded to that. It's the bulk

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1 liquid temperature and --

2 MR. DHIR: Local temperature. Local
3 liquid temperature.

4 MR. SCHROCK: And not a cross section?

5 MR. DHIR: No, where the bubble is.

6 CHAIRMAN WALLIS: That's the delta T --

7 MR. SCHROCK: I don't know what that
8 means.

9 MR. DHIR: Okay.

10 MR. SCHROCK: You don't know what the
11 temperature structure is in the cross section?

12 MR. DHIR: That's what I said, but we
13 measured the temperature distribution in the liquid.

14 MR. BANERJEE: But it's only an average.

15 MR. DHIR: Average temperature we measure.
16 I show you the temperature profiles in the liquid.

17 MR. SCHROCK: But that's axial.

18 MR. DHIR: Normal. No, no. That's normal
19 to the surface. Very early I show you liquid
20 temperature profiles normal to the surface.

21 MR. SCHROCK: I thought that was axial.

22 MR. DHIR: No, normal.

23 CHAIRMAN WALLIS: Anyway, there's a whole
24 other correlations here.

25 MR. BANERJEE: What is data?

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1 MR. DHIR: Data is the ratio of the
2 bubble, instantaneous bubble diameter to its initial
3 diameter.

4 CHAIRMAN WALLIS: And -- numbers are just
5 surrogate for T, it's a dimensionless time.

6 MR. DHIR: Right. And the time starts when
7 the bubble detaches.

8 CHAIRMAN WALLIS: Right.

9 MR. DHIR: So it's local liquid
10 temperature, not average temperature.

11 See, the temperature is changing. Let's
12 say this is the wall, the temperature's decreasing
13 normal to the surface. So we have a thermocouple with
14 which we get temperature distribution before we look
15 specifically at one bubble here.

16 MR. SCHROCK: Okay. So the wall is the
17 vertical boundary?

18 MR. DHIR: Vertical line here.

19 MR. SCHROCK: And you've measured
20 temperature and function of --

21 MR. DHIR: Temperature distribution.

22 MR. SCHROCK: Y, for example, and --okay.

23 MR. KRESS: And we assume the bubble is
24 always at the one position?

25 MR. DHIR: This is one bubble I'm showing.

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1 There's another bubble at different position.

2 CHAIRMAN WALLIS: Moving relative to the
3 fluid, that's where H comes from.

4 MR. KRESS: Right.

5 MR. SCHROCK: When you speak of
6 thermocouple in this -- in this bubbly field --

7 MR. DHIR: Right.

8 MR. SCHROCK: -- you're getting time
9 average of something --

10 MR. DHIR: Right.

11 MR. SCHROCK: -- sometimes the bubble is
12 on it.

13 MR. DHIR: Bubble when we know the
14 temperature goes up that the bubble crosses that
15 thermocouple, we know that. That's not we don't take
16 care of it.

17 MR. SCHROCK: No. But some fraction of
18 the time the thermocouple is influenced by the vapor,
19 not the liquid.

20 MR. DHIR: Right. Right.

21 MR. SCHROCK: Although it probably remains
22 wet.

23 MR. DHIR: But this is, again, a time
24 average.

25 MR. SCHROCK: Yes.

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1 MR. DHIR: That's what we're using.

2 MR. SCHROCK: Anyway, that defines what it
3 means.

4 CHAIRMAN WALLIS: And we're moving along.
5 You have further mechanism you account for the thermal
6 boundary layer effect?

7 MR. DHIR: Right. But keeping -- we are
8 saying is that as the bubble is condensing, the
9 thermal boundary layer thickens and that has to be
10 counted for.

11 CHAIRMAN WALLIS: Right.

12 MR. DHIR: In the past it has not been
13 done so. And our correlation, I'm going to jump to the
14 correlation now.

15 CHAIRMAN WALLIS: It's much better than
16 anybody else's except the Sideman ones.

17 MR. DHIR: Sideman, right.

18 CHAIRMAN WALLIS: Which doesn't have your
19 corrections.

20 MR. DHIR: No, it does not.

21 CHAIRMAN WALLIS: It's much simpler, but
22 it still works as well as yours.

23 MR. DHIR: Works almost, yes.

24 And the key premise we have is that as the
25 bubble shrinks, the thermal boundary layer is actually

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1 thicker than it would be if it did not shrink. And so
2 we think that -- number is effected by how long the
3 condensation has been going on along the bubble
4 surface.

5 MR. BANERJEE: The only thing is the
6 exponent on the --

7 MR. DHIR: Right.

8 MR. BANERJEE: Of course, the bubbles are
9 fairly small, but usually for a presurface problem
10 that would be to the half.

11 MR. DHIR: Presurface, that's not
12 presurface.

13 MR. BANERJEE: Well, it depends on how big
14 the bubble. If you have circulation around the
15 bubble, you wouldn't get -- that's a solid boundary
16 condition.

17 MR. DHIR: Right. But see the range of
18 numbers we have used --

19 CHAIRMAN WALLIS: The numbers, it doesn't
20 vary very much.

21 MR. DHIR: Right.

22 MR. BAJOREK:

23 MR. BANERJEE: So you probably should not
24 show that because that's surely something which any
25 reviewer will jump on, including Gary Leedle and

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1 people like that.

2 CHAIRMAN WALLIS: Don't send it to him
3 then.

4 MR. BANERJEE: Because it's a analytical
5 solution for, you know --

6 MR. DHIR: You have something?

7 MR. BANERJEE: In the book even.

8 MR. SCHROCK: You have a correlation then
9 which involves a transverse temperature profile which
10 you have found from your data, but is a variable that
11 the TRAC code doesn't have. So there's going to be a
12 problem in applying that correlation until they're
13 also given a basis for the transverse temperature
14 variation.

