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UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS (ACRS)
SUBCOMMITTEE ON THERMAL-HYDRAULIC PHENOMENA

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THURSDAY,

NOVEMBER 20, 2003

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ROCKVILLE, MARYLAND

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The meeting was convened in Room T2B3 of Two White Flint North, 11545 Rockville Pike, Rockville, Maryland, at 8:30 a.m., Dr. Graham B. Wallis, Chairman, presiding.

MEMBERS PRESENT:

- GRAHAM B. WALLIS Chairman
- F. PETER FORD ACRS Member
- THOMAS S, KRESS ACRS Member
- VICTOR H. RANSOM ACRS Member
- JOHN D. SEIBER ACRS Member

ACRS STAFF PRESENT:

- RALPH CARUSO Staff
- SANJOY BANERJEE ACRS Consultant

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- 1 ALSO PRESENT:
- 2 Joseph Staudenmeier RES
- 3 John Mahaffy Penn State
- 4 Ken Jones APT
- 5 Christopher Murray RES
- 6 Jack Rosenthal AEOD/ROAB
- 7 Stephen M. Bajorek RES
- 8 Joe Kelly RES
- 9 Ralph Landry NRR/DSSA/SRXB
- 10 Chester Gingrich RES/DSARE/SMSAB
- 11 Weidong Wang RES/DSARE/SMSAB
- 12 William Krotiuk RES/DSARE/SMSAB
- 13 Phil Reed RES/DSARE/RPERWMD
- 14 David Ebert ADSTM, Inc.
- 15 Birol Akdtas ISL, Inc.
- 16 Shandai Lu NRC/NRR/SXRB
- 17 Yue Guan ADSTM, Inc.
- 18 Zena Abdullahi NRR/DSSA/SRXB

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A-G-E-N-D-A

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ADJOURN

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

(8:20 a.m.)

1
2
3 MR. CARUSO: Good morning. We will resume
4 this meeting of the Thermal Hydraulic Subcommittee of
5 the ACRS, and we will hear some more about the trace
6 code. Looking forward to it. Steve Bajorek is here
7 from RES, and he's going to get us started.

8 MR. BAJOREK: Okay, good morning. My name
9 is Steve Bajorek from the Office of Research. What we
10 would like to do today is start moving into
11 assessments. First we're going to talk a little bit
12 about the assessments and some of the work that we've
13 done in 2003 in order to complete the code
14 consolidation.

15 Then I'd like to start talking about what
16 we feel is a heck of a lot more fun and interesting,
17 which is going to be the assessment and the work that
18 we are doing now and hope to extend into the remainder
19 of 2003, 2004 and beyond, which will really start to
20 put us in a position to be able to quantify the code,
21 get uncertainties that we can use later to propagate
22 in full scale analyses, and use these results to
23 improve and develop new models, which are going to
24 make the code more accurate.

25 Just by way of introduction, getting the

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1 code consolidated I think turned out to be more of a
2 daunting task that what had been anticipated five or
3 six years ago, whenever that started. In order to
4 preserve all of the assessments that had been done
5 previously by RELAP, TRAC-B and TRAC-P, we really run
6 into quite a large number of assessments.

7 I don't have an accurate count on them,
8 but there is a very broad range that has to cover a
9 large range of conditions not only for the currently
10 operating plants but assessments that had been done in
11 support of the advance plants, like AP600, AP1000, and
12 the ESBWR.

13 Most of our work over the last two years
14 has not been directed at trying to find out what are
15 the major problems in the models, why is the code
16 behaving as it does, but rather trying to demonstrate
17 that TRACE has the basic equivalency to TRAC-P and
18 TRAC-B, or in the case of mainly the small break
19 analyses, that TRACE has the equivalency to the RELAP
20 code.

21 MR. WALLIS: Can I ask you about that?

22 MR. BAJOREK: Sure.

23 MR. WALLIS: TRAC-P and RELAP don't always
24 agree. In fact, they probably never agree exactly.
25 So, does TRACE have to decide whether it's emulating

1 TRAC or RELAP and then make a comparison?

2 MR. BAJOREK: There are only a few cases
3 where you wind up with a RELAP, and TRAC, and then a
4 TRACE comparison where you're really deciding. I
5 think the overall majority of these cases, you're
6 comparing either TRACE to one of these or TRACE to
7 RELAP.

8 MR. WALLIS: That's what I mean. So,
9 TRACE has to decide whether it's going to be emulating
10 RELAP. Does it behave differently when it emulates
11 RELAP than when it emulates TRAC?

12 MR. BAJOREK: No, not really. It's really
13 a different test of the models.

14 MR. WALLIS: Okay, so it's itself, and
15 then you say it either has to be equivalent to RELAP
16 or to TRAC, but compatible?

17 MR. BAJOREK: They need to be compatible.
18 We need to be able to --

19 MR. WALLIS: But TRAC-P isn't necessarily
20 compatible with RELAP always.

21 MR. BAJOREK: No, no, no.

22 MR. WALLIS: But if TRAC is equivalent to
23 one or the other, it's okay?

24 MR. BAJOREK: Maybe I don't understand
25 your question.

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1 MR. WALLIS: Okay. TRACE is A and TRAC-B
2 is P, and we'll have to see. It equals B or it equals
3 C, but it can't equal both of them.

4 MR. BAJOREK: Only in the cases where B
5 and C are equal.

6 MR. WALLIS: Yes, but they don't.

7 MR. BAJOREK: No, no.

8 MR. WALLIS: So, what are you really
9 doing?

10 MR. STAUDENMEIER: Excuse me, can I
11 interject a bit? It's not saying whether they're
12 equal or not. It's looking at calculation results
13 compared to assessment data and deciding whether it
14 does as well or better than the other code in
15 comparing to that data.

16 MR. WALLIS: I thought it was supposed to
17 be exactly the same.

18 MR. STAUDENMEIER: It's not strictly
19 emulating RELAP.

20 MR. WALLIS: So it's a compromise between
21 the two?

22 MR. STAUDENMEIER: It's not a -- it's
23 looking at results that the code gives in deciding
24 whether they're as good or better or worse than the
25 other codes.

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1 MR. WALLIS: So it's an independent code.
2 I thought originally it was going to incorporate these
3 codes and then you could sort of make it behave like
4 RELAP if you wanted it to.

5 MR. STAUDENMEIER: It can run -- well, it
6 doesn't run all RELAP models yet, but it will run
7 RELAP models, but it's using the TRAC models and
8 correlations package in it.

9 MR. WALLIS: Okay, so it's never really
10 equivalent to RELAP?

11 MR. STAUDENMEIER: No, we haven't put in
12 the RELAP correlations package to make it --

13 MR. WALLIS: So what you mean here is that
14 the TRACE results look like the RELAP results. You
15 don't mean that TRACE itself is equivalent to RELAP in
16 all it's parts?

17 MR. STAUDENMEIER: Yes, in most --

18 MR. BAJOREK: It should have the
19 functionality.

20 MR. WALLIS: Oh, it has the functionality,
21 but it's not the same thing.

22 MR. BAJOREK: But you will not get the
23 same results because we're using model packages from
24 TRAC-P and TRAC-B.

25 MR. WALLIS: So it's a separate code

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1 essentially?

2 MR. BAJOREK: Yes.

3 MR. WALLIS: Okay.

4 MR. RANSOM: Well, there are some
5 differences in actually the mapping, and I'm
6 wondering, if I generate a brand new model in TRACE,
7 what does it follow? You know, which one of these
8 three options would it follow?

9 MR. BAJOREK: Right now, it's primarily
10 TRAC-P.

11 MR. RANSOM: So you would use the TRAC-P
12 topology --

13 MR. BAJOREK: The models and correlations
14 --

15 MR. RANSOM: -- in generating that model.

16 MR. BAJOREK: -- would be used to try to
17 model simulations and processes that had been
18 traditionally done with RELAP. I think the way I'd
19 like to think about it is TRAC-P had traditionally
20 been used for large break scenarios in PWR's, large
21 and small breaks in BWR's where you need the jet
22 pumps. In BWR, you need components. Those have been
23 incorporated into TRACE.

24 TRAC has the capability of modeling small
25 break processes. It doesn't do it in the same way as

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1 RELAP has done. I think the code that has most
2 commonly been used for PWR small break analyses. Our
3 goal is to show that we can model and approximate the
4 transients with TRACE about as well as TRAC-P could do
5 the large break, TRAC-B could do the BWR unique cases,
6 and RELAP could do the small break cases. At that
7 point, we'll have the functionality in TRACE and will
8 be able to begin to improve the models so we get
9 better accuracy.

10 MR. WALLIS: RELAP has the added mass in
11 it, and TRAC does not. So, if you had a transient
12 where added mass was important, it wouldn't be
13 equivalent to RELAP anymore, would it?

14 MR. BAJOREK: I suppose not, no.

15 MR. WALLIS: I think I understand.
16 Eventually you compare with data, and if TRACE does a
17 better job on the data than either RELAP or TRAC-P or
18 TRAC-B, then it's really good.

19 MR. BAJOREK: And that's where we want to
20 get. That's what we want to move towards. We want to
21 try to get the basic functionality there and then
22 focus our efforts on improving the models and getting
23 the right models into TRACE so that eventually the
24 code of choice is going to be a TRACE as opposed to
25 any one of these three.

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1 MR. MAHAFFY: This is John Mahaffy. Let
2 me interject something here from a historical
3 perspective. The word equivalent has never been used
4 in this project, okay? He just used it, but you know,
5 he's a newcomer.

6 Again, Joe Staudenmeier got it right in
7 terms of the assessment. The goal in terms of data
8 has been we are going to do as well or better, and
9 that's why we're looking for metrics, you know, as
10 RELAP or TRAC-P or TRAC-B on any given assessment
11 where it's appropriate.

12 In terms of the kind of questions Vic was
13 asking, in modeling, we are capturing all modeling
14 capabilities. When you think in terms of like
15 component modeling and whatnot, that all of these
16 predecessors had, and to broad the statement, if you
17 model something in TRACE native mode right now, it's
18 not simply TRAC-P input.

19 The only exception I can think of that at
20 the moment, and this is going to be corrected within
21 the next couple of months, is the gravity thing we
22 went through yesterday. If I put together a native
23 mode ASCII input deck in TRACE, it's going to lean
24 towards the TRAC-P side right now rather than RELAP5.
25 If you wanted the RELAP5 bends, which I would want,

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1 and I'm going to fix it, you would input a RELAP5 deck
2 into the SNAP, and you'd get it. It's just how the
3 input decks get interpreted.

4 MR. WALLIS: So, I'll ask another
5 question. This means then that eventually, a RELAP
6 capability will disappear unless RELAP is maintained.
7 It is not as if TRACE can emulate RELAP. TRACE is
8 itself.

9 MR. MAHAFFY: TRACE is itself, but there
10 is a commitment that if you have an input model that's
11 been created based on your understanding of RELAP5 or
12 built by somebody who's a RELAP5 expert, it will do
13 what it's supposed to do in TRACE.

14 MR. WALLIS: But it won't give exactly the
15 same answer as RELAP5 would.

16 MR. MAHAFFY: No, and it won't get exactly
17 the same answer as TRAC-P or TRAC-B. It is its own
18 beast, and it will be more its own beast as things go
19 on from a physical constitiute model standpoint, and
20 this is what you're going to hear more about today.

21 MR. FORD: I'm sorry. For a relative
22 newcomer in this, I was, from your presentation, I was
23 getting the impression that you just had this
24 architecture where you dumped in, you plugged in,
25 TRAC-B or P or RELAP. You just plugged it in to this

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1 gizmo and you get the same results as TRAC-B, and you
2 just a consolidator. That's not true. You in fact
3 modified the physics of the code?

4 MR. MAHAFFY: Not much so far, but that's
5 a process whose rate of change is increasing rapidly,
6 and Joe Kelly will speak to that.

7 MR. FORD: Okay, but you have changed the
8 physics of the course, of the model?

9 MR. KELLY: In general, the physical
10 correlations are the same as in TRAC-P, PF1 Mod 2,
11 okay, with the exception of specialized boiling water
12 reactor components like the jet model, where we
13 basically took the entire model straight from TRAC-B
14 and imported it in.

15 The idea is that volumes and junctions and
16 so on are more or less the same, but treated a little
17 bit differently. More or less the same in the various
18 versions of TRAC and RELAP5. We only want to have one
19 constitutive package in this code. We don't want to
20 have users going okay, this pipe is going to be a
21 RELAP5 model. This is going to be -- you know, who
22 knows what your answer would be. It would be a
23 nightmare.

24 We want to have one set of constitutive
25 models, and be the very best constitutive models we

1 can possibly find within the code. We know the ones
2 currently in the code are not very good. I'm going to
3 really show some bad problems in my next few
4 presentations.

5 The idea of the assessment here, it's to
6 show the equivalency, in Steve's terms, but it's more
7 than that, is to find out where it is an equivalent.
8 I mean, we know that some of the physical models in
9 TRAC are going to be deficient, and where they don't
10 perform as well as the models in RELAP, the assessment
11 will highlight. Then we know, okay, that's where we
12 have to go and spend our resources to make the code
13 better.

14 MR. FORD: Thank you.

15 MR. KELLY: You're welcome.

16 MR. BAJOREK: Okay, so what I'd like to do
17 this morning is to show some of the summary of some of
18 the work that we have done for the code consolidation
19 and then show some of the results where we're starting
20 to move ahead and assess individual packages within
21 the code, individual packages of models and
22 correlation, show some of those results and give you
23 an idea of the type of assessments that we have
24 planned for 2003, 2004, and a little bit beyond. I
25 don't think it's worth at this point trying to scope

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1 things out much beyond 2004 or 2005, but I wanted to
2 let you see what some of the near term work is we have
3 planned.

4 This shows a list of experiments that
5 we've completed in 2003 where the mission of the
6 analysts for each of these cases was to take an
7 existing input on TRAC-P, B, or in some cases RELAP
8 didn't show up on this one -- TRAC-P or TRAC-B,
9 develop a TRACE model for that same facility, modify
10 the input so that it runs with TRACE, compare it to
11 its base or constituent code, and to do a comparison
12 to experimental data.

13 The only exception to that are a couple of
14 cases, a couple of plant calculations where we'd like
15 to try to do a code to code comparison, and we don't
16 have experimental data for that particular transient.

17 What I'd like to do is to go through, show
18 some sample results for a large break assessment, a
19 couple of small break type assessments, to show what
20 the analyst was looking for, how they were
21 characterizing the transient, and move on to some of
22 the model involved in those.

23 MR. WALLIS: So what's the highlight?

24 MR. BAJOREK: Those are the ones I'm going
25 to show later on in the presentation.

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1 MR. WALLIS: Okay, okay, so you have done
2 all the other ones as well?

3 MR. BAJOREK: All of these are complete,
4 but we could take any one of these and probably spend
5 a good hour, hour and a-half on them.

6 MR. WALLIS: This looks like the list we
7 saw some time ago. Is it?

8 MR. BAJOREK: You probably saw this about
9 a year ago as assessments in 2002 that we were
10 planning for 2003.

11 MR. WALLIS: It was what you were planning
12 to do then?

13 MR. BAJOREK: Yes.

14 MR. WALLIS: Okay.

15 MR. BANERJEE: Did you do some RELAP ones
16 as well, RELAP input origin?

17 MR. BAJOREK: There are, but they haven't
18 shown up on this. The two problems that have held us
19 back a little bit on the code consolidation, one has
20 been the ability of SNAP to take RELAP decks and
21 convert those over into TRACE. So, our ability to be
22 able to model and simulate some of the more complex
23 small break tests, things like ROSA and BETHSY and
24 semiscale, has been impeded because we've been waiting
25 for SNAP to mature enough so we don't have to have an

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1 analyst go spend nine months just to regenerate an
2 input deck. So, we purposely held off on those.

3 We've also held off on a number of the
4 forced and integral forced reflood test simulations
5 because we've been waiting for the interim reflood
6 model to be completed before we go on. We know what's
7 in TRAC-P right now is insufficient. So, most of
8 these cases don't rely on either developing or
9 converting a RELAP input deck or on the reflood model.

10 The one thing I do want to point out is
11 where we have done comparisons of TRACE, or previously
12 known as TRAC-M to TRAC-P or B and RELAP, was last
13 year when we looked at Frigg and a number of the level
14 swell experiments. I think we talked about these a
15 year or maybe two years ago, and we showed you a
16 series of calculations, a series of simulations, this
17 being on the level swell tests in the Oak Ridge
18 bundle, where we concluded from that TRAC-M, or TRACE,
19 was doing about as good a job as RELAP or TRAC-B
20 relative to each other and the data.

21 We identified some problems in the TRACE
22 interfacial drag package, that I think as Joe
23 mentioned yesterday, I think we can resolve by going
24 to the BETHSY on interfacial drag model. That would
25 reduce the void -- this is showing void fraction

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1 versus elevation for this particular test. That would
2 reduce this and give us better agreement between the
3 level swell that you would calculate from the two
4 phase level and the collapse level. The collapse
5 level is too low in the TRACE model.

6 MR. WALLIS: So why did TRAC-M get a
7 different answer than TRAC-B? You put in some
8 different constitutive equations?

9 MR. BAJOREK: There's a different
10 constitutive package in each one of these.

11 MR. WALLIS: So you're not really showing
12 equivalents here. I don't quite know what you're
13 showing. Are you just showing that TRAC-M at that
14 time was sort of worse than RELAP.

15 MR. BAJOREK: Yes, it is.

16 MR. WALLIS: All right.

17 MR. BAJOREK: I mean, it's a different
18 constitutive package.

19 MR. WALLIS: It seems to have got off TRAC
20 at about a certain position, you know. It's gone
21 maybe to the left and then it doesn't come back.

22 MR. BAJOREK: But our conclusion at this
23 point is if you're going to try to correct any of
24 these to match the data which is the open triangles in
25 here, we're going to concentrate our efforts on TRACE,

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1 TRAC-M in this case. We're not going to go back and
2 try to correct RELAP, which for this test was actually
3 looking like it's doing a worse job in the
4 experimental data.

5 MR. WALLIS: It depends what you look at,
6 yes.

7 MR. BAJOREK: In ten to 15 of these tests,
8 yes, you'll find RELAP does a better job on some of
9 them. TRACE does a better job on some of them. TRAC-
10 B wins out on some of these. Our conclusion is, for
11 lack of a better term, they're approximately equal,
12 okay? It can model this test. We get about the same
13 results.

14 If we had defined metrics in terms of
15 level swell, we would get about the same number, even
16 though we haven't calculated that, but now is the time
17 to put this to rest. We'll move ahead. We'll put in
18 the BETHSY on interfacial drag model, and then the
19 next time we do these simulations, we're only going to
20 be looking at TRACE versus this data, and using a
21 metric to try to show how much better we can end up.

22 MR. WALLIS: One of the problems, maybe at
23 the beginning, so the initiation of flashing or
24 whatever is going on here.

25 MR. BANERJEE: Is that due to subcooled

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1 boiling, or what's the problem down below axial
2 location?

3 MR. BAJOREK: This test had very little
4 subcooling at the beginning. It think this is close
5 to a saturated test.

6 MR. BANERJEE: But why is almost all the
7 predictions are not showing any void until about .8
8 meters, where as in actuality --

9 MR. WALLIS: No, in actuality --

10 MR. BANERJEE: -- there's a significant
11 void by that time.

12 MR. WALLIS: I don't think so because
13 there's no data until you get to one.

14 MR. BAJOREK: Yes. Boiling begins
15 somewhere in here. We may have had a DP cell down in
16 here where you've got a zero.

17 MR. BANERJEE: There's a sharp change in
18 void there.

19 MR. BAJOREK: Well, if it's subcooled
20 boiling, you get a few bubbles there, and then it will
21 -- there's some subcooling at the bottom.