15 MR. DHIR: In other words?

16 MR. SCHROCK: It's a catch 22.

17 MR. DHIR: Right. But the question is,
18 firstly I want to know how with the physics we have.
19 The next question you're asking how do I implement it.

20 MR. SCHROCK: Yes.

21 MR. DHIR: And as I said, we have not
22 given that too much thought to that. That's all I can
23 say.

24 CHAIRMAN WALLIS: So can we move to the
25 next part, the void fraction?

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1 MR. DHIR: Okay. So --

2 MR. BANERJEE: Well, one question.

3 MR. DHIR: Okay.

4 MR. BANERJEE: The correlation that
5 involves the -- number and also the -- number.

6 MR. DHIR: Yes.

7 MR. BANERJEE: Now, that means that you're
8 looking at some fluid motion due to the collapsing
9 bubbles.

10 MR. DHIR: That's what we are seeing,
11 right. That as this bubble is shrinking, it's
12 carrying with this -- it's boundary layer around it is
13 thicker than it would be if it was just a solid --

14 CHAIRMAN WALLIS: Compresses the layers of
15 liquid around it.

16 MR. DHIR: Right.

17 MR. BANERJEE: But it's not moving very
18 rapidly.

19 MR. DHIR: No, they're moving.

20 MR. BANERJEE: It's relative to the
21 liquid.

22 MR. DHIR: The liquid, no. The velocity
23 of the liquid is much higher than the bubble velocity.

24 MR. BANERJEE: So wouldn't it strip off--

25 MR. DHIR: Again, this is maybe some

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1 mixing going on, but --

2 CHAIRMAN WALLIS: Can we move on to the
3 next --

4 MR. SCHROCK: Is your -- number the same
5 as Zeitoun?

6 MR. DHIR: Zeitoun. Where is Zeitoun?
7 Number he based on -- on the diameter. No, it's
8 different.

9 MR. SCHROCK: Different.

10 MR. DHIR: No, sorry -- number is same.
11 Same. Same.

12 MR. SCHROCK: And you measure time in that
13 from the onset of the bubble motion.

14 MR. DHIR: Motion, right. This zero is
15 when the bubble leaves the surface and starts to roll.

16 CHAIRMAN WALLIS: Well, I'll ask again if
17 we can move on to the next subject.

18 MR. BANERJEE: Trying to get on --

19 MR. DHIR: Get on what?

20 MR. BANERJEE: Never mind.

21 CHAIRMAN WALLIS: Well, there's so much
22 here that we haven't seen before. That last subject
23 was one we did get --

24 MR. DHIR: What did you see before? I
25 don't -- I don't know. I don't know the context.

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1 MR. BANERJEE: Well, the papers we have on
2 this discuss void fraction.

3 MR. DHIR: Oh, I see. Because there is
4 some papers you may not have seen.

5 MR. BANERJEE: Yes.

6 MR. DHIR: Okay. So I don't show you
7 anything with respect condensation?

8 CHAIRMAN WALLIS: No, that was in -- no.

9 MR. DHIR: The correlation and stuff.

10 CHAIRMAN WALLIS: Now void fraction.

11 MR. DHIR: Next is the void fraction. And
12 these are -- you see the photographs of boiling on the
13 flat plate. And at different heights from bottom.
14 Vapor film.

15 CHAIRMAN WALLIS: What's that got to do
16 with bubbles?

17 MR. DHIR: No, it's a two phase mixture.

18 MR. BANERJEE: Is it full of bubbles or is
19 it --

20 MR. DHIR: Bubbles, yes. Bubbles and
21 liquid mixture.

22 MR. BANERJEE: But it's not a film yet?

23 CHAIRMAN WALLIS: It's the extent of the
24 two phase --

25 MR. DHIR: Two phase mixture thickness

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1 should be there. And it's not a vapor film,
2 continuous vapor film. It's a mixture.

3 CHAIRMAN WALLIS: Oh, this is just a flash
4 and very --

5 MR. DHIR: Yes, yes, sure. It's one time
6 -- it changes. How this layer develops as you move
7 down stream. That's our key point here. And it
8 becomes thicker and thicker as you --

9 MR. BANERJEE: There's still subcooling
10 of--

11 MR. DHIR: Yes.

12 CHAIRMAN WALLIS: It seems to have a
13 structure, though. It's almost -- in all your models
14 I'm assuming these bubbles go off and behave in some
15 way, but you don't model this layer. So maybe the
16 layer itself is doing something, has waves on it or
17 whatever. Looks as if it's certainly not a smooth
18 layer.

19 MR. DHIR: It's not.

20 CHAIRMAN WALLIS: So --

21 MR. DHIR: But it keeps -- time also.

22 CHAIRMAN WALLIS: Well, that probably
23 effects things, too.

24 MR. DHIR: It's possible. Again, you can
25 start somewhere.

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1 CHAIRMAN WALLIS: Y is distance from the
2 wall?

3 MR. DHIR: Y is the distance from the wall
4 and alpha is the wall stretch, and average amount of
5 the span, right. Span boils average of the flat plat.

6 And the right hand side is basically you
7 see the edge of this two phased mixture layer as
8 observed from the movie and the gamma densitometer.
9 Gamma densitometer seems to correlate fairly okay.