22 MR. RANSOM: Is this a vertical system?

23 MR. BAJOREK: Yes. It's a rod bundle.
24 This is full hot rod bundle, I think something like 60
25 or 70 rods.

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1 MR. WALLIS: So maybe it starts on one rod
2 before the others. Look, we don't really need to go
3 into this particular one, I think.

4 MR. KELLY: Actually, it's real simple.
5 Actually, some of it is just simply the experimental
6 boundary conditions. You have very, very low flow
7 rates here. You're talking, you know, a centimeter a
8 second type of velocities. So, the uncertainty in
9 that determines where you reach the saturation line
10 and become two-phase. I mean, I can move about quite
11 a bit just to the uncertainties and --

12 MR. WALLIS: Because of the uncertainties,
13 they might well cover everything here.

14 MR. BANERJEE: Yes, so all the codes have
15 the same input models, so they start boiling at the
16 same place. Obviously for this case, the reported
17 experimental values were not quite right, but a very,
18 very small difference in the inlet flow rate, moves
19 where the saturation line is, and that's what you're
20 seeing here. Once you get away from the incipience of
21 boiling, then the flow quality is about right and
22 you're not too far off.

23 MR. WALLIS: What's the difference between
24 the TRAC-B model and the TRACE interfacial drag model?

25 MR. KELLY: Okay. Joe Kelly again?

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1 MR. BAJOREK: Go ahead.

2 MR. KELLY: TRAC-B takes a drip flex model
3 and converts it into an interfacial drag model. TRAC-
4 P, what it uses is a bubbly slug thing where it's size
5 of bubbles and sizes of slugs and ramps between the
6 two and then also puts a profile slug factor on that.
7 So, it tries to be more fundamental, but actually it's
8 a worse model. So, that's why TRAC-B for these kinds
9 of tests will work a lot better.

10 MR. BANERJEE: The TRACE model here has
11 the TRAC-P model in there?

12 MR. BAJOREK: Yes. That's correct. It
13 does now. It won't always.

14 MR. WALLIS: It's going to all have Kelly
15 models eventually.

16 MR. RANSOM: One question. You mentioned
17 the SNAP not able to convert the RELAP5 decks. That
18 didn't come out yesterday, I didn't think. What are
19 the problems there?

20 MR. BAJOREK: At the time we had started
21 this work several months ago, it could not.

22 MR. RANSOM: Now it can?

23 MR. BAJOREK: Now it can. Now it's
24 getting to the point where it can take either all or
25 most of the RELAP decks and convert those over to

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1 TRACE. Missing on this are things like ROSA, BETHSY,
2 semiscale, some of the more conventional small break
3 application where you would see RELAP doing a credible
4 job right now, and we know we need to get TRACE to do
5 a good job, but it's been waiting for our ability to
6 economically convert those input decks, is why we've
7 had to hold off on those.

8 MR. RANSOM: That's what I was asking.
9 The status is now you can do that?

10 MR. BAJOREK: Now we can to that, yes.

11 MR. STAUDENMEIER: This is Joe
12 Staudenmeier. It was on one of my later slides
13 yesterday that I had to zip through, so I probably
14 didn't get a chance to say it, but we're at the point
15 where we're working on typical PWR base model,
16 actually 1200, which is a typical PWR base model. We
17 have it converting and running all the way through if
18 you change some temperature inputs in the feedwater
19 and the steam generator.

20 We have a condensation problem that we
21 haven't determined if it's an input mapping problem or
22 an internal code problem yet, but if you make the
23 water temperature hot enough, it will run all the way
24 through. It seems to be converting geometry and
25 control systems and heat structures and models simpler

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1 than that, it can convert and run without any problem.

2 MR. BAJOREK: This is an example of some
3 of the things that we were looking for when these
4 simulations were performed. In each case, when they
5 ran a particular simulation, first of all, the analyst
6 was asked to put everything into an AV script format
7 that I think Chris talked about yesterday, is an
8 automation tool so that we're going to be able to go
9 back, change the code version in the future, rapidly
10 re-run these, and regenerate a number of the figures
11 of merit.

12 Now, we don't have time to go through all
13 the package of some 50 to 75 different figures that
14 make various comparisons to the data.

15 MR. WALLIS: Well, the first figure here
16 could probably be predicted by one or two node models,
17 and it's just a system with a hole in it. So, you
18 expect that to work out pretty well.

19 MR. BAJOREK: Blowdown.

20 MR. WALLIS: Blowdown, it's blowdown of a
21 system with a hole in it.

22 MR. BAJOREK: If your break flow is right.

23 MR. WALLIS: So, all the codes ought to do
24 pretty well if you've got the break flow right.

25 MR. BAJOREK: They ought to, if they're

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1 break models.

2 MR. WALLIS: Right.

3 MR. BAJOREK: Yes. In this case, we
4 compared TRACE to TRAC-P. This shows a cladding
5 temperature versus time. The blowdown peak here,
6 experimental data showed a rewet. Of course, the
7 question was whether that was the exterior amount of
8 thermocouples or the rod itself. In comparison to
9 TRACE, which is shown in the green, and TRAC-P in the
10 red, we looked at those and concluded that TRACE was
11 doing about the same job as TRAC-P.

12 Now, there are differences in the input
13 models that had been put together. There were some
14 small differences there. There have been changes in
15 the constituent package for TRACE that would make it
16 different from an earlier version of TRAC-B, but our
17 conclusion in taking a look at this simulation is we
18 were getting about the right results with TRACE and
19 was time to move on and focus our attention from that
20 point on on getting TRACE to better match the data.

21 MR. WALLIS: Is there a physical reason
22 why the big difference between both the codes and
23 data?

24 MR. BANERJEE: It may not be real.

25 MR. WALLIS: That's what my question

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1 really was. An explanation as to why the data is not
2 what it is?

3 MR. BAJOREK: Yes. In LOFT, the
4 thermocouples were not inside the rods as they are in
5 many electrically heated facilities. They're mounted
6 outside of the rod itself. The tip, okay, down at a
7 particular elevation, could potentially have been
8 struck with a droplet and could have cooled
9 prematurely compared to the heated rod surrounding it.

10 So, what we might be seeing is the
11 thermocouple having rewet and not able to rapidly heat
12 up again because it has been quenched and could
13 continually be struck by droplets in the flow, whereas
14 the rod surrounding or nearby may not have quenched
15 and have been at a higher temperature. I think that's
16 been an arguable point on LOFT since the tests have
17 run.

18 MR. RANSOM: It has been, but I thought it
19 was pretty much agreed there was a topdown reflood,
20 early rewet that occurred.

21 MR. BAJOREK: Okay.

22 MR. RANSOM: I don't remember how the
23 codes predicted that or how well.

24 MR. BANERJEE: Well, unfortunately in the
25 beginning, they tried to fudge it to fit the data, but

1 then it was found the data was incorrect, so they had
2 to go back and un-fudge it.

3 MR. RANSOM: That's with the external
4 thermocouple you mean?

5 MR. BANERJEE: Right.

6 MR. RANSOM: Yes.

7 MR. FORD: Is there any way that the model
8 could --

9 MR. BAJOREK: Model the external
10 thermocouple?

11 MR. FORD: Exactly.

12 MR. KELLY: You have to model the
13 thermocouple if you did that.

14 MR. FORD: If the model is good, extensive
15 enough, then it should be able to tell you what to
16 have been the conditions to give you that observation.

17 MR. RANSOM: I don't think anybody knows
18 what the effect of the thermocouple was on the film,
19 you know, and whether it would rewet or not.

20 MR. BANERJEE: There is a significant
21 difference between TRAC-B and TRACE then that you're
22 getting a much earlier rewet with the green line than
23 with the red.

24 MR. RANSOM: The final quench you mean?

25 MR. BANERJEE: Yes, and it's quenching

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1 from a higher temperature. What's causing that?

2 MR. BAJOREK: This quench here versus
3 that?

4 MR. BANERJEE: Yes.

5 MR. BAJOREK: It may be in the minimum
6 zone boiling models, but I really don't know.

7 MR. WALLIS: Maybe Joe Kelly is going to
8 explain it a little later.

9 MR. BANERJEE: The models are the same,
10 aren't they?

11 MR. BAJOREK: They're very close, but
12 they're not identical.

13 MR. RANSOM: Is that the correlation
14 that's causing that?

15 MR. WALLIS: Well, Landry wants to talk.

16 MR. BAJOREK: I think they are different
17 in TRACE and TRAC-B.

18 MR. WALLIS: Okay, would you yield the
19 floor to Ralph?

20 MR. BAJOREK: It looks like TRACE is too
21 high. We could always ask one of the experimenters
22 from Roth what happened.

23 MR. LANDRY: This is Ralph Landry from NRR
24 staff. At that point, I was in RES and was managing
25 the LOFT project. The rewet that occurred in the

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1 large break loca experiments, L22 through L26 in LOFT,
2 was partially attributed to a film thin effect of the
3 thermocouples that were surface mounted for those
4 experiments. That thin effect was estimated to be
5 about 20 degrees Kelvin. A later study said maybe it
6 was a little bit more, but we were at that point
7 taking the effect to be about 20K.

8 The energy balances that were performed on
9 the fuels did demonstrate that yes, indeed, there was
10 an early quench. The quench was real and did extract
11 the energy from the fuel.

12 What we were seeing was a major difference
13 between the design of an electrically heated fuel rod
14 versus a nuclear rod which had a true gap between the
15 fuel pellet and the cladding which did not exist in
16 the electrical rods. The electrical rods tried to
17 simulate the gap but did not have a true gap and were
18 thermally linking the cladding with the fuel much more
19 tightly than is true for a nuclear rod.

20 The later experiments that were done under
21 the OECD project, the large break loca experiments
22 under LOFT, used an embedded thermocouple in the wall
23 of the cladding. Those experiments would be much more
24 accurate for comparison, but those did show an early
25 rewet also, but not to the magnitude of the

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1 experiments that had the surface mounted
2 thermocouples.

3 It would be much better to use those OECD
4 NEA project large break locas for comparison purposes.
5 The thermocouples were embedded in the wall by
6 machining a small groove in the outer surface of the
7 cladding. The thermocouples were laser welded into
8 place and then ground smooth.

9 The early experiments were forced, and I
10 think Vic remembers those days quite well, to get the
11 codes to match up with the data. We were seeing
12 RELAP5 in those days giving very different results.

13 We saw a dramatic comparison with a code
14 work that was done at Los Alamos National Laboratory
15 using TRAC that miraculously overlaid the quench
16 perfectly. Unfortunately, they were using a heat
17 transfer correlation package that was giving the right
18 quench but for totally wrong thermal hydraulic
19 reasons. That was what Vic was referring to as having
20 been backed out at a later date, because they were
21 getting the right result for the wrong reason, and
22 that simply didn't work.

23 MR. KRESS: Steve?

24 MR. BAJOREK: Yes.

25 MR. KRESS: Let me ask you a hypothetical

1 question about this kind of curve, not specifically
2 that curve, but presuming you had great faith in the
3 data and a small uncertainty in the data, and your
4 code had a prediction somewhat like this, which was
5 significantly off, and if I wanted to use data to
6 express some level of uncertainty in my code, how
7 would I do that with this kind of transient curve
8 where sometimes it's right on the data and sometimes
9 it's off and sometimes it's under and sometimes over?
10 How do I use that to determine an uncertainty?

11 MR. BAJOREK: Okay, I think what you need
12 to do, and I've got a slide coming up that I think
13 addresses that.

14 MR. KRESS: Okay.

15 MR. BAJOREK: But I think what you need to
16 do is you need to look at the physical processes that
17 are going on in each one of these periods. DNB,
18 blowdown cooling, Tmin or lack thereof. Let's say
19 this is the rod. Tmin out here. Heat transfer,
20 coefficient --

21 MR. KRESS: So you could tie the
22 uncertainty to different time frames maybe when
23 different phenomena were occurring?

24 MR. BAJOREK: From different processes
25 which are dominating why this curve looks the way it

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1 does, okay, and I think when you go back and you want
2 to try to get a bias and uncertainty, you need to get
3 biases and uncertainties in those processes that you
4 can go back and use to say something about the models
5 in the code.

6 Okay, I need a let's say an uncertainty in
7 not reflood PCT here but in the heat transfer
8 coefficient for the steam cooling dispersed droplet
9 heat transfer that's going on. An uncertainty in T_{min}
10 of a quench temperature that appears to be different
11 in these two so that I can go into the code and say
12 even though I know I've got a model package that has
13 flaws and it doesn't capture all of the right physics,
14 there's a way that I might temporarily be able to
15 adjust it, fudge it towards the right value, something
16 that will make it right in the data, and then
17 propagate that in a PWR or a BWR at full scale to see
18 what its effect is for transients that may go a couple
19 of hundred seconds as opposed to what's going on here.

20 One thing that we are keenly aware of is
21 that we do not want to just focus our attention on
22 blowdown peaks, PCT's or let's say a reflood PCT, as
23 the sole parameter of merit to these. So, I think
24 from these, I would look at the processes, the
25 blowdown cooling, the reflood heat transfer minimum

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1 film boiling temperature, to go other parameters on
2 this that might tell me how much mass is in the vessel
3 as a way of getting something that will tell me about
4 the interfacial drag that goes on in the core itself.

5 MR. KRESS: So if I had the appropriate
6 uncertainties associated with my various parameters
7 and models in the code built into it and the code was
8 calculated in the uncertainty as it went along, when
9 those models come into play, you might distribute
10 higher uncertainty during that period, and it would
11 automatically kick it out, and you'd get a transient
12 uncertainty that is distributed.

13 MR. BAJOREK: That's right because we
14 still have the problem that the scale on this and many
15 other of these experiments is not the same as it is in
16 the full scale prototype.

17 MR. KRESS: So, the uncertainty, it
18 wouldn't be one sigma for uncertainty. There would be
19 a lot of them, depending on what you're dealing with.

20 MR. BAJOREK: It's a distribution.

21 MR. KRESS: It's a distribution.

22 MR. BAJOREK: We may have some models that
23 do a very good job at the small bias, and because of
24 the experimental database, the uncertainty might be
25 small. We're going do better than the scatter in the

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1 experimental data, but there may be other situations
2 where the model is ad hoc, or it may have a very large
3 bias, but the experimental data has such a large
4 uncertainty that you may need to incorporate that in
5 your full scale prototype predictions.

6 MR. BANERJEE: I have really a different
7 question. Why is there a difference between the red
8 and the green lines? I mean, they're supposed to be
9 based on the same, at least at the time when you ran
10 that simulation, based on the same physical models,
11 right? That seems more puzzling to me. Is there
12 something different in the numerics, or what's giving
13 that difference? You are starting with the same --

14 MR. BAJOREK: To get the constituent
15 package in TRACE, it's not necessarily identical to
16 all of the models that were there in TRAC-P. There
17 was a selection process that preserved most of these
18 but not all of those.

19 MR. BANERJEE: Which ones were not,
20 because you're showing some difference, right?

21 MR. STAUDENMEIER: Let me interject. It's
22 Joe Staudenmeier. I mean, most of the constitutive
23 packages are identical. There may have been some
24 small bug fixes between the two that didn't make it
25 from one to the other, but I think most of those were

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1 carried over.

2 One of the big differences is collocating
3 heat structures in TRACE. It used to be heat
4 structure nodes were on fluid boundaries. Now a heat
5 structure node is in the middle of a fluid cell, so
6 there was a difference in the conduction model and the
7 fuel rods that could be attributed to that level of
8 difference, I think. I mean, there could be other
9 things. There could be fixes -- I mean, we put fixes
10 in the break flow model and various other bug fixes in
11 TRACE that didn't make it back into TRAC-P that could
12 be attributed to that level of difference.

13 MR. MAHAFFY: John Mahaffy. Let me add to
14 that. You shouldn't underestimate the bug fixes,
15 particularly in a situation where you've got quenching
16 behavior. My experience with this is that, I mean, if
17 you really wanted to understand this, you'd want to
18 take each of these decks and introduce some small
19 perturbations here or there and understand how the
20 system responded to small perturbations.

21 Some of the perturbations that we've
22 introduced with bug fixes aren't all that small. So,
23 I mean, it's one of the reasons why I was telling you
24 earlier, you know, these are not identical physical
25 models. You can read the manuals and they look like

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1 identical physical models, but what's in there? There
2 are differences.

3 In a case like this, this kind of
4 difference in results should not be surprising to you.

5 MR. WALLIS: Is there a user effect? Many
6 code experts talk about user effects, or do you have
7 some choice in one of your codes, if that makes a
8 difference to the answer? Is there any user effect
9 with TRAC-P or TRACE?

10 MR. BANERJEE: They're the same decks,
11 right?

12 MR. BAJOREK: They should be the same
13 decks, although in some of these simulations, they did
14 have to make some changes to the nodalization to get
15 one to look more like the other. That was more the
16 case when we had some of the RELAP models.

17 MR. WALLIS: So there could be user effect
18 there?

19 MR. BAJOREK: Yes.

20 MR. BANERJEE: But what are you
21 demonstrating with the slide, that same, similar?

22 MR. BAJOREK: Similar.

23 MR. BANERJEE: Similar enough?

24 MR. BAJOREK: These are similar, yes.

25 MR. BANERJEE: And how do you sort of

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1 quantify the similar enough here? One is rewetting
2 ten seconds earlier than the other, which is
3 significant, and the peak is higher, and it's
4 rewetting from a higher temperature. So, what is the
5 similarity here?

6 MR. BAJOREK: It's essentially a
7 subjective opinion on looking at the various codes by
8 TRAC-P and TRACE in this case. We have not applied a
9 metric to this, but it's a way of doing the
10 assessments and telling the development team whether
11 there is a code error or a bug that is preventing
12 TRACE from running this, or it is deviating
13 substantially due to some model that may not have been
14 converted correctly.

15 MR. STAUDENMEIER: One thing about that
16 quench, too, is the quench in LOFT is totally
17 different than a PWR reactor quench because the short
18 core in LOFT, that quench happens when the
19 accumulators empty out and the gas pushes the surge of
20 water in the core. In a regular PWR, it would
21 decrease the temperature for a little bit, but then it
22 would recover, but with the short core in LOFT, it
23 just quenches the whole core all at once. So, that's
24 not typical of a PWR.

25 Essentially, that quench time is based on

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1 when the accumulator empties out.

2 MR. BAJOREK: I don't agree with that,
3 Joe.

4 MR. WALLIS: Well, maybe we should move
5 on. We've got a lot more comparisons to look at.

6 MR. BANERJEE: Well, what this shows at
7 the end of the day is that you're sort of
8 qualitatively similar, but it actually puts some
9 emphasis on these small changes having a fairly large
10 effect.

11 MR. BAJOREK: I think as John pointed out,
12 don't underestimate the bug fixes. When we were doing
13 development with COBRA track for Westinghouse, we'd
14 periodically find errors in some of the correlations,
15 and those would have substantial effects on both the
16 assessments. In some cases, they would have a large
17 effect on the PWR calculations.

18 In some cases they wouldn't, or it would
19 be vice versa. It really depended on the bug fix
20 itself, and I don't think you can really generalize
21 that other than that you should expect some difference
22 between a code version with and without the bug fix.

23 Another case where we were able to start
24 to see whether TRACE can handle a small break
25 transient was in the case of LOFT L3-7, which is a

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1 one-inch cold leg break. In this case, there were
2 TRAC-P decks available, so we didn't have to depend on
3 SNAP. Several months ago, converted this into the
4 TRACE format, simulated --

5 MR. WALLIS: Excuse me. TRACE actually
6 shows that the pressure increases over part of the
7 transient as a whole, and the pressure increases?

8 MR. BAJOREK: Yes, right over there.

9 MR. WALLIS: It looks a little suspicious,
10 that whole wiggling around there looks -- that cliff
11 where it goes down and then comes back looks very
12 strange, simply a depressurization through a hole.