10 MR. BANERJEE: From the movie how do you
11 get this?

12 MR. DHIR: Your picture, you see the
13 picture I showed you last time and now I look at the
14 edge.

15 MR. BANERJEE: Oh, just looking at the
16 edge?

17 MR. DHIR: Yes.

18 And this is the void fraction we talked
19 about earlier in the rod bundle. And looking at one
20 location. And how the rod bundle average basically
21 was.

22 CHAIRMAN WALLIS: So shooting through?

23 MR. DHIR: Through, right.

24 MR. BANERJEE: It says qualitative stuff.

25 MR. DHIR: I don't know if it's

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1 qualitative.

2 MR. BANERJEE: Qualitative in the sense
3 that it gives indication, but it's sampling many
4 different gaps, basically?

5 MR. DHIR: Gaps, yes. But it's average,
6 as I said, across.

7 So basically what you would expect as we
8 increase the heat flux at a given location, void
9 fraction goes up. And if you increase the flow
10 velocity, and even at a given heat flux the void
11 fraction goes down, as you would expect.

12 Okay. And if you extrapolate those
13 profiles, you see where -- would be and then we have
14 measured, they're not too far off but there's a
15 difference.

16 Next is kind of boiling curve, they're all
17 random. And basically you see single phase forced
18 convection stays there and then some point boiling
19 starts. After boiling starts the temperature of the
20 surface stays fairly constant. There's constant heat
21 flux.

22 Then we come to last task. So procedure
23 for calculating this wall heat flux and then coming
24 back to this plate of heat flux. And we say, that okay
25 you should give input, the geometry of the heater,

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1 marked velocity, contact angle, wall heat flux or wall
2 superheat, liquid subcooling and pressure. If you
3 give that kind of information and the fuel, whatever
4 fuel there is, then from the correlation we have
5 developed you can calculate ONB, OSV, bubble diameter
6 departure, lift off diameter, number density of active
7 sites. The sliding distance -- the force --
8 coefficient for force conduction. And then you look at
9 whether your lift damage is less than the spacing
10 between cavities. If it is, bubble damage is less
11 than the spacing, then you are in partial nucleate
12 boiling where the bubbles will slide and then lift
13 off. Or if the bubbles depart and lift off damage is
14 greater than the spacing, the bubbles will -- lift off
15 size and then leave.

16 CHAIRMAN WALLIS: Where do you predict
17 void fraction here?

18 MR. DHIR: Beg pardon?

19 CHAIRMAN WALLIS: Where do you predict
20 void fraction?

21 MR. DHIR: You don't predict one. I can
22 predict from the number density if you want what is
23 the wall void fraction.

24 CHAIRMAN WALLIS: This is of interest,
25 though, isn't it? Void fractions are interesting

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1 output from this?

2 MR. DHIR: No.

3 CHAIRMAN WALLIS: No.

4 MR. DHIR: Void fraction would be -- to
5 calculate void fraction it will provide the source --
6 how much vapor is coming into the bulk.

7 CHAIRMAN WALLIS: Well, I'm just trying to
8 make the bridge to the code. The code wants to predict
9 a void fraction, doesn't it?

10 MR. DHIR: Right.

11 MR. RANSOM: It seems -- I can't quite put
12 it together myself. But I mean it seems like it's an
13 attempt to utilize variables available and calculate
14 what regime you're in.

15 MR. DHIR: Right. You're in partial
16 nucleate boiling or wall nucleate boiling. I'm still
17 looking at the wall. I'm not looking at the flow. And
18 the void fraction in the flow to calculate you need to
19 know how much vapor I'm adding from the wall, what is
20 local liquid subcooling, how much vapor is condensing
21 and then you should be able to calculate how the void
22 is building up as you move downstream. We are not
23 doing that.

24 MR. RANSOM: That should be part of the
25 code calculation.

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1 MR. DHIR: Code calculation. Our part is
2 only to tell what is happening at the wall.

3 CHAIRMAN WALLIS: Well, I think your next
4 slide --

5 MR. RANSOM: They didn't ask you to get
6 rid of the partition, you're saying it's more of a two
7 step process now. You look at conditions based on
8 namely bulk variables and what you think you know
9 about the cladding, the contact angle, things like
10 that and calculate conditions at the wall. And then
11 from your other correlation or condensation we're
12 going to be able to calculate the net to the cell.

13 I think most things are there minus some--
14 you know, good questions on what is that temperature
15 profile which we need to the condensation, you know.
16 Are we going to -- getting to the right contact angle
17 and that higher pressure.

18 MR. DHIR: I don't -- first, I would say
19 that I would build this in your code as, you know, a
20 subroutine if you want to call it, and test it out as
21 can you predict it. We tested it out and again our
22 data and our correlation seems to work too good, I was
23 surprised. But, again, we want to do more of this
24 validation ourselves before I would say --

25 MR. BANERJEE: Yes, your correlation for

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1 the heat transfer coefficient condensation if it was
2 in the code would do difficulties because you have a
3 Fourier number there, which means you'd have to track
4 the bubbles to know what their lifetime is.

5 MR. DHIR: Right.

6 MR. BANERJEE: It would be much better if
7 you could get a heat transfer correlation independent
8 of your number.

9 MR. DHIR: You could -- average it out and
10 do it.

11 MR. BANERJEE: But we have to look at the
12 data in these cases and see.

13 MR. RANSOM:

14 MR. RANSOM: It would nice to fill this
15 out because --

16 MR. DHIR: Actually the spacing between
17 the cavities.

18 DR. MOODY: Like centimeters or --

19 MR. DHIR: They're really much smaller,
20 millimeter or even less sometimes.

21 MR. RANSOM: Yes, quite a bit is missing
22 from here like what you need to know about the
23 velocity shield and if you do need this time in order
24 to calculate the Fourier number --

25 MR. DHIR: mass velocity is there,

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1 geometries there, you calculate it.