13 MR. BAJOREK: It shouldn't hang on this
14 until you clear a vent path for the break.

15 MR. WALLIS: The pressure shouldn't rise,
16 should it?

17 MR. BAJOREK: No, unless there's a problem
18 with your steam generator heat transfer. If your heat
19 transfer in your steam generator is insufficient, the
20 system will, and the code will repressurize in order
21 to give you the delta T to get the heat out.

22 MR. WALLIS: See, is that the pressure of
23 a secondary or something which is there at that level
24 or just the steam generator pressure?

25 MR. BAJOREK: Steam generator secondary

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1 pressure is probably down here.

2 MR. WALLIS: Down there.

3 MR. BAJOREK: Would I would look for in
4 order to try to correct this is to take a look at the
5 steam generator return.

6 MR. WALLIS: So it hangs around, the
7 secondary pressure, you'd think, for awhile, right?

8 MR. KRESS: That little dip around 2000
9 looks strange.

10 MR. WALLIS: That's right.

11 MR. KRESS: There's something wrong with
12 it. I would say there's something wrong with that
13 there.

14 MR. RANSOM: In this comparison, this is
15 a TRAC-P deck converted to TRACE, and that's the TRACE
16 result. The RELAP5 is just basically a RELAP5
17 calculation. So, the models are two different models.

18 MR. BAJOREK: Two different models.

19 MR. BANERJEE: So when you ran this and
20 you saw that dip, does somebody go in and try to
21 understand anything which looks sort of weird and
22 figure it out?

23 MR. BAJOREK: At this point, no. We were
24 under the gun to try to get the consolidation moving
25 ahead just to do the basic comparisons, and we made a

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1 conscious decision at that point to try to get the
2 comparisons to try to show that there were in general
3 about the same accuracy as the data. Then in the next
4 phase, start to compare what would be the red curve
5 back to the black to really understand why there are
6 deltas between the predicted and the measured and what
7 is causing some of these individual --

8 MR. WALLIS: There's a funny sort of hump,
9 too. I mean, after 2000, between 2000 and 225 or
10 something, something odd happens.

11 MR. BAJOREK: Yes.

12 MR. RANSOM: It would be interesting to
13 see the break flow predicted by the two. I imagine
14 there is some --

15 MR. WALLIS: Maybe it changes the break
16 model.

17 MR. RANSOM: -- clues there, right.

18 MR. BANERJEE: I'm sure that there is a --
19 if you look at all the tests, you will see some
20 phenomena which are occurring which may be arising
21 from the code. How is that process of examining these
22 sort of results and feeding back that knowledge into
23 fixing things that are going to occur? Is there a
24 systematized way to examine these?

25 MR. BAJOREK: We have an error correction

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1 reporting system, that when we do find problems with
2 the code, these go into the reporting system, and then
3 as we can get to those various problems, we'll isolate
4 and look at a problem like this if that has been
5 reported as a problem.

6 Right now, because of where we're at in
7 the code development, things have stopped the code, or
8 make the code run excessively slow, are getting more
9 of the attention, okay, rather than trying to find out
10 what are the individual nuances in some of these.

11 MR. WALLIS: But your attempt was to show
12 that TRACE is equivalent to RELAP? I mean, it looks
13 as if TRACE is doing something new, which is
14 inexplicable over part of the transient which RELAP
15 did not do. Therefore, it's not really equivalent.
16 It's introduced some new thing, and we don't know what
17 it is.

18 MR. BANERJEE: It's noted anyway and kept
19 in some file, because we're not going to sit and look
20 at all these, and there are thousands of these curves,
21 right? Whenever this is generated and something looks
22 out of sync or an analyst doesn't understand why it
23 is, it should be put into a file of some sort saying
24 is this weird behavior in this figure which I haven't
25 figured it out, but we want to go back and take a look

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1 at it at some point and try to understand.

2 MR. CARUSO: Isn't this why you're
3 developing this ACAP system, figure of merit, to be
4 able to automate these sort of assessments and
5 determine if something like this occurs, whether it's
6 significant?

7 MR. STAUDENMEIER: That's correct, and I
8 bet if I ran this run again with the code fixes that
9 I put in recently, it would give better results than
10 that.

11 MR. WALLIS: How much are you betting?

12 MR. STAUDENMEIER: At the next break, I
13 was going to go up and start up the run and try to get
14 results before the afternoon.

15 MR. WALLIS: Go ahead.

16 MR. STAUDENMEIER: So, I'll show them to
17 you and whether they're worse or better at the end of
18 the day if you want.

19 MR. WALLIS: I'd like that.

20 MR. KRESS: Tell us what fixes you made,
21 and then we'll put a bet down. I was kidding.

22 MR. BAJOREK: Joe, when was the release of

23 --

24 MR. RANSOM: Who is the guy who will make
25 the changes to say improve the situation?

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1 MR. STAUDENMEIER: I mean, the bug fixes
2 I made had nothing to do with this run, but every run
3 I've made with these bug fixes in, it's an interfacial
4 drag model. It's improved everything I've ran so far,
5 and a better way to improve this.

6 MR. WALLIS: So would you do that? I
7 think that would be a wonderful test. You do that
8 today, and we'll see the results.

9 MR. STAUDENMEIER: Okay.

10 MR. BANERJEE: But in the end, there has
11 to be some sort of traceability where this is noted as
12 being a problem. Then when there's a fix, the problem
13 goes away. You know, I think without that, we're just
14 doing very qualitative stuff here.

15 MR. BAJOREK: It's also, and I want to try
16 to get to this because I'm going to go through some
17 UPTF calculations. It's also a bit dangerous to focus
18 your intention on a single transient or a single run.
19 You start focusing on how good this one might look or
20 what the error or problem might be on that specific
21 transient.

22 We feel that is of most value right now is
23 to get things set up so that we can do lots of
24 calculations, look at these en masse, in general, and
25 see is this happening in all of our transients? Is

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1 this something that's just happening in LOFT, or do we
2 see this in all of our small break transients to give
3 us a means of saying oh, you have a serious problem
4 either in the break flow model, the steam generator
5 heat transfer, and then focus your attention on that.

6 MR. WALLIS: I think we have to move on.
7 We're going to see a lot of these, and we're going to
8 have the same questions again. This is slide number
9 three I think here.

10 MR. FORD: The trouble is, it's
11 fascinating stuff.

12 MR. WALLIS: Well, we can stay until
13 midnight I suppose, too.

14 MR. BAJOREK: Okay, let me go through the
15 next few of these because I think we're going to wind
16 up with the same types of comments on why is the red
17 curve different from the blue and it's opposite from
18 the data. What I'm going to point out is that we have
19 run a wide variety of transients.

20 In some cases, we looked at these and
21 subjectively concluded that TRACE is doing about as
22 good a job as its predecessor code. The last one was
23 a separate effects for in surge, out surge. We've
24 looked at the radiation model for BWR components. In
25 this case, TRACE --

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1 MR. WALLIS: The data are right on top of
2 the --

3 MR. BAJOREK: It's doing a pretty good
4 job.

5 MR. WALLIS: Well, that's good. Now,
6 that's a nice thing to see.

7 MR. BAJOREK: I thought you were going to
8 catch this.

9 MR. WALLIS: How did you not manage to
10 catch that since you fudged everything else?

11 MR. BANERJEE: What happened to TRAC-B
12 there?

13 MR. BAJOREK: It was attributed to a
14 difference in the natural convection heat transfer
15 coefficient. In TRACE, it was a bit lower, quite a
16 bit lower than usual.

17 MR. WALLIS: That's predicted from a
18 correlation, natural convection correlation?
19 Predicted from a correlation?

20 MR. BAJOREK: Probably, yes.

21 MR. BANERJEE: How did TRACE get one-fifth
22 the heat transfer coefficient?

23 MR. BAJOREK: That I don't know.

24 MR. WALLIS: Now, that is interesting.

25 MR. BAJOREK: Okay. There are differences

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1 in some of the models. There are other cases where
2 TRACE is substantially different from the data or what
3 its predecessor code. These have been turned in,
4 okay, to the model development team.

5 This one, the suspicion was that there was
6 a problem in the 3-B level tracking model. In
7 addition, there were also problems that were indicated
8 in the transition boiling. They also may be related
9 to the latest bug fix that was found in the annular
10 mist, where some of the nodes, part of the core was
11 stuck, and it was inordinately low heat transfer
12 coefficient, even though physical conditions says it
13 should be quite a bit larger.

14 MR. WALLIS: It was funny, that one. That
15 was really a big difference.

16 MR. BAJOREK: Yes, and this is one that we
17 basically --

18 MR. WALLIS: Generally you'd expect your
19 modifications to TRAC-B to be improvements.

20 MR. STAUDENMEIER: Actually, that one I
21 looked at a little bit, and I think that's due to some
22 CCFL problems. You're not getting water penetration
23 into the bundle.

24 MR. WALLIS: TRAC-B does.

25 MR. STAUDENMEIER: That's right.

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1 MR. WALLIS: And you have the same CCFL --

2 MR. STAUDENMEIER: No, we don't. The
3 models are different. The interfacial drag models,
4 and I have to look at see about the CCFL.

5 MR. BANERJEE: Well, there's a big
6 difference between TRACE and TRAC-B at that stage, and
7 TRAC-B I presume, was just the flux model, right? I
8 mean, that's what works in a vertical broad bundle.

9 MR. MAHAFFY: John Mahaffy here. Let me
10 put this into context and hopefully let it run along
11 a little more smoothly. When you look at these
12 results, what you want to be thinking about are two
13 things. This is a baseline, and more importantly, it
14 disappeared in the noise a little bit.

15 He's setting this up as an automated
16 process so that all the work that he went through to
17 get these results, the next time around, he punches a
18 button, and they all come out again. Joe Kelly is
19 systematically going through all these physical
20 models. You come back here a year from now, and he'll
21 tell you a completely different story, I hope.

22 MR. BANERJEE: Can you revisit exactly
23 these ones?

24 MR. MAHAFFY: You can ask for whatever you
25 want there, but again, this is your baseline. If

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1 anybody is going to give you improvement in physical
2 models in one of these codes, Joe's the guy. You want
3 to look for what the changes are over time because
4 they are going to happen.

5 MR. WALLIS: I think we understand that.
6 I think we understand that any code is going to have
7 trouble because the physics are not very well modeled
8 somewhere, any code.

9 MR. MAHAFFY: These are a little worse
10 than most.

11 MR. WALLIS: The point is that eventually,
12 when we want to write or you want to write a letter to
13 I presume to the Commission, the public's going to
14 see, showing that with all this investment of time and
15 money, you have a code which is better than the one
16 before. Otherwise, why did we do it? So, eventually,
17 we want to reach that point. That would be a point we
18 would like to reach not too far in the future.

19 MR. BAJOREK: And that's what hopefully
20 we're setting ourselves up for because we're at the
21 point now that when we look at all of the simulations
22 en masse, we feel that the code consolidation part of
23 the effort is over. For the most part, we see TRACE
24 doing a comparable job to its predecessor code. There
25 are clearly some exceptions, and even in the cases

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1 where it looks like it's doing a comparable job, we
2 see problems. That's what we want to start to focus
3 our attention one.

4 Every single one of these cases that had
5 been run have been put into the AV script format. So
6 as we do get bug fixes, we're going to be able to go
7 back and repeat all of these. Six months or a year
8 from now as we improve the reflow model, we improve
9 condensation, approve interfacial drag, we hope to be
10 able to repeat most or all of these simulations to
11 find some parameters and metrics in order to track how
12 much better it's getting. So, this is really, I
13 think, as Dr. Mahaffy pointed out, this is a baseline.
14 This is a bit of a starting point.

15 MR. BANERJEE: So in your protocol, this
16 is the control? This is more or less what everything
17 else is going to get compared to?

18 MR. BAJOREK: Yes.

19 MR. BANERJEE: Okay, so periodically then
20 in your protocol, you repeat these and you will have
21 some measures, hopefully not too statistical with
22 those things, but eyes pretty good, and then you come
23 eventually to some point where all of these things
24 will improve. Then you will come to us and say wow,
25 now we've got a code, right?

1 MR. BAJOREK: We're hoping you say that.

2 MR. BANERJEE: Okay.

3 MR. RANSOM: Well, one thing about the
4 assessment effort, you know, in the past you've had
5 people like Brookhaven who were an independent
6 assessment. You know, they were not the code
7 developer and so there was a bit of an antagonistic
8 relationship which was beneficial, actually. You got
9 a little more objective view because you can pick
10 cases and prove about any point you want because of
11 these differences and plus or minus.

12 So, in a way, the assessment process needs
13 to have some independent objective way, I guess, of
14 giving it an across the border assessment. I guess I
15 haven't seen that yet in your plans. You know, the
16 developers are always going to choose cases that tend
17 to prove the point they want to prove, and it's just -
18 -

19 MR. BAJOREK: No, I think I'm going to
20 show you where that hasn't been the case, and what we
21 intend to do with the assessment matrix and the
22 treatment is going to change. Let me show you that.

23 MR. WALLIS: Approximately equivalent is
24 a pretty vague term, though.

25 MR. BAJOREK: Yes, it is. In the next

1 phase, we need to begin to establish these figures of
2 merit, these parameters, and I think what engineers
3 want, give me a number. Give me some type of a
4 parameter where I can get some type of a numerical
5 measure on how much better your code is getting with
6 time.

7 MR. BANERJEE: Well, it means to me that
8 the uncertainty bands between the two -- well, say the
9 prediction and the experiments, have at least some
10 overlap. There really something is wrong, right, but
11 if the experiment, your band is there --

12 MR. KRESS: Yes, I think in general, we
13 ought to think in terms of uncertainty bands as your
14 figure of merit somehow.

15 MR. BAJOREK: Okay. Just to wrap up the
16 code consolidation, we feel that the code
17 consolidation part is complete at this point. We've
18 identified problems and issues. There's been some
19 situation with robustness that have made the code run
20 slow, not giving us the results we want.

21 We've seen problems in the level tracking.
22 There's been several bugs in there that have been
23 fixed along the way. The reflow model, we know needs
24 to be improved, which is why we're going to the
25 interim reflow model.

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1 At this point, we'll start to focus on
2 better quantification of the models and improving the
3 models within the code.

4 MR. WALLIS: Does that mean that TRACE is
5 not ready for use for regulatory purposes?

6 MR. KRESS: Not ready for prime time.

7 MR. BAJOREK: I guess that --

8 MR. KRESS: So example, for AP1000 and
9 ESBWR?

10 MR. BAJOREK: I think it can do those
11 cases provided you have done the assessment that's
12 very important to those cases. I would not trust
13 TRACE until we do the assessment against APEX AP1000,
14 perhaps some of the APEX AP600 tests, okay? These are
15 small break processes, and we've seen that there's
16 problems in the L3-7 simulation, and we're still
17 moving ahead with some of the other small break cases.
18 So, I don't think we can trust it at this point.

19 In its behalf, I would add that we've
20 taken the RELAP model, converted that to TRACE. We've
21 rerun the simulation, and have gotten results that
22 look much like the RELAP calculation. RELAP as well,
23 we would have to do some additional assessments in
24 order to look at level swell and entrainment and some
25 of those things that we really don't trust in any of

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1 the codes at this point.

2 Some of the shortcomings of assessments
3 that have been done in the past, one, it really hasn't
4 been efficient use of the available input decks. In
5 some of the cases, ECC bypass for example, you go to
6 the trouble of setting up a model of a Creari or a
7 UPTF. spend months getting one of these decks
8 together, and you might simulate one test.

9 Well, there's been lots of very good tests
10 run in these facilities, and we haven't always
11 exploited this additional experimental data to look at
12 how does subcooling, how does pressure, how do other
13 flow conditions affect your transient.

14 In general, and I think you saw that, you
15 know, quite a bit over those last comparisons for the
16 code consolidation. In general, why a code looks good
17 or bad or excellent or whatever type of subjective
18 term you put on that, is really in the eye of the
19 beholder. The idea of assigning or developing a bias
20 and uncertainty to a particular transient or to a
21 model package has usually not been done. We want to
22 try to start getting into that.

23 So, as we take --

24 MR. WALLIS: Do you know what the vendors
25 do when they do this 59 runs using statistical stuff?

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1 They put in uncertainty and all the parameters. They
2 know how to put it in, so that is the way that things
3 are going in the use of vendor codes. It ought to be
4 the way to go with your code.

5 MR. BAJOREK: Well, that's pretty much
6 where we are headed. I think that we have a bit of a
7 tougher job to do because we need to get this code to
8 look at a much broader situation.

9 When we did the code for TRAC development
10 for Westinghouse, we only had to look at PWR's, and we
11 focused on three and four loop PWR's. By the time it
12 took us to freeze the code where we thought it was
13 doing a good job, to getting something with all of the
14 bugs out so that we and the staff were satisfied with
15 the assessments, that took another three or four
16 years. Now, that's a very small subset of plants.
17 We're trying to do this four a three, four loop PWR's
18 and BWR's and any other variations.

19 MR. WALLIS: Your model improvement you
20 talk about here is all in the constitutive of
21 equations. It's not in the T's and momentum equations
22 and all that stuff, is it? Why don't you put some
23 effort into that?

24 We know the representation of multi-
25 junction nodes is very poor so far, but we don't have

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1 any measures of its uncertainty. It would seem
2 impossible to put it in then. You've got some model.
3 Put some coefficients in it or something and try to
4 evaluate their range against some data.

5 Say yes, we've got a model for a T, which
6 is pretty crude, and does the momentum go this way or
7 that way. Well, it's got to have some range. We've
8 got a coefficient which we can compare with data, and
9 then we can use that in our uncertainty analysis, not
10 just that the constitiute level of correlations, but
11 more back of the fundamental bits that go into the
12 balances in the code.

13 MR. BAJOREK: I think that's a good idea.
14 How would I use that in a full scale application,
15 though, where I have lots of T's?

16 MR. WALLIS: Well, if you have a momentum
17 equation, which you know, you can put in some
18 distribution coefficients or something for the
19 averaging and say that, you know, you know there are
20 certain situations where it flows around the bend and
21 the liquids are all thrown to one side and so on,
22 where the averaging is not going to be very good
23 across the section. Maybe you're off by a factor of
24 two.

25 Okay, well, is the data that shows what

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1 the coefficient should be to get a better momentum
2 balance? Can you put that in your uncertainty
3 studies? You know, think about that.

4 MR. BAJOREK: Okay.

5 MR. WALLIS: You know, it's not just that
6 the correlation level, but you need to look at the
7 uncertainty.

8 MR. RANSOM: I think along those lines
9 what you'd like to get to is once you have put those
10 parameters in, then you'll do like 59 calculations and
11 take the temperature traces and what the bound of that
12 is, and you've got 95/95 certainty in terms of you
13 have bounded.

14 MR. WALLIS: Then you can answer the
15 critics then. You can say that we've made this
16 momentum model and these are the uncertainties in it.
17 We actually put those uncertainties in the code, and
18 we show that for this application, it matters or
19 doesn't matter.

20 MR. BAJOREK: Okay. Something to think
21 about.

22 Over the course of 2003, we're starting to
23 get into the point where we're going to start
24 assessing the code in order to try to get some of
25 these biases, uncertainties, parameters, to help to

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1 guide us in future model development. I would claim
2 at this point we've done work in UPTF looking at ECC
3 bypass.

4 A year ago, we had done some work for
5 taking a look at the break flow model, trying to
6 characterize its accuracy, looking at ECC bypass. Joe
7 Kelly is going to spend the rest of the morning
8 talking about work on the reflood model. We start
9 looking at those processes which are highly ranked in
10 most parts.

11 What we're doing is we're trying to go
12 after those first because we think those are the ones
13 that may have the largest uncertainty in BWP and BWR
14 application. We've done some work on those. We've
15 also been making use of some of the RBHT in order to
16 address level swell and heat up at low pressures, as
17 may be important for AB1000 application.

18 We're just getting to the point where
19 we're getting TRACE to start doing some of what I
20 would consider a traditional small break assessments
21 that would normally have been left to RELAP.