2 MR. RANSOM: Right. Those are fine.

3 MR. DHIR: Yes.

4 MR. RANSOM: But, again, like the Fourier
5 number would be how do you evaluate it?

6 MR. BANERJEE: It doesn't track the
7 bubbles.

8 MR. RANSOM: Well, there's no way of doing
9 that in the codes at the present time.

10 MR. BAJOREK: You know the evaporation
11 rate, so you can get effective bubble lifetime out of
12 that. You can't integrate it down to zero. You're
13 going to have to truncate it, but you should be able
14 to get the --

15 MR. DHIR: It depends on your -- number,
16 too, you know. Because that's a variable.

17 MR. RANSOM: This would be a great model
18 for the old discon code that we wrote that you tracked
19 all the bubbles. And you did know all this kind of
20 information. But I doubt if you want to put that kind
21 of model in TRAC.

22 MR. DHIR: We have to sometime -- that
23 this is what we have developed and this is what TRAC
24 would do. Now how do we transfer this -- we have to go
25 through that part.

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1 MR. RANSOM: Yes.

2 CHAIRMAN WALLIS: I've been looking at
3 your slide. I think what you're doing in the next few
4 slides is just a pulling together what you told us
5 already --

6 MR. DHIR: Exactly.

7 CHAIRMAN WALLIS: -- into the pieces of
8 this.

9 MR. DHIR: That's right. Exactly.

10 CHAIRMAN WALLIS: So maybe we don't need
11 to go into the details.

12 MR. DHIR: Oh, but I can show that as
13 well.

14 CHAIRMAN WALLIS: That's right, because
15 you've sort of taken the relevant parts of your
16 previous pieces.

17 MR. DHIR: Right. Now we have gone
18 subprocesses, now we go to total processes.

19 CHAIRMAN WALLIS: Right. So how well does
20 it work?

21 MR. DHIR: Too well.

22 CHAIRMAN WALLIS: Too well.

23 MR. RANSOM: Makes you suspicious.

24 CHAIRMAN WALLIS: Very suspicious.

25 MR. DHIR: That's what bothers me.

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1 MR. BANERJEE: Must be plotting the same
2 thing against --

3 MR. DHIR: I hope not. It works too well.

4 So let me just show you what we are
5 calculating and how we are -- what is the transient
6 conduction heat load and what is the forced convection
7 contribution and how it changes at vault superheat.
8 Okay. So as you're going from partial to fully
9 developed nucleate boiling, the heat loads are
10 changing. It's not a set variable, set number. The
11 number is changing with superheat.

12 So here we plot the ratio of Q total, show
13 a Q to Q total what the wall --

14 CHAIRMAN WALLIS: These are all
15 predictions?

16 MR. DHIR: These are predictions, right.

17 CHAIRMAN WALLIS: There's no data to
18 compare?

19 MR. DHIR: No. These are predictions.

20 MR. BANERJEE: What are those points then?

21 MR. DHIR: Points are predictions.

22 CHAIRMAN WALLIS: The line is just a line
23 through.

24 MR. DHIR: Just a line through there
25 predictions.

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1 CHAIRMAN WALLIS: So there's no comparison
2 with data here?

3 MR. DHIR: I'll show, yes, later on.

4 But this is the transient conduction
5 contribution. I will say initially transient
6 conduction is zero before the boiling starts, just as
7 the boiling starts. Because transient conduction, this
8 comes from the bubble motion.

9 CHAIRMAN WALLIS: Yes.

10 MR. DHIR: And as we continue to high
11 superheat it wraps itself -- wall superheat divided by
12 wall superheat at OSV. And as you go to high superheat
13 about two times this delta OSV, very high heat flux.
14 About 70 watts per centimetered square, now most of
15 the heat is going through transient conduction. Very
16 little from forced conduction.

17 MR. SCHROCK: Looks like you could have
18 drawn a perfectly reasonable line to pick up that
19 stray point in --

20 CHAIRMAN WALLIS: Oh, come on. It's just
21 putting --

22 MR. SCHROCK: Isn't that a lot of
23 nitpicking?

24 CHAIRMAN WALLIS: No. Let's move on. Line
25 and points are the same.

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1 MR. DHIR: Right. And then we do a
2 different flow rate. And as you increase the flow rate
3 or flow velocity and you can see the forced convection
4 continues to persist for a longer superheat -- for
5 higher superheats.

6 MR. RANSOM: What are the differences
7 between the lines and the points?

8 MR. DHIR: Points are just -- points are
9 predictions from the model.

10 MR. RANSOM: Yes.

11 MR. DHIR: And lines are just -- through
12 the prediction.

13 MR. RANSOM: Why wouldn't you just draw
14 straight lines and connect them all? I mean --

15 CHAIRMAN WALLIS: Okay.

16 MR. RANSOM: It's quite confusing.

17 CHAIRMAN WALLIS: Now the next curve is
18 similar?

19 MR. DHIR: Yes. Next it's similar. These
20 are flat plate. No -- but next is important one.

21 There we now having the total, we split it
22 to how much is going into vapor production to the bulk
23 and how much is going to the liquid either through
24 condensation or just post convection, or some bubbles
25 taking some hit liquid with them. And so you see the

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1 first diamonds are what is going into the liquid
2 either through condensation or directly from the wall.
3 The open triangles are what is going to the bulk as
4 vapor. And the circles are condensation occurring at
5 the bubbles either back to the surface or sliding
6 along the surface.

7 MR. BANERJEE: That's the Qc sub atc.

8 MR. DHIR: ATC. Flow condensation
9 attached bubbles which are either sliding or sitting.

10 So initially you start with all the heat
11 is going into the liquid. And as you go to high
12 superheat and for this particular case, 70 percent --
13 60 percent is going into the liquid, about 30 -- about
14 40 percent is going into the vapor production. Out of
15 that 60 percent for the liquid, about 15 percent is
16 coming via condensation. Okay?

17 And a similar case we do it on the right
18 hand side for higher flow rate and lower subcooling.

19 CHAIRMAN WALLIS: Then you do the same
20 thing for the rod bundle?

21 MR. DHIR: For the rod bundle we do the
22 same thing. And, again, transient conduction and
23 forced convection at high superheats or upper --
24 sorry, not high superheats. Upper portion of the rod
25 bundle because as the liquid heats up it becomes

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1 saturated and you see that most of the heat is again
2 going through transient conduction. And very little
3 goes through forced convection, but early on -- at the
4 start you mostly by forced convection.

5 And, again, we have done two cases
6 different flow rates and different subcoolings.

7 CHAIRMAN WALLIS: I'm a little concerned
8 about all the heat going to transient conduction
9 because that -- I'm not sure I can figure out how that
10 would be modeled.

11 MR. DHIR: This model, because bubbles
12 merge. I show you earlier, the bubbles merger model.
13 We assume the bubbles when they are growing they merge
14 with the neighboring bubbles, form a big bubble and
15 leave.

16 CHAIRMAN WALLIS: They just leave the --

17 MR. DHIR: As the transient conduction is
18 occurring before the bubbles form and new second
19 bubbles form is the waiting period.

20 CHAIRMAN WALLIS: So the liquid's
21 completely replaced when they leave?

22 MR. DHIR: Right. But there's no flow.
23 This is another interesting thing. Here is that forced
24 convection, that dies down. And that was the data I
25 showed also. If you plot full boiling curve and

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1 forced convection, and you go to fully developed
2 nucleate boiling, there's no effect of flow field. And
3 that's what we are seeing.

4 And now to obtain --

5 MR. BANERJEE: This is a total?

6 MR. DHIR: Yes. Now we are breaking it up
7 now into evaporation, condensation and going into the
8 liquid in this graph. And as you can see what this
9 particular set of conditions, rod bundle, contact
10 angles would be 7 degrees. Initially the total heat
11 flux was -- initially all of the heat is going into
12 the liquid and has moved downstream. At about 70
13 centimeters downstream the liquid bulk becomes
14 saturated in this case. And at -- of the bundle we
15 see that now about -- only about, oh maybe 5 percent
16 or 10 percent of the energy is going to the liquid and
17 90 percent is going into vapor.

18 Condensation play a very small role and it
19 dies down just before the liquid becomes almost
20 saturated.

21 MR. RANSOM: The point where the liquid
22 becomes saturated in your case, though, the bulk is
23 still subcooled, I guess?

24 MR. DHIR: No, bulk is saturated.

25 MR. RANSOM: The bulk is saturated?

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1 MR. DHIR: Yes. Liquid is subcooled here.

2 MR. RANSOM: Well, by bulk you mean where
3 the bubble is located, though --

4 MR. DHIR: No, no, no. The liquid is
5 saturated.

6 MR. RANSOM: The entire --

7 MR. DHIR: Liquid, right. Right. That's
8 the whole point of this. That you're describing --

9 MR. BANERJEE: So once it's saturated,
10 then it's just split.

11 MR. DHIR: Right, to vapor production.

12 MR. BANERJEE: Was it heating up the
13 liquid and --

14 MR. DHIR: Transient conduction and then
15 it's --

16 MR. SCHROCK: When the bulk liquid is
17 saturated, there is the possibility that part of it is
18 subcollected and part of it's superheated? Liquid real
19 close to the wall is superheated.

20 MR. DHIR: Right.

21 MR. SCHROCK: Liquid near the core is --

22 MR. DHIR: But I'm saying there's no
23 subcooling. The liquid near the wall is always
24 superheated.

25 MR. SCHROCK: Would this model then

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1 transition to an accepted, say, saturated nucleate
2 boiling model?

3 MR. DHIR: That's what it is. Beyond this
4 point it's all saturated.

5 CHAIRMAN WALLIS: So now we get to the
6 comparison with --

7 MR. DHIR: Right.

8 CHAIRMAN WALLIS: This is rather like the
9 code assessment where no matter what's in the code --

10 MR. DHIR: This is just all the data we
11 predicted and experiments.

12 MR. BANERJEE: But this is total, right?

13 MR. DHIR: Total. Wall heat flux.

14 CHAIRMAN WALLIS: And, of course, your
15 model was itself deduced from the same experiments?

16 MR. DHIR: Yes, that's true. But the data
17 -- the pieces were -- you know, developed for each --

18 MR. BANERJEE: They were all consistent
19 and treated each of them well, the this is what you
20 would expect?

21 MR. DHIR: That's true.

22 CHAIRMAN WALLIS: All right.

23 MR. DHIR: And that's what I said, it
24 works too well. You need to test for different
25 pressures and different data points and see if --

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1 MR. BANERJEE: But you haven't --

2 MR. DHIR: No, not as yet. But you can
3 see, you know it's -- I think NRC got its money's
4 worth.

5 MR. BANERJEE: It's all self consistent.

6 MR. DHIR: Right. That's what it shows.

7 MR. KRESS: That's good, yes.

8 MR. BANERJEE: That's better.

9 MR. DHIR: So you can see all of the data
10 is within about 20 percent of what we get from the
11 model. And this is what is embarrassing in some sense,
12 it's too good.