22 An example on how we're changing the
23 assessment in the approach. Let me use ECC bypass as
24 an example. If I go back to the developmental
25 assessment manual, you'll find one case in there to

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1 look at ECC bypass, which is important because it
2 really sets the stage for reflood and the PCT's and
3 the PWR that determine as you get closer to the 2200
4 limit. This is really your major period for energy
5 removal from the core.

6 Right now in the developmental assessment,
7 you'll find a single case in there. UPTF test 6, run
8 133. We're not going to depend on that single case,
9 and I'll show you why you don't want to. We're
10 expanding that to look at the other cases in test 6,
11 which is a relatively simple thing to do once you have
12 these scripts set up, and it's just a matter of
13 changing the input deck and gathering the experimental
14 data from which to do the comparison.

15 MR. WALLIS: We have had some concern with
16 the way that NRR lets the vendors sometimes do one
17 assessment rather than a whole lot of assessments. If
18 they really wanted to show that their code is good,
19 they should do a whole patch of assessments.

20 MR. BAJOREK: Traditionally what the
21 vendors have done is this set right here, and partly
22 because of that concern, these tests look at uniform
23 injection around the downcomer. That's fine for a lot
24 of cases, but it's not for all plants because there
25 are some cases, then you look at their single failure,

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1 they have the asymmetric injection around the
2 downcomer.

3 That can behave significantly different
4 than this type of an injection pattern. That's seen
5 here. AP600. AP1000 has direct vessel injection,
6 okay. You need to look at a case like this, test 21
7 where the conditions might be quite a bit different.

8 But, you look at the assessment for the
9 code, they're relying primarily on test 6. So, what
10 we've done is we've taken the model for UPTF. We've
11 tried to use a nodalization that eventually will be
12 preserved, in this case a PWR, preserving the axial
13 noding and the radial noding. In this case, we've
14 picked one where we have eight sectors, so each of the
15 hot legs and cold legs can be isolated into a separate
16 region.

17 Just by way of reference, UPTF was run by
18 injecting steam into the central region where the coil
19 would -- the steam would go down through the lower
20 plenum up the downcomer, and out through a broken
21 loop, sweeping liquid that might be injected through
22 any of the three cold legs.

23 Okay, our approach now is to, let's say
24 now, we've missed part of it. This is UPTF test 133.
25 This was the previous developmental assessment. It

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1 shows the core steam flow. Subcooling, when it gets
2 up to its maximum pressure, is about 36 degrees.
3 Think of this as a test where the water is coming in
4 essentially saturated, most of it.

5 Figures of merit that we've defined for
6 this, okay, the ones of most importance, upper plenum
7 pressure, lower plenum water level. We want to see
8 when, and what's the net delivery to the lower plenum.

9 Is the water going to the lower plenum out
10 the break, or is it collecting in the cold leg, which
11 is possibly in a one dimensional pipe which represents
12 those. So, we define figures of merit. We look at a
13 lot of other things, but these are the ones which we
14 feel are the most important. We made comparisons then
15 to the upper plenum pressure, to the data.

16 The data are the X's. The upper plenum
17 pressure is the blue curve in this case. It does a
18 reasonable job for this run. This tells us something
19 about the break, where the water is collecting, and
20 the other one, which is of most importance, is the
21 lower plenum water level.

22 MR. WALLIS: Which curve is which here in
23 all of these?

24 MR. BAJOREK: Yes. One code, now, okay?
25 We're only looking at TRACE. This top one shows --

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1 MR. WALLIS: More than just one data and
2 one curve?

3 MR. BAJOREK: In this one, there are
4 pressures at two locations.

5 MR. WALLIS: There's a TRAC and a TRACE,
6 isn't there? It's hard for me to tell.

7 MR. BAJOREK: They're both TRACE.

8 MR. WALLIS: Both TRACE.

9 MR. BAJOREK: They're both TRACE.

10 MR. WALLIS: Just TRAC-M. TRAC-M is a
11 trace then?

12 MR. BAJOREK: TRAC-M is TRACE.

13 MR. WALLIS: Okay.

14 MR. BAJOREK: Upper plenum pressure, the
15 blue curve with the circles. E, experimental data are
16 the X's.

17 MR. WALLIS: So what's the red curve?

18 MR. BAJOREK: The red curve is the
19 pressure in the downcomer.

20 MR. WALLIS: Oh, it's not the same place?

21 MR. BAJOREK: So you want to compare the
22 blue curve to the X's, not the red one.

23 MR. WALLIS: Okay.

24 MR. BAJOREK: Okay. This just shows the
25 boundary conditions, the core steam flow is this.

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1 This was the loop flows with this. That's just simply
2 the boundary condition, so there's no comparison
3 there. There's no comparison here either, but this is
4 the total break flow.

5 This is the steam flow going out the
6 break, so the difference is the liquid that is left
7 out the break. This blue one, this is the net
8 delivery when that flow rate to the lower plenum.

9 MR. WALLIS: This is all just data?

10 MR. BAJOREK: This is coming out of the
11 code. There's no data here. There's no data here,
12 but this gives us an indication of what the code --
13 but the most importance in terms of comparisons to the
14 data, the pressure gives us an indication of the
15 condensation rates.

16 The most important one, the net delivery
17 to the lower plenum, the data, or the X's, comes out
18 and tops out with the --

19 MR. WALLIS: That's the cumulative amount
20 of water delivered?

21 MR. BAJOREK: Yes. The code here in the
22 black, those are the most important. We take that
23 transient. We also evaluate it to get the lower
24 plenum filling rate, basically this blue curve, okay?
25 We get this -- we also have information from the

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1 experiment to tell us what that rate was, and it's the
2 slope of the level there, and the condensation
3 efficiency.

4 Now, life would be just great if we just
5 stayed with UPTF tests, run 133. It's a great job.
6 There's not sense looking at any other cases. This is
7 the result that you would get --

8 MR. WALLIS: Something's been tuned here.

9 MR. BAJOREK: Well, either tuned or you're
10 very lucky, but because we are now able to run a lot
11 more cases, we go through the same thing for others,
12 the same figures of merit, the same comparisons,
13 breaking them down. This is the calculated delivery
14 to the lower plenum versus the measured delivery to
15 the lower plenum, okay?

16 MR. WALLIS: The rate of flow at some time
17 or other?

18 MR. BAJOREK: Yes, it's the net, the
19 average rate over an evaluation period. There's only
20 a certain period of time where it would dumped, that
21 you would want to make that same time in there.

22 MR. RANSOM: So it wasn't related to the
23 previous graph. Isn't that the one where you're
24 showing the delivery as a function of time?

25 MR. BAJOREK: Yes.

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1 MR. RANSOM: In your previous slide, which
2 did not agree all that well, and yet the --

3 MR. BAJOREK: Well, wait a second.

4 MR. RANSOM: You're saying the integrated
5 value as well?

6 MR. BAJOREK: What you're looking through
7 -- well, basically you're getting this blue curve by
8 looking at the slope of the black one. This is what's
9 collecting, the rate at which it's coming in is by
10 this squiggle. There's not data on here.

11 MR. RANSOM: Right. The bottom one what,
12 is the integrated value?

13 MR. BAJOREK: The bottom is the collapsed
14 water level in the lower plenum. It's sitting there
15 at zero for awhile. All of a sudden, water starts to
16 dump. It fills up and reached a --

17 MR. RANSOM: And the squares, though, are
18 the data, right?

19 MR. BAJOREK: The X's are the data.

20 MR. RANSOM: And you're showing
21 substantial disagreement, but yet on the other slide,
22 you're showing exact.

23 MR. WALLIS: I don't see how you can get
24 exact 1000 because the blue curve doesn't give exact
25 1000. The blue curve average is less than 1000. The

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1 third figure down, the bright blue curve, who's going
2 to say that's exactly 1000? This is 1000 here, right?
3 It's doesn't look to me as if it's exactly 1000. That
4 blue curve, the third one down.

5 MR. BAJOREK: It looks like it should be
6 a little bit under a thousand. I'm going between the
7 two vertical lines.

8 MR. WALLIS: Average between the two
9 vertical lines, less than a thousand.

10 MR. BAJOREK: It should be less than a
11 thousand.

12 MR. RANSOM: Maybe I'm missing something.
13 Is this just the measured rate at the end of the
14 graph?

15 MR. BAJOREK: It's throughout the
16 evaluation period.

17 MR. RANSOM: Throughout the entire
18 evaluation period?

19 MR. BAJOREK: No, we focused on the times
20 when the NPR associates went through and did
21 evaluations and EPTF tests, and they defined some of
22 the evaluation periods that was used in a lot of the
23 2D3D.

24 MR. RANSOM: So what is the period that
25 this corresponds to?

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1 MR. BAJOREK: Between these, approximately
2 these two, these two lines. It doesn't make any --
3 you don't really care about what goes on very early in
4 time because your steam flow is ramping up, okay, and
5 you're starting to inject over in this period.
6 Nothing is getting to the lower plenum. Then there's
7 a period over which you're starting to fill the lower
8 plenum, and then after which it's just basically full.

9 Okay, so we're focusing on that, when does
10 it start. Once it starts, does the code throw more
11 liquid to the lower plenum than what the data was
12 showing, or substantially less?

13 I'll go back and check the numbers because
14 that does look a little bit higher than what I would
15 get out of this blue curve. It may be the way it's
16 plotted here, the way the squares shifted up, but when
17 we go through this evaluation that has been used in
18 the past for UPTF, it would tell us that test 133
19 comes out pretty good.

20 Now, we're not going to just stay with 133
21 because we realize there are a lot of other
22 situations. Steam flow could be different. Pressure
23 could be different. Injection patterns could be
24 different. So, we've gone through now, and we've done
25 a series of tests.

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1 Test 6, the traditional vendor
2 calculations here, okay, and do that evaluation for
3 all of them. In general, not too bad. We get more
4 problems, however, when we start to take a look at
5 test 7, asymmetric high patterns.

6 Now the code is having a bit more
7 difficult time, and we started to look at this,
8 wondering why are we starting to have differences?
9 These aren't too bad, but there's a few cases, these
10 in particular, where the data was showing delivery to
11 the lower plenum, and the code wasn't doing anything
12 near as well.

13 MR. WALLIS: Was the code a one
14 dimensional code? It doesn't model asymmetry?

15 MR. BAJOREK: Well, there's cross flow
16 within the downcomer. It's like a 2-D representation.

17 MR. WALLIS: It's a 2-D representation of
18 the downcomer, so you would catch some asymmetry?

19 MR. BAJOREK: Yes.

20 MR. WALLIS: If water were all pouring
21 down one side and the steam going up the other?

22 MR. BAJOREK: Yes.

23 MR. FORD: Steve, if you just go back to
24 the previous one.

25 MR. BAJOREK: Sure.

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1 MR. FORD: There's obviously a
2 distribution of the ratio of the observed to
3 calculated values from that database. If you did the
4 calculations for one of the TRAC models, would you get
5 the same distribution, or would it be offset from one?
6 The distribution of the ratio calculated to observe,
7 would it be offset from one?

8 MR. BAJOREK: I would suspect that TRAC
9 would do something similar, okay, but the original
10 developmental basis didn't look at any other cases.
11 To my knowledge, I don't think anyone has used any of
12 the codes to take a look at test 7. At least I
13 haven't seen it.

14 MR. FORD: Because that would be a useful
15 metric for determining whether your TRACE model has
16 improved over the others. That is, what is the mean
17 value of the observed to calculated value, and the
18 variance in that distribution. If you've squashed up
19 the variance and moved it to one, then you're doing
20 great.

21 MR. BAJOREK: Yes, if we get everything on
22 that line, we're good. Now, what we're getting to now
23 is coming up with that metric. We can take these and
24 get some type of an average bias and uncertainty for
25 this distribution. Of course, we can identify which

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1 cases are doing worse, and we want to focus why. We
2 want to correct that, but from this distribution for
3 the baseline model now, we can assign a metric to
4 this, as bias in water delivery and an uncertainty
5 about that.

6 I wish we had that for TRAC-P or for some
7 of the other codes, but no one has run those, and
8 since this is what we're going to use for future
9 development, I don't think it's worth instituting
10 another project to look at a code that we aren't going
11 to be using anymore.

12 MR. FORD: Obviously I've never done
13 correlations for thermal hydraulics problems. I have
14 done it for others. The interesting thing is to look
15 at the uncertainty of your measured values. In two of
16 your previous cases, you showed that the measured
17 values is a huge uncertainty, which actually swamps
18 out any of the uncertainty in your models.

19 MR. BAJOREK: Yes.

20 MR. FORD: I don't know whether that would
21 be planned.

22 MR. BAJOREK: I haven't done it to this,
23 but in the past, I remember we had done that for
24 reflood heat transfer. At some point, you realize you
25 can't make the code any better than the scatter in the

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1 data.

2 MR. FORD: Dead right.

3 MR. BAJOREK: So at some point, when the
4 bounds of this, if I put arab bands on either side of
5 this, and they start to approach the experimental
6 data, my job is done until I get better experimental
7 data where I can run a better test.

8 So, we started to focus on these two in
9 particular. We weren't getting anywhere near the
10 delivery, and we were realizing, well, these were at
11 slightly different pressures. We were seeing more
12 subcooling going on in these. Well, that's pretty
13 important now for something like test 21 where I'm
14 injecting directly to the downcomer. We were seeing
15 some additional variation, okay. A couple of tests
16 were delivering a lot more and a couple more where we
17 aren't getting anything.

18 MR. FORD: That one way over in the left-
19 hand side there, that one, is that experimental
20 uncertainty, or you moved that all the way over?

21 MR. BAJOREK: No, this one probably should
22 be replaced with a question mark at this point,
23 because as we looked --

24 MR. FORD: Because of the model or the
25 data?

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1 MR. BAJOREK: I think it's something in
2 the model. This is one where I think we really want
3 to go back and look at the input. This one is just
4 behaving so strangely in comparison so something else.

5 MR. FORD: Down there, too.

6 MR. BAJOREK: Well, this one --

7 MR. WALLIS: Down there, yes.

8 MR. BAJOREK: In this one, this points out
9 a code deficiency. Once we went through these and we
10 got to test 5, which is the same as test 6, uniform
11 injection but very high subcooling. Now it confirmed
12 the deficiency that we were suspecting when we looked
13 at the condensation efficiency of these. I wish I had
14 that prepared because when we went through all of
15 these, rather than getting a condensation efficiency
16 on the order of .8, which is typical for a lot of
17 those, we were getting condensation efficiencies on
18 the order of .95 to one.

19 We were underpredicting the pressures in
20 many of these, and grossly missing it over here. We
21 delve into this further to find that the root cause of
22 this is the way that TRACE is behaving and generating
23 the interfacial area at the junction between the
24 injection point and the downcomer. It's immediately
25 taking all of the liquid in these cases when it's

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1 subcooled, breaking it into a fairly fine mist of
2 droplets, artificially enhancing the condensation.
3 What this is tending to do is it's trying to
4 increasing the vapor flow to the region, and that's
5 sweeping everything out.

6 So, we look at this for saturated
7 conditions, and we would conclude at this point the
8 ACC bypass model, probably doing a reasonable job.
9 We'll cast that in terms of a metric, in terms of
10 condensation efficiency and lower plenum delivery.
11 That will be a baseline number so that as we make
12 changes, revisions to interfacial area, drag, whatnot,
13 as it affects the downcomer, will be able to track
14 what it does.

15 MR. WALLIS: This is a very difficult
16 problem. I remember Creari had a whole lot of probes
17 in the downcomer, and they measured the flow pattern,
18 and it jumps all over the place.

19 MR. BAJOREK: Yes. Even at UTPF, you see
20 a chugging. There is a chugging, and there's a
21 preferential delivery on the opposite side of the
22 downcomer, but you should be getting, and the code
23 should be predicting more bypass consistent with the
24 subcooling.

25 So, we've noted this as a deficiency.

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1 Future efforts are now going to be correcting this.
2 I think the important thing to point out of this is
3 because the code has been consolidated and we've
4 developed some of these tools that allow us to do
5 additional cases, we're now in a better situation
6 where we can run enough cases to get a bias and
7 uncertainty, and we can run enough cases over a wider
8 range of conditions where we can identify problems
9 that you would not have seen in the prior
10 developmental assessment.

11 I'm not going to go into this too much.
12 How am I doing on time?

13 MR. WALLIS: I wonder if when you do all
14 of this, you're doing to learn that some of the vendor
15 codes maybe need to be compared with more data, and
16 the NRC has accepted comparisons with one test.

17 MR. FORD: I must admit, I'm astounded the
18 way that the GE's and the Westinghouses in this little
19 apex, to get away with just one test. It's
20 unbelievable.

21 MR. BAJOREK: For AP600, we did also do
22 AP-21, the direct vessel injection. I'm not aware of
23 anyone doing the test 7.

24 MR. WALLIS: This is good, though. It
25 means that you're being thorough enough to challenge

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1 some of the comparisons that we've made before, and
2 you're learning.

3 MR. BAJOREK: Yes, and we've picked out
4 cases in the matrix. We haven't picked out the cases
5 which are fairly kind. The test 7 is a difficult one
6 because of the asymmetry. Nodalization and a number
7 of models come into play. So, we are picking cases
8 which are truly going to challenge the code and the
9 modeling.

10 Likewise, reflood separate effects cases.
11 This is in 2003 and 2004. Now that we have the
12 interim reflood model, we want to really start to do
13 a lot more assessment here.

14 MR. WALLIS: Is this what Joe Kelly is
15 going to tell us about?

16 MR. BAJOREK: Joe is going to talk about
17 the models. He's going to show you some results,
18 current and with the interim reflood model from 31504,
19 which is a one-inch per second -- one inch per second
20 will be greater?

21 MR. KELLY: Yes.

22 MR. BAJOREK: One inch per second case.
23 31701, which is 6.1 inch per second case. Both these
24 are run at 40 psi. They've been used traditionally
25 for TRAC-M and a lot of codes developmental

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1 assessment. TRAC-M has also used this one.

2 Well, in a similar fashion, we don't want
3 to rely on tests at just two reflood rates and one
4 pressure because we know there is a large pressure
5 effect, especially when we need to analyze PWR's where
6 the containment pressure might be 20 psi.

7 So, we're expanding the matrix to include
8 these. We'll keep these. These will hang around, but
9 we'll look at reflood rates, which are lower than one
10 inch a second, and give us peak cladding temperatures
11 greater than 2200 degrees and so is a few
12 thermocouples over 2200. Different pressures,
13 variable reflood rates, and we won't just focus on one
14 particular facility.

15 MR. WALLIS: Are you going to look at all
16 of the evidence and again a selected set?

17 MR. BAJOREK: Selected -- I'm sorry,
18 selected set of evidence as to?

19 MR. WALLIS: Well, previously you looked
20 at three FLECHT-SEASET's. Now you're looking at
21 whatever it is here, a 14 or something. How many
22 tests were there? If there were 100, why not all of
23 them? I don't know, are you looking at all of the
24 tests?

25 MR. BAJOREK: Well, you wouldn't want to

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1 do all of them.

2 MR. WALLIS: Why not?

3 MR. BAJOREK: Because more than two rods
4 burned out in the FLECHT-SEASET.

5 MR. WALLIS: Okay, if there was something
6 wrong with the test, you can disregard it, but again,
7 that's okay, but are you essentially looking at all of
8 the valid tests?

9 MR. BAJOREK: I think we have most of the
10 valid tests.

11 MR. WALLIS: Okay.

12 MR. BAJOREK: We certainly have the ones
13 that will give us a way to examine reflood rate,
14 pressure, inlet subcooling, and as we take those
15 similar situations to other facilities, we'll see the
16 effect of hour shape, okay, which changes the overall
17 hydraulics in the bundle, pitch to diameter ratio here
18 in the FLECHT 98 rod bundle. We will be using the
19 RBHT. We're getting that data now. We have a model
20 set up.

21 We haven't selected which tests or how
22 many, but we would expect to put somewhere between a
23 half a dozen --

24 MR. WALLIS: RBHT is what's going on at
25 Penn States, is that it?

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1 MR. BAJOREK: Yes, that's the Penn State
2 bundle. We'll be getting a number of those -- we're
3 getting that data right now into the format that we
4 can use, but rather than relying on one, two, or three
5 tests, hopefully within a year, year and a-half, we've
6 got to collect data for all of these.

7 We're looking at the upwards of 25 to 30
8 different reflood tests from which we'll do similar
9 evaluations to get bias and uncertainties in transfer
10 coefficients, droplet size, steam temperatures,
11 whatever parameters we can glean out of the data.

12 MR. WALLIS: Now, for regulatory purposes,
13 is this because reflood is the process which
14 determined the peak clad temperature, which is a
15 regulatory measure, and there's a likelihood that
16 PWR's might ask for say power upgrades or something,
17 which would challenge this peak clad temperature, and
18 therefore, the Agency needs more certainty about what
19 that peak clad temperature is going to be? Am I just
20 rambling, or am I talking sense here?

21 MR. BAJOREK: Well, I think you're making
22 sense because as plants are changing today, we're
23 seeing two things coming up over the horizon. One are
24 power upgrades, trying to get as much reflood out of
25 the core.

1 MR. WALLIS: Reflood is the key process.

2 MR. BAJOREK: Right now in most PWR's,
3 it's your reflood and peak cladding temperature that
4 is the lumening factor.

5 MR. WALLIS: So it's a regulatory need on
6 which you're hanging all this work?

7 MR. BAJOREK: Yes. It may increase if we
8 start to go to risk informed regulation. One
9 possibility is with performance based fuel, that limit
10 for peak cladding temperature may increase to 2300.
11 It may change to something else. A temperature in
12 some type of an oxidation criteria.

13 I won't go in, but they're looking at a
14 number of different possibilities here, but it may
15 translate into the core being upgraded, operating so
16 that in a hypothetical accident, it's there at a
17 higher temperature for a longer period of time.
18 Uncertainties in your heat transfer coefficients now
19 are going to be magnified.

20 We saw some of that in upgradings that we
21 did awhile back when best estimate was first applied.
22 The transients became sufficiently long, and boiling
23 in the downcomer started to become a concern.
24 Transients became longer, okay?

25 We'd expect to see other types of changes

1 to the transient, perhaps making them longer so
2 uncertainties propagated over a longer period of time
3 have more of an impact on peak cladding temperature or
4 clad oxidation or whatever regulatory limit that is
5 eventually set as the fuel becomes performance based
6 and perhaps as the break size is also redefined.

7 So, in terms of assessment that we --

8 MR. WALLIS: What you're saying is
9 compatible with what someone from NRR would say, in
10 terms of the need?

11 MR. BAJOREK: I've been warned about
12 speaking for NRR.

13 MR. WALLIS: I mean, it would be good if
14 both sides -- I mean, you must be talking to them, and
15 presumably what you're saying takes into account input
16 from those guys. Yes?

17 MR. ROSENTHAL: Rosenthal Research, NRR
18 and RES are jointly participating in the efforts to
19 risk inform 5046. There's a working group of NRR and
20 RES people. NRR is putting forward documents that
21 show a rulemaking -- I don't want to get out a head of
22 what's in the concurrence -- rulemaking related stuff.

23 MR. WALLIS: All right.

24 MR. ROSENTHAL: I think that we're charged
25 with the technical basis so that in providing

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1 information to NRR. So, for example, in the RES
2 branch operating plant, the implication of what would
3 happen if you changed the break size to let's say
4 eight inches, changed the -- allow a power outbreak
5 based on an eight-inch break in the current regulatory
6 criteria, what would then happen to beyond eight-inch
7 breaks, and would that be okay, and what might we be
8 seeing. That kind of work is in our operating plant.

9 So, I think we're reasonably well
10 integrated, but the code running to support this
11 rulemaking effort will be done in our branch.

12 MR. BAJOREK: Yes.

13 MR. WALLIS: Thank you. We're going to
14 see this. In our other activities, we're going to see
15 results of this work?

16 MR. BAJOREK: Yes.

17 MR. WALLIS: Thank you.

18 MR. BAJOREK: I think in terms of the
19 focus of this work in comparison to what NRR is doing
20 right now, I think the focus right now is on the
21 advance plants. There's so much work and so much need
22 to evaluate what's going on there, that some of this
23 isn't quite in the forefront.

24 MR. WALLIS: Is that really so? I mean,
25 it seems to me that power upgrades for PWR's are

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1 really going to happen, or maybe really going to
2 happen. Advance plants may or may not really happen.
3 So, I'd be more concerned about it proving a power
4 upgrade for PWR's that are there now, if there was too
5 much uncertainty about peak clad temperature and about
6 what might happen years from now when a more advanced
7 reactor is built.

8 MR. BAJOREK: I think completing this is
9 going to help give us a tool by which we might be able
10 to do audit calculations. I don't think we're there
11 yet, but with the interim reflood model, assessment
12 that we're planning here in the near term basis that
13 I'd mentioned on the previous overhead, we've also
14 initiated work to look at CCTF and SCTF.

15 In some cases, these are run in a separate
16 effects type of mode. In other cases, we have gravity
17 reflood in the case of CCTF and at least one of the
18 SCTF. That's not on here.

19 As we started to do in the UPTF example,
20 we want to try to characterize the accuracy of the
21 code in terms of a bias and uncertainty on those
22 parameters which are of most interest, not peak
23 cladding temperature or necessarily quench time, but
24 things like the heat transfer coefficients, the carry-
25 over fraction that we get in these reflood tests. The

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1 void fraction or mass distribution that we see in the
2 bundles. Steam temperatures, other parameters that we
3 can relate to models which are actively used in the
4 code for that.

5 Now that we have SNAP up to speed, we're
6 also starting on the small break integral tests. We
7 have people working on ROSA, modeling SB-CL-05, and
8 would anticipate including a number of additional
9 cases where I think this is like an equivalent of
10 about a four-inch cold leg break, and we would be
11 looking at various break sizes and eventually
12 expanding this to look at other parameters that were
13 found to have large effects in the ROSA facility.

14 BETHSY, it's unfortunate there isn't more
15 experimental data readily available to that because it
16 was a well instrumented facility. It's I believe the
17 only or one of two which has a full integral facility
18 layout, keeping all of the loops, all three of the
19 loops rather than lumping them compared to other
20 tests, or modeling ISP-27, which was a small break in
21 which they had shut off the high head injection system
22 in order to get a peak cladding temperature.

23 We're starting some of the semiscale
24 tests. We're also using the APEX data that we're just
25 getting for the AP1000 type tests. We're setting up

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1 a model, and we'll be running at least first the
2 double ended DVI line cases. We've also got a couple
3 of cold leg small breaks that we're putting in that.

4 We have run, and we set up the AV scripts
5 to do THETIS as well as the Oak Ridge case, which I
6 showed on the overhead earlier so that as we start to
7 make changes to the interfacial drag model in the
8 core, we're going to be able to rerun those, and we
9 anticipate using THETIS and some of the RBHT
10 interfacial drag tests to help us answer the question
11 that we've been getting out of AP1000, is TRACE and
12 RELAP. We're using RELAP for this assessment as well,
13 over predicting the amount of level swell if we were
14 to get uncovering in a hypothetical accident in AP1000.

15 MR. RANSOM: Maybe I missed something, but
16 how is the RBHT test series going to provide
17 interfacial drag?

18 MR. BAJOREK: This was a series -- we had
19 three passes in which those tests were being run. In
20 2001 and 2002, they ran a series of traditional
21 transient reflood tests. Heated the bundle up,
22 reflooded from the bottoms and various flooding rates,
23 different pressures. So, we have a set of data that
24 looks -- it's comparable to FLECHT and some of that,
25 those types of facilities.

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1 Earlier this year, in order to get some
2 better information on rod bundle interfacial drag, we
3 ran a series of tests in which the bundle was
4 essentially flooded. It was run at different powers,
5 different pressures, at relatively low powers, so that
6 the exit void fraction was on the order of .4 or .5.
7 Joe, do you remember?

8 MR. KELLY: Maybe a little higher.

9 MR. BAJOREK: Maybe a little bit higher.

10 MR. KELLY: But they're basically level
11 swell tests.

12 MR. BAJOREK: Yes.

13 MR. RANSOM: But the interfacial drag is
14 obtained by just inference, I guess? You try to
15 simulate it?

16 MR. BAJOREK: Yes.

17 MR. RANSOM: See what interfacial drag?

18 MR. WALLIS: Try to predict the void
19 fraction, presumably.

20 MR. BAJOREK: What?

21 MR. WALLIS: You try to predict the void
22 fraction?

23 MR. BAJOREK: Right, yes. What's nice on
24 this compared to many of the other tests, is we've got
25 a very detailed pattern of DP cells. Three inches in

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1 the central part of the bundle, and the test matrix
2 was adjusted to try to get a variation in void
3 fraction to maximize during where those DP cells had
4 their maximum sensitivity and smallest span and
5 getting some unique data that's going to help us look
6 at interfacial drag. This is going to help Joe come
7 up with a better reflood model in the future.

8 They're also very useful because the lower
9 pressure. The Oak Ridge data and most of the THETIS
10 data was run at high pressures. So, there's been a
11 bit of a crying need for low pressure interfacial
12 drag, and we're very interested in simulating some of
13 these tests. So, we sort of move this up.

14 We're also doing this, these simulations
15 with RELAP so that at some future meeting when we're
16 asked well, even though RELAP has a low collapse
17 level, is it really flossed up to the top of the core,
18 we're going to have a better -- we're going to be
19 better able to answer that.

20 MR. BANERJEE: So RELAP has just an
21 interfacial drag without any sort of drip flux model
22 at all in it?

23 MR. BAJOREK: No, I think it has a drift
24 flux model in it.

25 MR. RANSOM: That's my understanding.

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1 It's drift flux based.

2 MR. BANERJEE: There's a simple analytical
3 solution to this level swell, using a drift flux
4 model.

5 MR. WALLIS: Steve, I think we're a little
6 bit behind in time. I suggest this is an important
7 slide. You talk about this one. Then you jump to the
8 conclusions.

9 MR. BAJOREK: Let me do that.

10 MR. WALLIS: Because we're just going to
11 look at curves otherwise.

12 MR. BAJOREK: Right, but what I wanted to
13 spend just a few minutes talking about is where we're
14 going in the long run with all of this. We're set up
15 now. We've automated a lot of this. We have a
16 baseline code.

17 As I mentioned in the examples for UPTF
18 and with the reflood, we're going to get now to the
19 point where for various model packages and various
20 models in the code, what would determine a bias and an
21 uncertainty. Now, we haven't exactly decided what
22 parameters those were going to be.

23 I mentioned a few of those, but as we're
24 going through future assessments and model
25 development, we'll define what those parameters are.

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1 We'll do the assessments, be it for reflood or level
2 swell, condensation, break model, come up with a bias,
3 and use those to come up with a multiplier, a term,
4 something that can be varied within the code so that
5 we can sample these in full scale simulations of the
6 PWR or BWR and the results of that in terms of what
7 we'll call the regulatory parameters of interest, PCT
8 or ECR.

9 We'll be able to go from biases in certain
10 models to how they are varied within the code to a
11 statistical distribution at full scale, okay, to
12 determine --

13 MR. WALLIS: Like some of the vendors are
14 doing?

15 MR. BAJOREK: Similar to Westinghouse took
16 a response surface technique. Framatome has done
17 something very similar to this. The details of how
18 you combine these and what cases you run, whether it's
19 59 or 114 and how you are -- that's something that we
20 are going to address.

21 It is in the future because our concern
22 right now is getting the code accurate, quantified,
23 and then in the position so perhaps a year or two from
24 now, then we can start talking about well, does this
25 really correct this bias to get this right, and then

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1 when you propagate its effect at full scale, what does
2 it do out here. Then you have I think a much stronger
3 basis then for saying well, this particular model
4 doesn't really affect your situation, or it has a
5 large effect, depending on what your transient.

6 MR. FORD: Steve, I'm convinced you've got
7 TRACE now in a working mode, and you've got all this
8 data that's been created. Why is it going to take you
9 two years to go through this sort of evaluation
10 process?

11 MR. BAJOREK: Well, I would think it would
12 take about a year to go through and develop all of
13 these and perhaps another year to really --

14 MR. FORD: Is it not just a question of
15 plugging in the inputs of your model and comparing the
16 output with your data, or am I oversimplifying?

17 MR. KELLY: It's a little bit more
18 complicated, like when he talks about looking at heat
19 transfer coefficients, you have to window it over the
20 transient to figure out when you're in that regime and
21 do the comparison. Otherwise, it becomes meaningless.

22 Just as an example, when the vendors do
23 this kind of thing as part of their, say, large break
24 best estimates, they're talking about 20 to 30 staff
25 years to do this work. Of course, we don't have

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1 anything like those kind of resources.

2 MR. BAJOREK: I'm just going back to the
3 days when we developed the best estimate methodology
4 at Westinghouse, to go from a code that we thought was
5 frozen and pretty good to a time when we got some
6 begrudging smiles from the staff, and in an SER, it
7 took on the order of about six or seven years.

8 I think I mentioned that what we're trying
9 to do with TRACE is bigger than that because we have
10 more plants that we have to do it. I guess it could
11 sort of happen in two years if we got to the point
12 where we're (inaudible).

13 I guess we go on. As we get these biases,
14 we'll know what models are being impacted. That's
15 going to guide us in our model development and as we
16 go along, if we need to know what's the effect of
17 disburse flow film boiling heat transfer coefficient
18 on a particular application, we should be able to get
19 that. We'll be able to get individual components.

20 To wrap it up into a nice, statistical
21 methodology that we're convinced is the right thing
22 for the staff and is independent from what the vendors
23 have produced, that's going to take a little bit.

24 MR. WALLIS: If the rationale is very
25 straightforward. You take the data, you make some

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1 comparisons with something. You calculate bias and
2 sigma. That can be automated. You don't have to have
3 someone looking at all these curves and all that. So,
4 that really ought to proceed pretty quickly, one would
5 think. Someone's got to manage it and check that
6 things are happening, but once you know what you're
7 going to do, you show the procedure for doing it, it
8 shouldn't require all that time.

9 MR. FORD: I thought the whole idea of
10 this TRACE development was it was relatively simple.
11 Everything was in one box, if you like, and maybe I'm
12 oversimplifying what I thought it was.

13 MR. BAJOREK: Well, we would love to speed
14 it up, but I think it's a matter of resources. I
15 think in terms of the development team, speaking for
16 everybody, this is the fun part here. It's getting to
17 this and finding out well, why doesn't this particular
18 model work correctly and fixing it. That's the fun
19 engineering.

20 I think we'd love to spend more time on
21 that, but we do have repeating priorities.

22 MR. WALLIS: Well, the fun is in the
23 answer, not in the process. The real fun or the real
24 achievement or the real bang for everything is getting
25 the answer, not just in doing the work.

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1 MR. BAJOREK: You won't believe this until
2 you're convinced of this. I think in terms of
3 competing our priorities, we've got AP1000, ESPWR, ACR
4 --

5 MR. WALLIS: We know these are coming, so
6 we're very impatient waiting for this stuff.

7 MR. BANERJEE: This will be the first code
8 that really can be used with AP1000, will be taking
9 into account the low pressure, reflood level swell,
10 all this sort of stuff. There's no other code that
11 really does that at the moment, does it?

12 TRAC-P doesn't do that, and RELAP doesn't
13 quite get the right --

14 MR. BAJOREK: Nobody's going through this
15 for any small break applications, be it AP1000 or even
16 a conventional plant. This idea or this statistical
17 distribution has only been done for large break
18 applications at this point.

19 MR. BANERJEE: But you're doing it also
20 for small break.

21 MR. BAJOREK: We need to get the small
22 break processes into this as well.

23 MR. BANERJEE: And the ADS and all this
24 sort of stuff? If it's going to be applicable to
25 AP1000, it must have that, right?

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1 MR. BAJOREK: Yes.

2 MR. BANERJEE: Does this preclude that ADS
3 phase, ADS-4?

4 MR. BAJOREK: I think that's in there.
5 I'm just thinking in terms of priorities, getting
6 models that affect all plants versus models and
7 uncertainty for one particular unit that isn't
8 operating yet. You're right. I mean, uncertainty is
9 in the ADS performance and CMT. All those would have
10 to be incorporated into that, and I think in a
11 statistical methodology, okay, you would have to
12 incorporate all of these plus any of those unique
13 features.

14 You know, the performance of the ADS or
15 other components would have to be, those uncertainties
16 would have to be incorporated in this, as would other
17 uncertainties associated with the plant. Has your
18 power shape changed? What's the water temperature at
19 any particular time? What's the burn-up?

20 MR. BANERJEE: The priority is existing
21 plants with the focus on upgrades? What?

22 MR. BAJOREK: Yes. I would say that
23 that's --

24 MR. BANERJEE: I mean, I'm just trying to
25 find a rationale for how you're going to organize

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1 this.

2 MR. ROSENTHAL: Steve, if I could, I think
3 the Office's priority is to risk inform 5046.

4 MR. WALLIS: What's that?

5 MR. ROSENTHAL: Of the ECCS. That will
6 include LOCA, break size redefinition, and all the
7 ramifications thereof, and that comes direct from
8 mission interests and guidance.

9 In order to do that, I think that we
10 recognized that maybe in prior decades, thermal-
11 hydraulics, this kind of work was large break LOCA-
12 centric, and we're trying to get more balance in
13 considering small break stuff as opposed to large
14 break. So, that would be the priority, what kind of
15 work do you need to do to risk inform 5046.

16 Then power outbreaks, although let me
17 remind you that power outbreaks have mostly been --
18 the big power outbreaks are boiling water reactors,
19 and the little stuff is the PWR's, while PWR's tend to
20 be LOCA limited, and large boilers are not LOCA
21 limited. Then the new plants, in part, were using
22 (inaudible), and that's a reality.

23 MR. BANERJEE: But this will work for
24 boiling water reactors, too.

25 MR. BAJOREK: Yes. Okay, just to

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1 summarized and to conclude, we feel at this point
2 consolidating is behind us, and now is the time where
3 we're going to start focusing on model development,
4 accuracy improvement, quantification of how well the
5 code is doing so that at a future time, we can start
6 using this as a part of a statistical methodology for
7 conventional plants and other type, and newer plants.

8 As we've been going through these
9 assessments, again I just want to mention again that
10 we're setting these up so that they're automated so
11 that much of the real grunt work in doing these work,
12 generating these figures, it's going to be more
13 automated. We're still going to have to go back and
14 look at these very carefully, but we think we're in a
15 position now where we can look at a broader number of
16 assessments, and the benefit of that is going to be
17 able to make code improvements faster and hopefully
18 come up with models which are more accurate.

19 MR. WALLIS: Thank you very much. Are
20 there other questions from the members of the
21 subcommittee?

22 MR. RANSOM: Could you remind me what ECR
23 stands for

24 MR. BAJOREK: Equivalent cladding reacted.

25 MR. RANSOM: Reaction?

1 MR. BAJOREK: Reacted, clad oxidation.

2 MR. BANERJEE: Do you have a list or a
3 table of the tests that you are going to be using as
4 the basis for these assessments?

5 MR. BAJOREK: This is the one that I can
6 get copies of this.

7 MR. BANERJEE: Is it in here?

8 MR. BAJOREK: No, it's not in there, but -
9 -

10 MR. BANERJEE: That would be helpful.

11 MR. BAJOREK: I can get you a copy. This
12 is more or less the tests that we've either run or are
13 running or plan to. It's just a working copy that I -
14 -

15 MR. BANERJEE: That would be good, if you
16 could supply that.

17 MR. WALLIS: Are there any more questions
18 or requests?

19 I'd like to thank you, Steve, for being
20 very informative and for having a good interaction
21 with the subcommittee.