13 And these are the data for flat plate.

14 CHAIRMAN WALLIS: It's probably the same
15 reason then, and you actually do experiments you used
16 to develop the model, so --

17 MR. DHIR: Right, but the model has now
18 bubble frequency, bubble diameter and now the
19 transient conduction, force convection.

20 MR. BANERJEE: It all hangs together?

21 MR. DHIR: It all hangs together.

22 CHAIRMAN WALLIS: Right.

23 MR. DHIR: And this is the data and this
24 is our prediction. And the good part was you see the
25 media tracking it when it becomes -- nucleate boiling,

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1 the number densities is there and the model where the
2 bubbles merge is included in there.

3 MR. BANERJEE: The only way to tell if it
4 works really is to do an experiment in a slightly
5 different diameter?

6 MR. DHIR: Right. Blind experiment, I
7 would want to do it. And that's a standard problem,
8 you do a blind experiment, give all that information.
9 Somebody does the experiment, see how good it comes
10 out. Maybe you should do the experiment.

11 MR. BANERJEE: I'll do the prediction.

12 CHAIRMAN WALLIS: I'll do the reviewing.

13 MR. DHIR: So this is for the rod bundle.
14 We tried to put it -- the wall temperature for the
15 heat flux is given. And these are the data which we
16 measured for this particular set of conditions. And
17 the triangles are the data and this is our prediction.
18 And we marked out so where we put it to ONB to occur--
19 experiments where we saw ONB occurred. OSV where we
20 occurred --

21 MR. SCHROCK: Is this the best comparison
22 or is this --

23 MR. DHIR: This is one we did. We have
24 not done many. These are the ones we have done. So
25 there was no attempt to make the -- show you the best

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1 one. But I was kind of surprised. I thought there was
2 much more difference, but it seems --

3 MR. BANERJEE: What if you did good job in
4 correlating each piece, right?

5 MR. DHIR: Within the limitations we have,
6 we did it. But, again, I'm not given credit --

7 MR. SCHROCK: Why does the rod bundle data
8 expand a much smaller range of heat flux?

9 MR. DHIR: Because power input, see, we
10 could not go too much power. We put in rod bundle,
11 you know, enthalpy is increasing. Heat flux -- total
12 heat input is about 60 kilowatts.

13 MR. SCHROCK: So it's just total surface
14 area.

15 MR. DHIR: Is so large, right.

16 See, the flat plate we were putting only
17 about 15 -- 10 to 15 kilowatts and here we are putting
18 about 50 kilowatts.

19 And should I describe the boron?

20 CHAIRMAN WALLIS: Yes, I think you do, and
21 we're doing very well.

22 MR. DHIR: So, you know, one of our -- as
23 I said, the rod bundle has degraded. So we said let's
24 -- why not use it before we discard it to study some
25 effect of boron. So we added boron to water, about

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1 7,000 ppm. Generally at the startup it's about close
2 to 5,000 I think. And so we looked at different --
3 velocity, liquid subcooling was kind of fixed, but
4 different heat flux. Up to 30 watts per centimeter
5 squared. And as I said, contact angle with boron in
6 the liquid we found was the same as was without boron.

7 CHAIRMAN WALLIS: And does boron get
8 deposited on the wall in the reactor?

9 MR. DHIR: Yes, that's an issue.

10 CHAIRMAN WALLIS: So as crud thickness
11 builds up on the --

12 MR. DHIR: On the rods, yes. That's an
13 issue. Axial offset anomaly.

14 MR. BAJOREK: One of the big problems
15 right now is called axial offset anomaly. And we
16 believe what's going on is hot assemblies are up into
17 the range where a good part of it is in subcooled
18 boiling. The boron is plating out and then being
19 such a good neutron grabber, that's causing some very
20 oddball --

21 CHAIRMAN WALLIS: This is in normal
22 operation of a reactor?

23 MR. BAJOREK: It's in normal operation.

24 CHAIRMAN WALLIS: Actually get boiling?

25 MR. BAJOREK: Yes. Oh, yes.

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1 CHAIRMAN WALLIS: Oh, well --

2 MR. DHIR: So it's a very important piece
3 of information which we got.

4 And this outer surface likes like it was
5 kind of photographed.

6 CHAIRMAN WALLIS: 50 microns sounds to me
7 like a lot.

8 MR. DHIR: Beg pardon?

9 CHAIRMAN WALLIS: 50 microns is a lot of
10 degradation.

11 MR. DHIR: Yes, 40 -- 45 microns is
12 developed in 12 hours about, 11 hours. And you see
13 the surface, you see how it's structures, like a
14 porous structure on the surface.

15 MR. BANERJEE: This was at low velocities
16 or --

17 MR. DHIR: No, the velocities were as I
18 showed you last viewgraph. I don't remember it.

19 CHAIRMAN WALLIS: You get enough of that
20 in the reactor, it would shut it down.

21 MR. DHIR: Yes. Velocity was about 60
22 centimeters per second.

23 MR. BANERJEE: Okay. So it's low.

24 MR. DHIR: Low. But this boron
25 concentration was high, at 7,000.

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1 CHAIRMAN WALLIS: This is boric acid, this
2 is boron --

3 MR. DHIR: Yes, boric acid.

4 CHAIRMAN WALLIS: So what's on the surface
5 then? So it's not pure boron is it? What is it
6 that's on the surface?

7 MR. DHIR: What do you mean? I don't --
8 boric acid, I guess.

9 CHAIRMAN WALLIS: It's boric acid?

10 MR. DHIR: Right.

11 MR. BANERJEE: It's tomoxide.

12 MR. DHIR: Tomoxide. We have not looked
13 at the composition.

14 CHAIRMAN WALLIS: So what's the pH on the
15 surface? Do you have a --

16 MR. DHIR: We measured the pH. I don't
17 remember now. But not at the surface. But in the
18 liquid what the pH was we measured it.