22 MR. WALLIS: Thank you.

23 MR. WALLIS: As always, we could always
24 spend more time.

25 MR. BAJOREK: Well, one thing, too, what

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1 we would like to get out of this subcommittee is where
2 would you like to focus attention in future meetings.
3 I mean, there's an awful lot of stuff in any of these
4 simulations. Joe is going to start with the reflood
5 model. We'll go into that, but in the future, if you
6 want to see us go into a condensation model, more into
7 the bypass problem or you know, take a particular
8 transient and tear it apart, we can do that.

9 MR. WALLIS: We are planning, I think, a
10 series of three meetings, isn't it? Isn't this the
11 first one?

12 MR. RANSOM: At least three.

13 MR. WALLIS: At least three meetings, and
14 we can set up the agenda for the next meeting. I
15 think it's going to involve going more deeply into
16 certain aspects of TRACE. I hope we don't have to get
17 some rehashing with some of the faults knew about in
18 the other codes, which is still there.

19 Anyway, we are going to set up several
20 meetings.

21 MR. WALLIS: Okay.

22 MR. BANERJEE: Just one thing, Steve.
23 ROTH was pointing out that the OECD data on LOFT is
24 more reliable. So, perhaps you should look at that as
25 well as --

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1 MR. BAJOREK: We've got a few of the OECD

2 --

3 MR. BANERJEE: You have access to that, of
4 course, don't you?

5 MR. BAJOREK: Yes, we have some of that.

6 MR. BANERJEE: Okay.

7 MR. BAJOREK: That was -- was it LB-1?
8 That's in there. L2-5, L2-6 are in there. Those are
9 good because they're higher temperature. I think LB-1
10 might have been the highest temperature one. That's
11 in the test matrix.

12 A lot of driving the code consolidation is
13 what was already out there and what they had used
14 already for TRAC-P or TRAC-B. So, we kind of had to
15 stay with that, but now that we have the baseline, now
16 that sort of frees us to start looking at tests which
17 are more interesting.

18 MR. BANERJEE: But also could be more
19 accurate.

20 MR. BAJOREK: Well, that's true. I mean,
21 rather than focusing on let's just semiscale, for
22 example, they will make more use out of ROSA, which
23 was a test that was run later on, has other
24 instrumentation, has tests which are, you know, unique
25 and give you information that you didn't get from

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1 those prior assessments.

2 MR. BANERJEE: Also, the series of I don't
3 know how many LOFT runs were done, but one where, you
4 know, the pump effects, the pump rundown was very
5 important in LOFT, which is why you got this rewet.

6 MR. BAJOREK: Yes.

7 MR. BANERJEE: That was artificially cut
8 off, so that you don't get this early drop. You might
9 consider those, too.

10 MR. BAJOREK: I think we do have --
11 there's a pumps on or off. I think it might be L2-5
12 and 6. I can't remember the numbers, but those are in
13 the matrix. I don't know if those were OECD tests or
14 not.

15 MR. BANERJEE: That's why I want to look
16 at the matrix and take a look and see where it is.

17 MR. BAJOREK: Let me take a look.

18 MR. BANERJEE: Okay.

19 MR. WALLIS: Okay. I think this is a very
20 good time to take a break. We're running a little
21 behind. I'm not sure if Joe Kelly is going to be able
22 to go any faster, so we may be here a little after
23 5:00.

24 Anyway, we'll take a break now, from 10:30
25 to 10:45.

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1 (Whereupon, the foregoing
2 matter went off the record at
3 10:32 a.m. and went back on the
4 record at 10:48 a.m.)

5 MR. WALLIS: Let's come back into session.
6 We'll be hearing from Joe Kelly.

7 MR. KELLY: I'll be talking about the
8 interim reflood model development for TRACE code. My
9 colleague in this is Weidong Wang.

10 I'm going to divide the presentation
11 basically into three parts with a brief introduction.
12 I'm going to address two questions. First, why do we
13 need a new reflood model? That's what TRAC was
14 supposed to always be able to do to begin with.
15 Second, why is it called an interim model?

16 To give an example of some preliminary
17 results, what this is is the interim model is
18 developed. It's running. I'm going to show some of
19 these results and compare them to results with the
20 RELAP code. For two cases, a low plating red case and
21 a high plating red case. It's like one inch a second,
22 six inches a second.

23 Then what I'm going to do is show you an
24 example of how I developed the model for one
25 particular heat transfer regime, and that's the

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1 inverted annular film boiling. I'm not going to
2 describe all the input models because we'd be in a
3 two-day meeting, just with that alone. Its reflood
4 touches many different regimes and many different
5 models within each regime.

6 MR. WALLIS: I wondered if you'd rehearsed
7 your presentation of 43 slides and checked that it's
8 only going to take 50 percent of the time. That's the
9 rules, you know?

10 MR. KELLY: Right, so please feel free to
11 cut me off if need be.

12 This is an example of an assessment case
13 I did with TRAC-P actually several years ago, clad
14 temperature versus time. There are three data curves,
15 and a predicted TRAC temperature, which is obviously
16 nowhere close. The reason it's nowhere close is there
17 were very large oscillations in the calculations.
18 Basically vapor explosions, they were throwing all of
19 the liquid out of the rod bundle and FLECT-SEASET the
20 upper plenum acts as a steam separator. So, once the
21 LIFT was thrown up to the upper plenum, it's gone.

22 An example of those oscillations, this is
23 vapor temperature versus time. The blue curves are
24 measured basic temperatures, and you see the TRAC
25 results, which is totally out here.

1 MR. WALLIS: Well, these temperatures
2 represent something way beyond what's permissible,
3 too.

4 MR. KELLY: Right. That calculation,
5 there is no way you can use that model. That's why we
6 needed something new. Now the question is why am I
7 following this new model and interim model.

8 The reason is we needed something that
9 would be reasonably accurate, but we needed it
10 quickly, and that's that we can go ahead and do the
11 large break LOCA assessment cases that Steve showed in
12 the previous presentation, and hopefully be able to do
13 some realistic auditing calculations to get to the
14 housing.

15 Because we needed it quickly, we couldn't
16 wait for the implementation of the droplet field which
17 John Mahaffy is working on now, and likewise from
18 analysis of the data from the NRC experiment at Penn
19 State.

20 Consequently, we do plan to take the Penn
21 State data, take the work that John's doing in the
22 droplet field, and come up with a true best estimate
23 reflood model, and that work is planned for the 05-06
24 time frame.

25 We'll be taking advantage of the droplet

1 field and the RBHT data. We'll be implementing a grid
2 spacer model. You saw some of the test data. You saw
3 how important the grid spacers were, but also, and
4 this is one of the deficiencies, and one of the things
5 that makes it very hard to do, we'll need to put in
6 some kind of subgrid resolution scheme and fluid
7 solution.

8 What I'm not going to talk about here is
9 the way we model the heat structure, and what I'm
10 talking about is we call it a fine mesh rezoning
11 model. It's been presented here before, but it's
12 basically an adaptive grid scheme, and it's applied to
13 the fuel rods in order to resolve the axial profiles
14 at temperature and heat flux.

15 So, typically our hydrocells are in the
16 order of a foot. We get down to heat transfer cells
17 that are less than a millimeter because the entire
18 transition blowing region is only about two
19 centimeters long, and that's where all the big heat
20 splash is.

21 MR. WALLIS: You've seen the results,
22 though, from the RBHT?

23 MR. KELLY: Yes.

24 MR. WALLIS: And in developing this
25 interim model, you can't ignore them. You're not

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1 going to develop an interim model which is
2 incompatible with what's observed there because that's
3 making trouble down the road.

4 MR. KELLY: That's true, but we don't yet
5 have the RBHT data and electronic data.

6 MR. WALLIS: Yes, but you have seen the
7 kind of results they're getting.

8 MR. KELLY: Right.

9 MR. WALLIS: You cannot ignore them when
10 you're doing this interim model.

11 MR. KELLY: That's true, and I haven't.
12 I won't talk about that today, but there is one -- I
13 actually tailored some of the tests there to look at
14 something that I thought was an uncertainty, but I
15 wasn't able to have a reduced version of that data and
16 use it in helping you do the model, which is
17 unfortunate, but that's a timing thing.

18 MR. WALLIS: That's what's troubled us all
19 along, is to do the experiment. The experiment has
20 got to feed in as soon as possible in the models, not
21 to wait for four or five years.

22 MR. KELLY: Well, I started this work more
23 than a year ago, so it is a timing thing.

24 Okay, we have a model that works now, and
25 I'm going to do some preliminary assessment on it.

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1 It's the second part of the presentation.

2 FLECHT-SEASET forced flooding rate tests.
3 FLECHT-SEASET is 161 rod bundle. It's full height,
4 top cosign power profile, and we looked at two tests.
5 They are both 40 psi and the flooding rate is one inch
6 a second and six inches a second. Both of these cases
7 are pretty high with subcool, not just in the
8 traditional type subcoolings, which are more like
9 water you get out of an accumulator rather than the
10 water you get out of a lower plenum in Tsat.

11 Now, what is the --

12 MR. WALLIS: Do you ever get that kind of
13 subcooling in the real world?

14 MR. KELLY: Only if the initial
15 accumulator discharge. If you look at all of the
16 FLECHT-SEASET cases which were run back in the 70's
17 and 80's, most of them have these high inlet
18 subcoolings, and that's what most of the code
19 assessment has been against.

20 Now, I picked these cases because they've
21 been used before. What we are going to do, as many of
22 the subcooling cases as there are in FLECHT-SEASET,
23 and one of the deficiencies we addressed in the RBHT
24 program was we ran a number of cases with the low end
25 on the subcooling, basically always paired. We got

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1 some dramatically different behavior.

2 MR. BANERJEE: What about the effect of
3 the lower plenum itself? I mean, these tests didn't
4 have anything, right?

5 MR. KELLY: Not at all. This is separate
6 effects that help me with development for one specific
7 model, reflood model in the core.

8 MR. BANERJEE: Right, now what did the
9 SCFT and I don't remember --

10 MR. KELLY: CCTF was cylindrical core test
11 facility.

12 MR. BANERJEE: Right.

13 MR. KELLY: SCTF is slab core test
14 facility.

15 MR. BANERJEE: Right.

16 MR. KELLY: They both are reflood, so they
17 don't do the blowdown in the ECCS bypass phase.

18 MR. BANERJEE: Right.

19 MR. KELLY: They both have approximately
20 2000 heater rods, so instead of something yeah big,
21 you're talking about a pretty sizeable vessel here.
22 So, you now have the possibility of two to three
23 dimensional effects going on inside. Cylindrical core
24 is exactly what it says. Cylindrical, the slab core,
25 you take the same eight rod bundles, and you put them

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1 in a plane.

2 The idea is it's supposed to be a 2D slice
3 from the centerline of the reactor core through the
4 downcomer.

5 MR. BANERJEE: They have the downcomer and
6 the plenum?

7 MR. KELLY: That's correct.

8 MR. KRESS: These are, both were full
9 length, weren't they?

10 MR. KELLY: Yes, they're both full height.

11 MR. KRESS: They're both full height.

12 MR. BANERJEE: Now, those tests, were
13 there effects which would be different, like due to
14 the gravity effects that were oscillations?

15 MR. KELLY: They're core inlet oscillates.

16 MR. BANERJEE: Yes, oscillates.

17 MR. KELLY: And that can completely
18 disrupt your model if it's sensitive to that. That's
19 why we absolutely have to assess the model against
20 those tests.

21 MR. BANERJEE: So you're developing a
22 model using, the logic is use this to develop a model,
23 but we know that there's going to be oscillations that
24 bend that because that's what real life is.

25 MR. KELLY: Right.

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1 MR. BANERJEE: And that these models must
2 be robust then to oscillations.

3 MR. KELLY: And we'll find out.

4 MR. BANERJEE: Yes, because that affects
5 carry-over and all sorts of things.

6 MR. KELLY: Oh, yes. So, I'm going to do
7 these calculations twice, or with both TRAC and or
8 TRACE and you'll have five. In TRACE, the input model
9 has a 1D vessel, because it's only a 161 rod model.
10 Twelve axial nodes in the heated length. I picked the
11 length of those cells to match the DP cells so that I
12 could do comparisons between the amount of water in a
13 TRACE cell and what was measured in a DP cell. That
14 gives you one put, or 30 centimeters.

15 Two heat structures. One heat structure
16 model the actual electric heater rods, one for the
17 bundle housing. The one thing I did that you should
18 always ask is what is your graphics edit interval. We
19 do these plots with the squiggly lines. How often are
20 you pulling points from the code calculation in
21 plotting?

22 So, I'm matching that with the test data.
23 This is a two Kilohertz symbol.

24 MR. WALLIS: Otherwise you don't know what
25 things that --

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1 MR. KELLY: You don't know.

2 MR. WALLIS: Right.

3 MR. KRESS: Now, the grids, and A grids,
4 are they following the middle of these 12 axial nodes?

5 MR. KELLY: In the interim model, there is
6 no specific grid spacer model other than the pressure
7 loss coefficient.

8 MR. KRESS: Okay.

9 MR. KELLY: I don't do drop shatterings.

10 MR. WALLIS: But we know that that can be
11 important.

12 MR. KELLY: And I've developed those
13 models before. I developed ones that are in COBRA TF
14 or COBRA TRAC, but that was back in 1984 because the
15 code has a droplet field, is one of the reasons that
16 we're implementing the droplet field with TRACE.

17 MR. KRESS: Yes, okay.

18 MR. KELLY: RELAP5, the input model, is
19 identical to the TRACE model, so that we could do an
20 apples to apples comparison. They don't have a
21 vessel, so we're using a pipe. The reason we used the
22 vessel in TRACE is that's what the reflood model is
23 implemented, and the first doesn't yet work for the 1-
24 D component, so the pipes are heated --

25 MR. KRESS: Now, when you say pipe, does

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1 that mean the heat is coming from the walls of the
2 pipe?

3 MR. KELLY: No, it means that a pipe is
4 just an axial stack of volumes and attributes it says
5 on the pipes. I used pipe models, and you can attach
6 heat structures to it in any way.

7 MR. KRESS: In any way you want to.

8 MR. KELLY: So in effect, there's a rod in
9 the middle, you know, and a porosity factor, if you
10 will, and then another heat slab to model one more
11 housing, both connecting to the same volume.

12 MR. WALLIS: Why isn't the vessel the same
13 as the pipe? A 1-D vessel looks to me like a pipe.

14 MR. KELLY: It is, but a 1-D -- in TRACE,
15 there are parallel codes for the 3-D component and 1-D
16 components, and so the solution and minimum equations
17 for the 3-D vessels done one place, 1-D stuff
18 somewhere else. So what I did is I used the 3-D
19 vessel model. I just only discretized it in the axial
20 direction. So, there are no radial rings and no
21 aspect of the sectors.

22 We're taking it a 3-D component and making
23 it a 1-D.

24 MR. WALLIS: So why is it different from
25 a pipe?

1 MR. KELLY: It isn't, but --

2 MR. WALLIS: Well, you made a big deal of
3 it being different.

4 MR. RANSOM: Do the both use the same
5 constitutive package?

6 MR. KELLY: Well, remember I was preparing
7 TRACE and RELAP5.

8 MR. RANSOM: No, I'm talking about in
9 TRACE.

10 MR. KELLY: No.

11 MR. RANSOM: TRACE you have a vessel and
12 you have a pipe, probably.

13 MR. KELLY: Right. In the current version
14 of TRACE, there are differences between some of the
15 models using the vessel and some 1-D components. You
16 know, you shouldn't have different constitutive
17 packages unless there's a good reason for it. There
18 are specific components where you should have models
19 developed for that component.

20 But what we're going to eventually do is
21 consolidate it into one constitutive package that would
22 be applied both to vessels, or 1-D components, but
23 within that constitutive package, there will be
24 branches out for different types of components where
25 you expect the phenomena to be different.

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1 I mean, obviously, you're talking about
2 interfacial drag. Interfacial drag in a rod model is
3 not the same as interfacial drag in the downcomer,
4 which is not the same as interfacial drag in the
5 preferred model.

6 MR. WALLIS: The one dimensional balances
7 are all the same for the pipe and the one dimensional
8 vessel. It's just that the constitutive equations
9 are different somehow?

10 MR. KELLY: Most of the equations would be
11 the same. Some of them are different. The thing here
12 is this has all the overhead of being able to
13 calculate radial and azimuthal minimum equations
14 stuff. It's not being used, but it's there. So, I'm
15 going to show you some computational statistics on run
16 time stuff, and that's going to be impacted because
17 this is a vessel.

18 This is quench front versus time, quench
19 front elevation versus time for the case 31504. I'm
20 only showing the TRACE result because there is not a
21 plotting variable in RELAP5 for the quench front
22 position.

23 Obviously, the blue diamonds are the data.
24 The black curve is the bottom of the quench front
25 coming up. The orange curve is the top quench front,

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1 which is not moving. It's just sitting at the top,
2 which is about what happened in the test. We do need
3 some improvements here.

4 A good prediction up through the core mid-
5 plane, then they underpredict the quenching rate in
6 the top half of the report. You can see that in our
7 slide. Now, this is clad temperature. This is time.
8 It's a 78 inch elevation, which was actually the peak
9 temperature elevation.

10 The blue curves are all of the
11 thermocouples in the center of the bundle that I
12 plotted and were reasonably valid. The black curve is
13 TRACE. The orange curve is RELAP5. Both codes turn
14 over and miss the peak temperature. RELAP does a
15 little bit better job here. Both quench late with
16 TRACE doing a little bit better.

17 Moving up to 90 inches, you see exactly
18 the same kind of behavior. The flow codes
19 underpredict peak temperature. The flow codes quench
20 late, where TRACE does slightly better.

21 This is vapor temperature at 78 inches
22 versus time. Moving on, there are two different steam
23 flows at that elevation, and those would be only
24 instruments at that elevation.

25 When the steam temperature drops down to

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1 Tsat, that doesn't mean the steam is really in Tsat.
2 What it means is enough droplets hit these probes that
3 the probes quench, and that's why, you know, it's both
4 codes continue to show super heated vapor until that
5 elevation quenches.

6 MR. WALLIS: This is the same run that was
7 so bad before?

8 MR. KELLY: Yes.

9 MR. WALLIS: And you have fixed the code
10 up in some way you haven't told us?

11 MR. KELLY: Right, and I'm going to give
12 you an example of one of those regimes.

13 MR. WALLIS: You're going to tell us how
14 you fixed it, or is it a secret?

15 MR. KELLY: Yes. I'm going to go all the
16 way through inverted annular, and then I'll come back
17 and talk about other regimes. Like I said, that would
18 be a two-day meeting if I were to go through all of
19 the models.

20 MR. WALLIS: No, it's okay, but you've
21 just given us the bottom line now and now you're going
22 to tell us how you got there?

23 MR. KELLY: Exactly. I'll give you a good
24 glimpse of the process we went through.

25 So, this is TRACE and this is RELAP5.

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1 TRACE is too high. RELAP5 is too low. Even though we
2 both underpredicted the quad temperature, and that's
3 because the heat transfer models.

4 There's a lot more noise in a RELAP
5 calculation, and that's because that's one of the
6 things I went after in the TRACE development, was to
7 minimize unphysical oscillations, oscillations that
8 shouldn't be there.

9 This is void fraction versus time at the
10 four to five-foot elevation. So, what I'm looking at
11 is the amount of water between one DP cell which is
12 over a one-foot span. That blue line is the data.
13 What you really see, up in here is in dispersed flow.
14 The DP cell is not going to give you anything except,
15 you know, frictional pressure drop. You're not going
16 to see the amount of water.

17 If you look in the TRACE calculation, the
18 void fraction here is pretty consistently about .995.
19 There's very little water from a volume fraction
20 standpoint, but there's a lot of water from a quality
21 standpoint. The quality might well be 30 to 50
22 percent.