19 MR. SCHROCK: How do you measure that
20 thickness?

21 MR. DHIR: That's a good question.

22 CHAIRMAN WALLIS: This is concentrated
23 boric acid --

24 MR. DHIR: See that removable
25 thermocouple? And thickness is very small. So we put

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1 a big dial so that when we move the micrometer close
2 to the surface, made the contact and then backed off
3 how much we back off from the clean surface and from
4 that we deduced how much it was.

5 CHAIRMAN WALLIS: This is a Zircalloy
6 surface?

7 MR. DHIR: Zircalloy.

8 CHAIRMAN WALLIS: Did you get zirconium
9 borate or something formed on the surface?

10 MR. DHIR: No, no. I don't think it's a
11 chemical reaction. It's just a deposition on the
12 surface.

13 And we are doing now various detailed
14 experiments, it's funded from DOE looking at a single
15 bubble in boron and see how this deposition occurs
16 during subcooled boiling. And we see very nice
17 interesting patterns how it forms.

18 CHAIRMAN WALLIS: You get more nuclei with
19 boron then?

20 MR. DHIR: Yes.

21 So next is nucleus and site density and
22 you can see how it looks like. In the upper surface is
23 clean surface and lower is with boron at same
24 superheat.

25 CHAIRMAN WALLIS: And we should see more

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1 nucleation sites?

2 MR. DHIR: Yes, that's what you should
3 conclude. And that's where we plotted. These are all
4 bundled with boron, 35 micron or 40 micron layer on
5 it. And these are the clean surface.

6 MR. SCHROCK: Is the solution conducting
7 then? Is this an electroplating process?

8 MR. DHIR: When it evaporates you taking
9 only the liquid out and boron is left behind. With a
10 concentration, local concentration exceeds the
11 saturation limit.

12 MR. BANERJEE: It doesn't dissolve again,
13 right?

14 MR. DHIR: It builds up with time, but it
15 may be dissolving but the rate you are producing it
16 more than it's dissolving back.

17 MR. BANERJEE: Well, but you know if there
18 was a fluctuation of liquid over it --

19 MR. DHIR: Right.

20 MR. BANERJEE: -- it would tend to
21 dissolve. So there's some irreversible process going
22 on which doesn't allow it to go back.

23 CHAIRMAN WALLIS: If you stop boiling and
24 flushed it with water, would it -- with just boric
25 solution, would it dissolve the boron again?

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1 MR. DHIR: If I flushed with clean water,
2 I think so.

3 CHAIRMAN WALLIS: Or with the boric
4 solution.

5 MR. BANERJEE: Do you think so or do you
6 know so?

7 MR. DHIR: I think so I said.

8 CHAIRMAN WALLIS: You just --

9 MR. DHIR: It's a guess. I have not tested
10 it.

11 MR. BANERJEE: It's not obvious that that
12 happens.

13 MR. BAJOREK: I think it would behave very
14 much like the calcium sulfate that you see in a lot of
15 heat exchangers. And even if you have a flow going
16 over, you still have the no slip condition at the
17 boundary or near your surface. Even if it's flow,
18 you're going to continually build up this crud.

19 MR. DHIR: But even if water --

20 MR. BANERJEE: I don't think it's going to
21 dissolve.

22 MR. DHIR: No. Even water we have found --
23 clean water and you always have some contaminants. And
24 when you do boiling after a while something is left on
25 the surface.

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1 And we have numerical simulation, too, to
2 predict it. And basically some microlayer underneath
3 where you evaporate and your concentrations go way
4 beyond saturation limit and that's just there. Now
5 how the -- I don't know the mechanism. But I'm just
6 saying it's left behind.

7 MR. BANERJEE: There's not a soluble form
8 then?

9 MR. DHIR: Right.

10 MR. BANERJEE: Something happens

11 MR. DHIR: So something has to happen.

12 CHAIRMAN WALLIS: Maybe it reacts with the
13 zirconium?

14 MR. DHIR: Could be. But maybe we can
15 take a sample and see how -- what it does.

16 MR. BANERJEE: Now in the reactor it's not
17 the boron that's directly plating out. What they
18 think it might be are other contaminants within the --
19 nickel coming out of the tube and iron plating out
20 forming a crud and then the boron getting trapped in
21 that matrix.

22 MR. DHIR: This is the boiling curve we
23 got, like starting without boron in water. And that's
24 what we had done earlier. And now then we tracked
25 after every set of experiments. These are the three

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1 sets of experiment, like for 3 hours and 6 hours and
2 11 hours or something. And as you see with time, we
3 find that single phase heat transfer goes down, but
4 the boiling heat transfer goes up.

5 CHAIRMAN WALLIS: Well, this water's in
6 the reactor for days and months, it's not just --

7 MR. DHIR: Right, but the concentration we
8 used was higher than would be in the reactor. See,
9 that's one other way. But the key thing was it's
10 surprising result in some ways that in nucleate
11 boiling your heat transfer is higher with boron
12 because of the more -- nucleation sites. It also
13 indirectly tells you that -- site density is important
14 to know.

15 And in the single phase case it drops down
16 because of the thermal resistance of this layer.

17 So what the future work, we are saying is
18 that we still need to measure the void fraction in the
19 rod bundle in a more detailed fashion, and especially
20 also at higher pressures. And that's what we are
21 doing now.