23 So, there's a lot of entrained droplets,
24 but you don't have much in volume fraction. You can't
25 do any comparisons here.

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1 What's happening in this part where the
2 void fraction in the data dies, it's just simply the
3 quench front is going through that DP exam. This is
4 one of the tests where you almost have a dissident
5 continuity at the quench front. You have a two phase
6 mixture, you know, bubbly slug plant flow below the
7 quench front, and you have dispersed droplet flow
8 above it.

9 So, what's happening is the quench front
10 comes through and you basically go from something near
11 one down to about 40 percent.

12 Both codes have similar behaviors. They
13 drop as the quench front goes through. So, what
14 you're seeing in here is not so much how accurate the
15 interfacial drag package is, just where was the quench
16 front relative to that DP cell? That's unfortunate,
17 but it's one of the things that makes coming up with
18 figures of merit difficult.

19 A couple more things to notice, the TRACE
20 curve is remarkably smooth. If you've ever looked at
21 calculated void fractions in any of these codes, the
22 RELAP5 is a little bit noisier with some jumps, but
23 both codes come to about the same answer.

24 This is about when the elevation quenched,
25 is in here, and what you're seeing is the effect of

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1 decay heat on the void fraction coming out. You
2 notice they both overpredict. The reason they
3 overpredict is this is the first cell at which you get
4 a two-phase mixture, and actually about half of that
5 DP span is subcooled water at this point in time. In
6 the other half is two-phased mixture.

7 Well, reality can do that, and you get a
8 void fraction of about 12 percent. The code thinks
9 it's all two-phase mixture and in effect uses your
10 J sub G to do a void fraction, and you're getting a
11 void fraction of around 25. So, that's why that looks
12 that way. If I use smaller nodes, the answer would
13 change.

14 MR. WALLIS: So you should run smaller
15 nodes and show it does.

16 MR. KELLY: Yes, and you'll see that one
17 of my things had a slide on work that needs to be
18 done, and one of those is doing conversion studies,
19 both on voiding size and noding size.

20 Moving on up, you'll notice the codes
21 quench later, so we can see that fall on to be
22 dispersed two phase later. Again, interestingly
23 enough, even though the codes have drifting
24 interfacial drag packages, it becomes almost exactly
25 the same answer. In this case, we matched the data

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1 very well.

2 Now, in doing this interim reflood model
3 development, my philosophy was to only change the
4 post-CHF reflood models. What I wanted to do was take
5 everything from before pre-CHF, you know, normal two-
6 phased flow stuff, use the extant models in TRAC.
7 That's what I tried to do. It turned out I couldn't
8 do that.

9 There were some oscillations in the
10 interface flow package which destroys this
11 calculation. I had to go in and replace the bubbly
12 slug model, the bubbly slug interfacial drag, and
13 that's when I chose the Bestion model based upon some
14 work, some assessment work that had been done earlier.
15 It works very well, and it's a relatively simple drift
16 flux correlation whereas the one in UF-5 is the EPRI
17 model, which is very complicated, which seem to give
18 about the same answer, at least for these conditions.

19 MR. BANERJEE: Does the model in RELAP5
20 work as well as the Bestion model, or is there some
21 problem?

22 MR. KELLY: It'd say it's -- well, from my
23 experience when I was working with it in '96 or so for
24 the AP600, I'd say it has some problems because there
25 is a lot of switching in it, and so that it will tend

1 to be noisier, but if you forced the condition to say
2 be for an upflow, it will give the answers of
3 equivalent accuracy.

4 MR. BANERJEE: But the Bestion model
5 doesn't have this problem?

6 MR. KELLY: It's a very simple one-line
7 correlation. The EPRI package goes on for a couple of
8 pages.

9 MR. BANERJEE: Right, right, okay.

10 MR. RANSOM: Well, isn't this when you
11 damp the drift flux model, it's complicated by wall
12 friction enters into it and you really have to worry
13 about the partitioning or the difference, you know,
14 how wall friction and interface drag both interact.
15 I assume you've done the same thing here.

16 MR. KELLY: And there is a huge thing in
17 RELAP5 to try to take you to make, if you will, the
18 wall drag, the void fraction neutral, and I think
19 that's wrong. You shouldn't do that, but what you
20 should do is develop your interfacial drag package
21 with the wall drag model that you're going to use so
22 it's a consistent behavior. It turns out --

23 MR. RANSOM: Is that what you've done
24 here?

25 MR. KELLY: No.

1 MR. RANSOM: What have you done for that?

2 MR. KELLY: Well, I selected a model. I
3 didn't develop one. Now, what's actually in my
4 condensation tank, we'll talk about wall drag and its
5 partitioning some, because it's wrong. It shouldn't
6 be done. In these cases, all of the wall drag should
7 go in the liquid. The liquid is what's in contact
8 with the wall.

9 It turns out for these conditions, it's a
10 no never mind because your velocities are so low that
11 the wall friction is basically negligible, and your
12 void fraction prediction is governed almost entirely
13 between the buoyancy balance and interfacial drag.

14 Now, where that would not necessarily be
15 the case is maybe a boiling water reactor operating
16 condition where you have very large flow rates, and
17 then your wall drag becomes appreciable. We're going
18 to have to check that through assessment. It's hard
19 to remember everything we've done, but we did do
20 assessments with the Frigg test which are at boiling
21 water reactor conditions, and the Bestion correlation
22 did perform acceptably.

23 But you're right, we're going to have to
24 check how the wall drag is done, and if the time comes
25 that we decide we need to develop an interfacial drag

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1 model, then we're going to do it with a consistent
2 wall drag model so that they are together and work
3 together.

4 MR. RANSOM: In the TRACE results, there
5 is a wall drag model.

6 MR. KELLY: Yes.

7 MR. RANSOM: And somehow you're also then
8 backing out an interfacial drag from a drift flux
9 model, Bestion model, right?

10 MR. KELLY: Yes.

11 MR. BANERJEE: Have you written this up
12 somewhere, a page or two?

13 MR. KELLY: Not the interfacial drag
14 stuff.

15 MR. BANERJEE: How do you get from the
16 Bestion model to the interfacial drag?

17 MR. KELLY: No, I haven't, but I will.

18 MR. BANERJEE: Yes, that would be useful
19 to have so we understand the assumptions you've made.
20 Precisely as Dick says, you must have assumed
21 something about the wall drag at that point.

22 MR. KELLY: Actually, what I did was
23 follow what they did with the CATHARE codes where the
24 Bestion model was developed.

25 MR. BANERJEE: Right.

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1 MR. KELLY: And they basically ignored the
2 wall drag.

3 MR. BANERJEE: Okay.

4 MR. KELLY: And said, you know --

5 MR. BANERJEE: So that's an assumption.

6 MR. KELLY: Yes.

7 MR. BANERJEE: And then --

8 MR. KELLY: It works great for these
9 conditions.

10 MR. BANERJEE: Right.

11 MR. KELLY: And I think it still works
12 okay for BWR conditions, but I haven't checked it, but
13 I will.

14 MR. BANERJEE: But you will write up
15 something so we know how you went through this
16 procedure?

17 MR. KELLY: Yes, and that will be part of
18 the revisions to the theory end. The way the theory
19 manual is going to be done, like if I look at the
20 physical model stuff in that now, it would be a huge
21 job to rewrite it all just so I can move the TRAC E's
22 and make it clearer. I don't see the point in that
23 because I think most of the models over the next few
24 years will probably be replaced.

25 What we're going to try to do is replace

1 them as a result of a rational selection process, and
2 as we replace them all, then we will be rewriting that
3 section of the manual with a new model to try to do a
4 better job of it.

5 MR. BANERJEE: Does CATHARE have an
6 explicit expression for the interfacial drag based on
7 this drip flux correlation?

8 MR. KELLY: They now have a more
9 complicated drop flux model, but yes.

10 MR. BANERJEE: They had an explicit saying
11 whatever the interfacial, this is the formal fit?

12 MR. KELLY: Basically you say okay, this
13 is, for a certain void fraction, this is what the
14 buoyancy force should be, and then that's recorded
15 one-half FA narobes D relevant squared. Then you go
16 in and plug in the drip flux model for the void
17 fraction, and you come up with what the interfacial
18 drag coefficient ought to be.

19 MR. STAUDENMEIER: I was going to say,
20 actually in the development of the TRAC-BWR models and
21 correlations, there is a derivation of how you go from
22 drift flux to interfacial drag in steady state
23 conditions. I mean, essentially you're declaring its
24 equivalency in steady state conditions, and shows the
25 transformation on how to take a drift flux correlation

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1 and turn it into an interfacial drag correlation.
2 There's a NUREG on that, and we can get you a copy of
3 the NUREG if you're interested in a derivation of how
4 to do that.

5 MR. KELLY: That's right, thanks.

6 MR. RANSOM: Is that from TRAC-B you said?

7 MR. STAUDENMEIER: Yes.

8 MR. RANSOM: I'd like to have a copy.

9 MR. BANERJEE: Well, originally the paper,
10 I remember a paper on this written by Rohatki way
11 back, before it sort of entered into fact, but I've
12 forgotten all of the details. I want to look at it
13 again.

14 MR. KELLY: Moving on to the high flooding
15 rate case, which is 31701, and we're talking about
16 six-inch per second reflood rate. This is case that
17 would be dominated by the input annular regime,
18 whereas the previous case was dominated by
19 (inaudible).

20 A quench run versus time for TRACE. The
21 bottom quench run does quite well, a little slow in
22 here, but still within the spread of the data. The
23 top quench run doesn't move for awhile. In total, the
24 very top of the rod cooled enough for liquid film to
25 be deposited. Then we have the top one coming down.

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1 MR. KRESS: Is that a counter flow limit?

2 MR. KELLY: No, it has to do with the way
3 the model transitions, and it's something that needs
4 to be worked on in order to do this job correctly, and
5 especially in order to do it for when we start on
6 RELAP.

7 MR. KRESS: What does TRACE do when the
8 top front and bottom front meet? It looked like a
9 little strange dip in there.

10 MR. KELLY: There is.

11 MR. KRESS: Yes, I didn't understand that.

12 MR. KELLY: Okay. The quench front model,
13 if you will, is an adaptive grid technique. So, what
14 you've done is you take the heater rod, you look at
15 both axial profile wherever the temperature profile
16 exceeds certain criteria, and it remeshes. So you get
17 these very small nodes where the quench fronts are.

18 MR. KRESS: I see.

19 MR. KELLY: So there's no actual quench
20 front model. What these numbers are, this is a
21 plotting variable, and what it does is it starts at
22 the bottom of the rod and says okay, I'm cold, so I'm
23 below the quench front. It goes up until it sees a
24 transition from one node that has nuclear boiling to
25 the next node that has transition and says ah, the

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1 quench front is between those two. That's what I'm
2 plotting.

3 The other one, it searches from the top
4 down. When the whole bundle is quenched, there is no
5 quench front. So, the search kind of fails, and I'm
6 going to have to make sure that's a little more
7 robust.

8 MR. WALLIS: It seems to be really
9 disbursed on the top. You've got three to the left
10 and two to the right.

11 MR. KELLY: Yes, you've got 161 rod
12 bundle, and it becomes somewhat chaotic. You know, at
13 the same elevation, some quench, some don't.
14 Sometimes you can say ah, and the data you see here,
15 I threw out the rods near the housing. We're only
16 looking at the rods more in the center part of the
17 bundle. But even then, you can sometimes go and look,
18 okay, this thermocouple is on a rod facing a guide
19 tube.

20 MR. WALLIS: That makes sense. This is a
21 CCFL limit, isn't it? It's steam coming out the top
22 or something?

23 MR. KELLY: Actually, not really, because
24 we have water coming up from the bottom here.

25 MR. BANERJEE: Thermocouple limitations.

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1 MR. KELLY: And sometimes it, you know,
2 you wet the rod and you form a liquid film. It just
3 kind of hangs. It may go up or down, but it doesn't,
4 you know, it's -- you'll never model this exactly
5 because some rods quench, some don't, and it's just
6 hard to say. You can look at the data and say ah, I
7 know why that one quenched. It's near a guide tube,
8 but then you look at one that's nowhere near a guide
9 tube, and it's surrounded by hot rods that didn't
10 quench.

11 MR. RANSOM: Do the ones that quenched
12 early, do they heat back up again at all? Do you have
13 any way to tell that?

14 MR. KELLY: Some might. Not in this test
15 because this is a six-inch per second reflood case,
16 and it's got just so much water going up through the
17 bundle that once you quench one of these, it's
18 quenched.

19 MR. SIEBER: It stays.

20 MR. KELLY: In a low flooding rate case,
21 you could have that, and we talked about what
22 Professor Banerjee said. In a real case, we have an
23 oscillating inlet flow. Then you could definitely
24 have a quench line receding and preceding.

25 MR. RANSOM: Also in the changes you have

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1 made, you started out saying you were only going to
2 change the post-CHF regime, but you've now said you
3 also changed the interface drag.

4 MR. KELLY: Right.

5 MR. RANSOM: Have you changed the heat
6 transfer correlations that are used in the different
7 regimes?

8 MR. KELLY: Post-CHF, everything was
9 changed.

10 MR. RANSOM: Okay.

11 MR. KELLY: Wall heat transfer,
12 interfacial heat transfer, interfacial drag,
13 everything. It's an entire package in its own little
14 module.

15 MR. RANSOM: For post-CHF?

16 MR. KELLY: For post-CHF. That's all the
17 regimes. Everything was changed. Now, in pre-CHF,
18 first off, you have CHF. I changed that as well. I
19 went to using the AECL, and I decided to go ahead and
20 do a consistent package because -- we're talking about
21 wall heat transfer now. I couldn't make things match
22 up between pre and post, so for the wall heat
23 transfer, I went ahead and did a consistent package.
24 So, I changed to nuclear boiling, and I changed forced
25 convection both to single phase vapor and single phase

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1 (inaudible). When that case, we actually implement
2 correlations specifically for rod bundles instead of
3 just using an old standby.

4 In pre-CHF phase, for the fluid solution,
5 and what I'm talking about is interfacial drag and
6 heat transfer, I implemented an interfacial drag
7 coefficient for a bubbly slug regime for rod bundles,
8 and I had to do that because the model it was in,
9 TRACE, the low pressure was causing such large
10 oscillations that I couldn't have the -- I couldn't
11 calculate the low flooding rate cases.

12 I made a small change to the super heater
13 liquid interfacial heat transfer, and the one at TRACE
14 you can't really dignify with the name of a model.
15 It's something like 10 to the 7th for ramp to 10 to
16 the 8th over one degree, you know, something like
17 that.

18 MR. RANSOM: It has a subcooled boiling
19 model, though, I assume.

20 MR. KELLY: It's super heated, but --

21 MR. RANSOM: Right.

22 MR. KELLY: And I put in a more typically
23 based model because that was giving me some very large
24 oscillations as well. You get a little bit of super
25 heat, and the liquid went down, but that's pretty much

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1 it. I tried to leave those models alone.

2 MR. RANSOM: So, it's pretty much a
3 revised heat transfer package, I guess then, right?

4 MR. KELLY: Yes.

5 MR. RANSOM: Are the other assessors using
6 the same package yet?

7 MR. KELLY: They will be soon.

8 MR. RANSOM: Not yet, okay.

9 MR. KELLY: We're just now making it
10 available to them.

11 This is cladding temperature versus time.
12 Again, the blue curves are the data. The black curve
13 is TRACE, and the orange curve is RELAP5. In this
14 case, they both do an excellent job of predicting the
15 behavior, and they both quench about the same time but
16 just a little bit late.

17 This is void fraction versus time, and
18 again, the blue curve is data. Now, in this case,
19 some of the blue curve actually indicates real two-
20 phase conditions that would be inverted annually.
21 What I mean is you have a significant amount of water
22 in the DP cell to give you a void fraction reading
23 before the quench front gets here.

24 The quench front gets here right about in
25 here. So, this has to do with the quench front going

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1 through the DP cell, and the rest of it is actually
2 real water in the cell.

3 You see the RELAP5 calculations. Noisy,
4 but the results of efficiency in the TRACE
5 calculations are much smoother except for this big
6 blip.

7 MR. WALLIS: What's that original dip at
8 the beginning there in TRACE?

9 MR. KELLY: That's when the first node
10 quenches. What happens, the bottom of these bundles
11 is very cold because they're basically started at Tsat
12 and you have a cosign power shape. So, the bottom
13 two, 3T to this is sitting there, not much of a Tsat,
14 just you know, it's basically in transition boiling,
15 and it's just waiting for a little bit of water to get
16 there.

17 One of the problems is when you bring
18 water into that first cell, how you discriminate where
19 the water actually is, and that's -- when I talked
20 about having a subgrid resolution scheme for the fluid
21 solution, now there's a model end, -- not a model.
22 There's a scheme for interpolating void fractions and
23 vapor temperatures computed by the hydrocells onto
24 those small mesh nodes.

25 MR. WALLIS: So you must be taking that

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1 water as it first comes in and squirting it up to the
2 --

3 MR. KELLY: Exactly.

4 MR. WALLIS: Four or five foot level?

5 MR. KELLY: All the way through the
6 bundle. Once you throw it up, push it up, you have
7 enough vapor generated that you can just carry it on
8 the rest of the way. You notice RELAP has the same
9 kind of behavior. It's just a problem, and it's one
10 of the things we need to address.

11 MR. WALLIS: Is this seen in the tests at
12 Penn State?

13 MR. KELLY: Well, tests don't have nodes,
14 okay?

15 MR. WALLIS: But they visualized the flow
16 and so on.

17 MR. KELLY: There are quite often, when
18 you first start one of these tests, you do get some
19 violent boiling and throw water up through the bundle,
20 but that's not -- this isn't reality. This is because
21 of the node being in there.

22 MR. RANSOM: The problem is that an entire
23 node changes its heat transfer regime, right, and so
24 more mass.

25 MR. KELLY: Well, actually not heat

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1 transfer regime because we have the fine mesh nodes,
2 but when water comes into that cell and you do an
3 interpolation of the void fraction profile, you
4 artificially say there's water where there shouldn't
5 be. So, some of those fine mesh nodes that are in the
6 transfer heat boiling regime get high heat fluxes.
7 So, the vapor generation rate for that cell goes high.

8 MR. RANSOM: Right.

9 MR. KELLY: Really, the velocity at the
10 top of this cell, it ends up determining the void
11 fraction of the cell. So that's what was happening
12 there.

13 MR. WALLIS: So you instantly get enough
14 steam velocity to carry liquid all the way through?

15 MR. KELLY: Well, to move it up a couple
16 cells, but move it up a cell, then there's more vapor
17 generation in that cell, and just as you go up, the
18 vapor velocity keeps increasing, and the vapor would
19 carry it out.

20 MR. WALLIS: It doesn't evaporate at all
21 then?

22 MR. KELLY: Not as much as you'd think.
23 One thing, it's fairly cold water, and even when it's
24 a droplet, they go through the bundles so quickly, not
25 as much evaporates as you would expect.

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1 The one deficiency, well, other than this
2 of course, is this, and this has to do with the quench
3 time entering the cell. This is inverted annular film
4 boiling while the void fracture decreases here.

5 Now the quench time has cracked the cell
6 boundary into this one-foot section, and the vapor
7 generation rate went up a little bit and comes up with
8 a disproportionately large increase in the void
9 fracture. This is one of the things that I have
10 remaining to work on.

11 It turns out that, you know, it's a non-
12 linear behavior, and if I were to plot the data
13 generation rate, you know, it would be coming along
14 actually, and a very small little blip will give you
15 that kind of change in void fraction.

16 MR. RANSOM: Could you say a little bit
17 about what you've done to achieve smoothness?

18 MR. KELLY: One thing I've done, you'll
19 see some of this when I talk the model development, is
20 I try not to have unphysical transitions, and I try to
21 make one regime evolve naturally.

22 MR. RANSOM: Does that mean you spread
23 them out or something, or put a delay factor?

24 MR. KELLY: No, I try not to use ramps
25 whenever possible, but it's hard because I don't want

1 to get into a two-day discussion.