22 And then we have to generalize the models
23 and correlations to other pressures.

24 CHAIRMAN WALLIS: Then are you going to
25 take these models and apply them to some data which

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1 was taken at more --

2 MR. DHIR: Conditions, right. Right.
3 That's my idea, to see how far we are predicting.

4 MR. SCHROCK: What do these negative delta
5 T wall mean?

6 MR. DHIR: T wall is less than T_{sub} .

7 CHAIRMAN WALLIS: It's T minus T_{sub} ?

8 MR. DHIR: Right. Okay.

9 CHAIRMAN WALLIS: Well, you're very
10 courageous to do this. To give up all these
11 complicated models for difficult looking phenomena and
12 put together a way of predicting boiling heat
13 transfer.

14 So I invite the Committee to send in
15 comments and make comments now if there are any.

16 DR. MOODY: Just a question that goes way
17 back to your page 55 where you made that correction.

18 Page 55 where you made a correction in
19 that correlation.

20 MR. DHIR: Number?

21 DR. MOODY: Page 55. It's the label
22 number 10, condensation heat transfer coefficient.

23 MR. DHIR: Just one second.

24 MR. BANERJEE: With the famous Fourier
25 number.

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1 MR. DHIR: Yes, 55. Okay. I don't have
2 the transparency, but I have the sheet.

3 DR. MOODY: Yes, that's fine.

4 Now in the material we got --

5 MR. DHIR: Right.

6 DR. MOODY: -- there was a figure 7 that
7 showed some spread in your data versus Fourier number.

8 MR. DHIR: Right.

9 DR. MOODY: And I'd just appreciate what
10 you did. You took that data and brought it together
11 with this correction?

12 MR. DHIR: Right.

13 DR. MOODY: And that's really a key --

14 MR. DHIR: Right.

15 DR. MOODY: In the whole contribution you
16 have here?

17 MR. DHIR: At that part, not the total.

18 DR. MOODY: Yes, okay. And then you
19 carried that over into the Nu number.

20 MR. DHIR: Nu number correction.

21 DR. MOODY: Okay. I just wanted a little--

22 MR. BANERJEE: That's how the Nu number
23 correction was made?

24 MR. DHIR: Correction was made, right.

25 And then that correct double diameter as well.

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1 DR. MOODY: Just off hand, how do you make
2 that correction? Is this a computer program that
3 tells you what exponents --

4 MR. DHIR: No. It will be part of it. It
5 also that I thought there should be some effect of the
6 history. And then we went back and see how we could
7 decide it. And that's how we put it --

8 DR. MOODY: So a little insight,
9 understanding, a little -- yeah, yeah. Okay.

10 MR. DHIR: And it is published in
11 international journal --

12 DR. MOODY: Yes.

13 MR. BANERJEE: But Eisenberg and Siesman
14 correlation seems to do pretty well?

15 MR. DHIR: Right, pretty well, right.

16 MR. BANERJEE: Considering that they're
17 not -- number there doesn't have a Fourier number.

18 MR. DHIR: Right, right. So it's kind of
19 -- or whatever it does. That's the closest --

20 MR. BANERJEE: But effect is fairly small,
21 right?

22 MR. DHIR: Right. But it becomes important
23 when -- number is large. When high subcooling it's
24 very important.

25 MR. BANERJEE: I guess because you get

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1 rapid --

2 MR. DHIR: Rapid condensation, yes, that's
3 what we see.

4 CHAIRMAN WALLIS: Any other words. Ready
5 to close this session?

6 MR. BAJOREK: Just maybe to add from our
7 office, we're very pleased with the work. We think
8 it's really identified a lot of the fundamental
9 physics and we think it gives us now a basis for
10 developing and trying to come up with models that can
11 put into the code.

12 Dr. Ransom's gone, but we wish we had been
13 in a state where we could have started development on
14 this sometime in the past. But it's in our model
15 development plans and we hope to try to develop the
16 routines, find exactly the ways to put this into TRAC-
17 M over about the next year.

18 CHAIRMAN WALLIS: TRAC-M's going to
19 calculate things like waiting time and --

20 MR. DHIR: There is no need for them.

21 CHAIRMAN WALLIS: No need for that?

22 MR. DHIR: They don't need to, we can give
23 them recipes that this is what you do.

24 CHAIRMAN WALLIS: You mean boil this down
25 into --

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1 MR. DHIR: Right, into something which is
2 manageable. They don't need to do it. Once we have
3 validated our modeling, then other sets of data, we
4 are confident, then we can give them what --

5 CHAIRMAN WALLIS: We still have to
6 calculate all these things, don't they, in order to
7 get your answers you have to calculate these waiting
8 times and things?

9 MR. DHIR: They would need those in that
10 information.

11 MR. BANERJEE: They're all phrased in
12 terms of the parameters, right?

13 MR. DHIR: Right.

14 MR. BANERJEE: So that means you just make
15 it a little black box and feed in these parameters--

16 CHAIRMAN WALLIS: Out comes a table lookup
17 thing. If you have this, this flow rate, this
18 temperature, this -- and you just --

19 MR. BANERJEE: A net it does it for them.

20 MR. SCHROCK: You're going to have to have
21 a prescription for contact angle. You're going to have
22 to have a prescription for transverse temperature
23 distribution. And you're going to have to have a
24 model for calculating alpha -- all those things.

25 MR. DHIR: Right.

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1 MR. SCHROCK: I think they'll need some
2 help getting that.

3 CHAIRMAN WALLIS: I think we're done. We
4 are done.

5 (Whereupon, at 5:59 p.m. the meeting was
6 adjourned.)

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