2 When you go from inverted annular and you
3 want to break up that inverted annular and go to the
4 next regime downstream, what most codes have done in
5 the past is try to look at some break-up criteria.

6 What I did say is okay, you are going to
7 make me two criteria. You have to be able to break
8 that liquid column up, but then whatever your liquid
9 fragments are, you have to have enough vapor velocity
10 to carry them out. If your vapor velocity isn't
11 enough to carry them out, they would fall down, and
12 the column would reform.

13 It turns out the carry-over criteria is a
14 more stringent one, so I made the break-up, the change
15 from one regime to the other at the point where the
16 liquid could be carried up. What I did for that
17 regime, quite often what a code will do, they may
18 think they know something about disbursed flow, and
19 they may have some half-way decent ad hoc model for
20 inverted annular, and between the two they'll do a
21 ramp based on void traction.

22 I didn't do that. I came up with a new
23 regime in between which is kind of like a simplified
24 fluidized bed model. So, it's large liquid fragments,
25 and if you will, something like a fluidized bed. I

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1 made it so that the interfacial drag coefficient is
2 the same at the point where it breaks up.

3 MR. RANSOM: So, this is something you do
4 at each junction, I guess then?

5 MR. KELLY: But it was, by doing the
6 physical models, so that when I developed the one for
7 interfacial direct for inverted annular, I made it so
8 that the interfacial friction naturally transitioned
9 into the next regime instead of having something that
10 is an order of magnitude apart and putting a ramp
11 between them. I made them naturally evolve.

12 MR. RANSOM: Providing the physical basis
13 for that link between the two. Interesting to see how
14 those work in things like level swell where, you know,
15 it's more depressurization rather than heat transfer
16 from the walls type of thing. I assume the assessment
17 process will eventually get in.

18 MR. KELLY: You'll find lots of
19 deficiencies going on. That's right, I haven't gotten
20 to the interesting part of this.

21 This is computer time, computational
22 statistics, comparing TRACE and RELAP5 on the two
23 different tests. Transient time, you know, it's 700
24 seconds for the low flooding rate case, 200 for the
25 high. This is what is the maximum time step that we

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1 used for inputs. I made them the same between the
2 codes. I used a smaller number here, and that's just
3 because things happen fast through here.

4 This is the number of time steps the code
5 takes, 14,000 for TRACE, 42,000 for RELAP5. This is
6 because the SETS numerical method allows you to
7 violate the time limit. We're running this at about
8 a time limit of three, where there is a time limit
9 conditions around five.

10 In a high flooding rate case, it's not
11 quite so dramatic, but still it's more than 1-1/2
12 times the number of time steps.

13 Total CPU time, it turns around the other
14 way. RELAP5, 174, TRACE, 276. So, it's less than a
15 factor of two that the TRACE is slower.

16 MR. WALLIS: That's not really common.
17 That's what really counts. If you're spending more
18 time in the time step, you haven't gained anything if
19 you cut the time steps. There's no real gain in
20 cutting the time steps if you take from the grind
21 time.

22 MR. KELLY: If you didn't cut time steps,
23 this would be three times, worse, okay?

24 MR. WALLIS: Yes. The SETS method
25 presumably is taking longer to grind than the RELAP

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1 approach.

2 MR. KELLY: It's not so much SETS, though.
3 It's everything else. Also, the difference between
4 this being a pipe and this being a vessel, is a lot of
5 overhead in the vessel. You're leading into my next
6 slide.

7 MR. WALLIS: Let's go there, then.

8 MR. KELLY: Yes, well, the grind time, and
9 this is what -- the amount of time it takes to do one
10 cell and one time step, okay, and that's where you see
11 the fact of a little bit greater than four. So,
12 RELAP5, the structure is about a fact of four faster
13 than a TRACE vessel.

14 I knew comparing a vessel to a pipe wasn't
15 quite fair, so I had Weidon do a series of cases to do
16 pipe to pipe comparisons. What I did is basically
17 level swell tests. Instead of an artificial, I took
18 the conditions in the low flooding rate case after the
19 entire bundle had quenched. So, it's just simple
20 boiling two-phase swell. We've got a transient to a
21 steady state two-phase condition.

22 Again, the same kind of thing. You do
23 four calculations here now. RELAP5 with the 1-D pipe,
24 which took about 6300 time steps, which is very
25 similar to a TRACE pipe, using the Semi. We used the

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1 SETS method. You're dropping on the time steps to
2 4700, and for some reason with the SETS and a 1-D
3 vessel, it's about 4200. I haven't understood that.

4 RELAP5 is still the fastest, but you
5 compare RELAP5 with 15 seconds to SETS 1-D pipe and
6 23, that's about 50 percent, and actually, that's not
7 too bad. It's about what we'd expect. The grind time
8 is a factor of two.

9 MR. STAUDENMEIER: If I can say a little
10 bit. If you'll remember from my slide yesterday, the
11 TRACE time per time step is about 1.7 times what the
12 F77 time for time step was, and once we tracked down
13 that unaccounted for difference and speed that up,
14 then I think we're back in the same time range as
15 RELAP5 for 1-D components.

16 MR. KELLY: So, a summary of this second
17 part of the presentation, code accuracy. The overall
18 accuracy of the interim reflood model is slightly
19 better than RELAP5. The TRACE calculated results are
20 much smoother, but we still need some improvements in
21 accuracy for the low flooding rate test. I need to
22 work on peak clad temperature because I undercut those
23 significantly, and the quenching rate for the upper
24 part of the bundle.

25 For the high flooding rate tests, the

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1 accuracy was okay, except for that void fraction bump
2 associated with the quench front entering the cell.

3 MR. WALLIS: This is conclusions just from
4 two different runs. Now, if you had compared with
5 other ones, something else might have happened.

6 MR. KELLY: Right. I at least know I've
7 got to work on these.

8 Computational efficiency, TRACE can use
9 larger, therefore fewer time steps, but its grind time
10 is higher than that of RELAP. If you compare the pipe
11 versus the vessel, it's about a factor of four. So,
12 we need to put some effort on making TRACE faster.

13 So, this is what I have left to do. We
14 have to apply the interim reflood model to 1-D
15 components. Right now it only works with the vessel
16 module, and that has to do with data transfers. So,
17 I have to get it to work for the pipe, and after we
18 get it for the pipe, we can work for BWR channel.

19 We need to improve the models for top-down
20 quench, and I haven't even begun to look at blowdown
21 rewet yet, and that's something that's important for
22 LOFT.

23 Of course, the accuracy improvements that
24 I noted on the previous slide.

25 Assessment, we need to greatly expand the

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1 matrix. Looking at two cases alone is not sufficient,
2 and actually, the two cases I picked are the ones that
3 were done as part of the RELAP5 assessment.

4 I won't go over this. This is basically
5 what Steve said earlier, but I do have to develop
6 metrics so I can do quantitative comparisons and just
7 kind of say ah, the black curve is a little bit higher
8 or closer to the data than the orange curve, and I
9 need to do conversion studies, both on time step and
10 noding size.

11 Of course, the ever present documentation.

12 Now, the fun part of the presentation.
13 We're going to talk about one of the models in detail
14 and how I developed it. So, we're going to talk about
15 inverted annular film boiling. This is a picture from
16 an early FLECHT-SEASET or maybe even a FLECHT
17 document. What it shows is the various regimes as you
18 go from the bottom of the rods --

19 MR. WALLIS: Is this what you think
20 happens, or is there evidence that this is what
21 happens?

22 MR. KELLY: There's evidence that this is
23 what happens.

24 MR. WALLIS: There aren't any spaces in
25 here.

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1 MR. KELLY: No, depending upon the
2 flooding rate.

3 MR. WALLIS: If these things hit the
4 spacers all the time as they go through, all this
5 stuff does.

6 MR. KELLY: Right, and if you're in a low
7 flooding rate case, that can have a drastic effect on
8 the vapor's superheat just downstream of the grid.

9 The transition boiling region is indicated
10 here. That's where most of the vapor generation
11 occurs, where the quench line is. What you're looking
12 at is a region that's maybe one, two centimeters long.
13 It's very small, and that's where most of the vapor is
14 being generated.

15 Just above that is what's labeled here a
16 film boiling region, and that's what's generally
17 turned inverted annular. That's what I'm going to
18 speak about today.

19 Then there's this chaotic regime where
20 that liquid column breaks up into liquid slugs.

21 MR. WALLIS: But you can't do it annular
22 because the tubes are tubular so that it's a -- it's
23 not an annulus.

24 MR. KELLY: Right, but that's, you know --

25 MR. WALLIS: It's what people have called

1 it.

2 MR. KELLY: Yes, ever since Bromley, you
3 know, back in 1950 something.

4 So, that's the terminology we're going to
5 use, and this right here is the regime we're going to
6 look at. For the moment, we're going to ignore all
7 the others.

8 The first thing you want to do if you're
9 going to develop a model is try to educate yourself a
10 little. So, you look at data. You also look at a lot
11 of other models people have done, but you'd better
12 look at data.

13 The one I picked is a fun, low quality
14 film boiling experiment. It's a tube with a hot
15 patch, and the reason for the hot patch is you can
16 freeze the quench front here so that you're able to
17 have the entire tube and film boiling, so you can have
18 steady state film boiling at low flow rates without
19 going to temperatures that, you know, would destroy
20 your experiment.

21 The reason I picked this, in addition to
22 the ten-wall thermocouples, it has a gamma
23 densitometer and measures void fraction at five axial
24 elevations. So now I'll be able to have heat transfer
25 measurements as well as void fraction, whereas a lot

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1 of the tests, all you get are the heat transfer
2 measurements, and you're left to guess at what the
3 fluid condition was.

4 The one bad thing about this test is the
5 atmospheric pressure. I would like to have rod bundle
6 tests, but this is very hard to do with a rod bundle.

7 MR. WALLIS: Doesn't Mr. Fung have a
8 theory, too?

9 MR. KELLY: I think the answer is yes, but
10 I don't remember, but it wasn't developed within -- to
11 work within a two fluid framework.

12 MR. WALLIS: Okay.

13 MR. KELLY: That's always one of the
14 problems whenever you grab something out of the
15 literature.

16 MR. RANSOM: Whose experiment is this?

17 MR. KELLY: I think it was done at AECL.
18 it was funded by the NRC, and the person's name was
19 Fung, F-U-N-G, This isn't a NUREG.

20 Well, when you take this test data, what
21 does it look like? So what I'm plotting is --

22 MR. WALLIS: We've seen this before I
23 think.

24 MR. KELLY: Yes, you've seen some of this
25 before.

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1 MR. WALLIS: All right.

2 MR. KELLY: This is heat transfer
3 coefficient versus void fraction. I'm showing all of
4 the test data, not one test. I'm showing every
5 measurement where there's a measured void fraction and
6 thermocouple for all six different mass fluxes. The
7 only thing I'm leaving out is data where the
8 equilibrium quality is greater than zero. So, I'm
9 only looking at subcooled data, and that's because
10 that's where you expect to find inverted, what I'll
11 call inverted annular conditions.

12 MR. WALLIS: So by void fraction, you mean
13 some measure of the thickness of the film,
14 essentially?

15 MR. KELLY: In this case, it's a gamma
16 densitometer, so in effect it's measuring how much
17 water is there.

18 MR. WALLIS: Yes, the annular flow. It
19 gives you a measure of the --

20 MR. KELLY: The film.

21 MR. WALLIS: Heat transfer resistance in
22 the film, presumably?

23 MR. KELLY: Exactly. We're getting there.
24 But what you see is this almost exponential decrease
25 to nearly constant value. Very strong void fraction

1 dependence, because like you said, the film thickness.

2 MR. WALLIS: What is the value of the void
3 fraction of zero? Single phase liquid, void fraction
4 of zero? What is the value at the top then on the
5 axis?

6 MR. KELLY: Oh, you mean the closest?

7 MR. WALLIS: No, on the axis. No, it
8 would be right on the axis. You'd have a single phase
9 liquid. I just want to know how high that is.

10 MR. KELLY: Oh, if there's no vapor film -

11 -

12 MR. WALLIS: Is it way off the graph, or
13 is it --

14 MR. KELLY: Yes, it would be --

15 MR. WALLIS: Or does it magnitude off, or
16 is it just off? So, it's an extrapolated, too?

17 MR. KELLY: Yes, it does extrapolate.

18 MR. WALLIS: You don't have it.

19 MR. KELLY: There's no data for films that
20 small.

21 MR. WALLIS: But you can predict it from
22 theory?

23 MR. KELLY: Right, and actually that's in
24 the --

25 MR. WALLIS: It depends on G?

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1 MR. KELLY: That's in the model, and you
2 actually will see that coming up.

3 MR. WALLIS: Okay.

4 MR. KELLY: The other thing to notice is
5 a factor of five in the mass flux here, and you might
6 be able to fine some mass flux dependence here, but
7 you're not going to find much. It's pretty much
8 within the scatter of the data, and that's contrary to
9 a whole lot of models that are out in the literature.

10 The other thing I want you to note is this
11 is subcooled, but the void fraction is greater than 70
12 percent, and that's very different than what you see
13 in normal bubbly two-phased flows. You might get void
14 fractions up around 40 percent in subcooled boiling,
15 not 70 percent. I mean, that's most of the tube is
16 vapor, and the liquid is subcooled.

17 Did I skip one? Yes, this is the slide
18 I'm looking for.

19 Now what I've done is include the data for
20 which the equilibrium quality was a positive. So,
21 this is all of the data points now, and instead of
22 plotting it versus void fraction, I plotted it versus
23 equilibrium quality. What you see is in a negative
24 quality region, which is where I expect to have
25 inverted annular, I do. I have this very little mass

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1 flux effect. All of the data points, you know,
2 they're scattered, but they have the same behavior.

3 Shortly after the quality becomes
4 positive, there's a change in the behavior, and a mass
5 flux dependence sets in.

6 MR. WALLIS: There's a real trend with
7 mass flux, too.

8 MR. KELLY: Right. This would be where
9 you're breaking down into a highly dispersed flow with
10 a lot of vapor superheat. You notice as you increase
11 quality, you should be increasing your vapor velocity
12 and you'd expect to increase your convected heat
13 transfer coefficient.

14 That doesn't really happen with the lowest
15 case because of the superheat, but as you go to the
16 higher mass flux cases, that's exactly what is
17 happening. The vapors relatively close to T_{sat} so as
18 you increase the quality, you increase the vapor mass
19 flux, you increase the conductive heat transfer, and
20 you see that trend.

21 So, what this says is if you look at the
22 subcooled part, what that's primarily a function of is
23 the liquid subcooling because that's all the
24 equilibrium quality is when it's negative.

25 If it's primarily a function of the liquid

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1 subcooling, then what is controlling the heat transfer
2 process? It's the interfacial heat transfer inside
3 this liquid core. It's from the saturated interface
4 to the subcooled liquid in this inverted core.

5 MR. WALLIS: It doesn't know what G is
6 because it's -- the wall is away from it by vapor.

7 MR. KELLY: Yes, and the vapor film has to
8 adjust so if the heat transfer through the vapor film
9 matches what the liquid core can assume, can take up.
10 That's exactly where I'm headed.

11 MR. WALLIS: Because the water isn't
12 touching the wall, the fact that it's going faster is
13 not so significant for it.

14 MR. KELLY: Right, and the --

15 MR. WALLIS: Unless I didn't know what G
16 was. That's what I meant.

17 MR. KELLY: Right. Unless that liquid
18 mass flux affected the interfacial.

19 MR. WALLIS: Yes, somehow.

20 MR. KELLY: And a lot of people used
21 Dittus-Boeter for this. We're going to get to that
22 later.

23 So, if we're going to do this for a two
24 fluid model, and that's what we're faced with --

25 MR. WALLIS: Well, most of the velocity

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1 grade is presumably in the film. The core is going
2 along without much velocity variation across it.

3 MR. KELLY: Right.

4 MR. WALLIS: You'd expect the velocity
5 differences in the core to scale the next thing or
6 whatever.

7 MR. KELLY: Yes, and in the core, the
8 typical velocity in the order of centimeters a second.
9 In the film, meters per second. There's about a two
10 order of magnitude difference between the two.

11 A little cartoon with a wall, superheated
12 vapor film, subcooled liquid core. The primary heat
13 transfer mode from the wall is wall to the vapor film,
14 but of course thence from the vapor film to the
15 saturated interface where some of that energy
16 generates some vapor which produces this vapor film,
17 but most of it goes into the subcooled liquid core.

18 So, what models do we need in order to
19 simulate this in a two-fluid code, right? You need
20 water vapor heat transfer, vapor to the interface,
21 liquid to interface, interfacial. There's also a
22 contribution of the water liquid radiation. You need
23 interfacial drag between this vapor film and the
24 liquid core. Then I already alluded to you need some
25 criteria for the regime transition.

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1 The little note down here says I've got
2 this idealized drawing. It doesn't look like this at
3 all. Even in two, at very, very highly subcooled
4 conditions, you may get void fractions that are like
5 10 percent, in which case you will have a very, very
6 nice, smooth, flat film, and you can even see this in
7 some of the FLECHT-SEASET reflood tests when you look
8 through the windows,, but most of the time, once you
9 get very much vapor at all, there are waves on this,
10 and they tend to be very large, disruptive waves.

11 Not only do you have the waves, you have
12 this entire column moving around. There are some
13 neutron radiographs taken in England by Castigan and
14 Wade, I believe, and it's really neat. I mean, you
15 actually see this thing moving around inside a tube.
16 Then other visualizations you can see the wave on
17 this.

18 So, the actually fundamentals of this are
19 incredibly complicated.

20 MR. WALLIS: Well, heat transfer
21 coefficient is defined in terms of the wall
22 temperature minus the bulk liquid temperature, or bulk
23 temperature minus saturation?

24 MR. KELLY: Sorry, I didn't explain that.
25 In everything I've shown up to date, when I compared

1 the heat transfer coefficient, that's based upon
2 saturation temperature.

3 MR. WALLIS: So, it's based on the vapor
4 being the resistance?

5 MR. KELLY: Well, it's just that T_{sat} is
6 what you know.

7 MR. WALLIS: That's the difference,
8 though. The difference is of course the vapor, the T_W
9 minus T_{sat} ?

10 MR. KELLY: Right, and that's just
11 traditionally, that's the way they define heat
12 transfer coefficients for film boiling, because T_{sat}
13 is a number you know. You don't know the vapor
14 temperature, and you don't know the liquid
15 temperature.

16 MR. WALLIS: Unless you have some way of
17 calculating it or something.

18 MR. KELLY: Right.

19 MR. WALLIS: If it's subcooled, it makes
20 a difference. You ought to bring it into account.

21 MR. KELLY: Right, but from the
22 experimental standpoint, he doesn't know it, so he
23 uses T_{sat} .

24 This is your same heat transfer stuff that
25 I showed before, reference to T_{sat} , and I should have

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1 said that, versus void fractions. The same data you
2 showed before.

3 What I'm doing now is saying this is what
4 the wall heat flux would be, and if you take, you
5 assume it's a laminar smooth film, and this is exactly
6 where you were headed before, the heat transfer
7 coefficient is nothing more than the vapor funnel
8 connectivity divided by the film thickness, which I'm
9 using delta for. That's this black curve.

10 You'll notice that very small values of
11 the void fraction does a very good job. The theory,
12 if you will, of a smooth, laminar film, works. As you
13 go to the higher void fractions, it breaks down
14 completely and underpredicts significantly.

15 MR. WALLIS: It looks like a lower limit,
16 though, which is a useful thing.

17 MR. KELLY: And one of the first things
18 people did in trying to fix up Bromley type models was
19 to say this vapor film could go turbulent. So, if by
20 now make this a turbulent force convection with the
21 characteristic length being the film thickness, I do
22 this.

23 So, to prove it, I cut the difference in
24 about half, but I'm still undercutting the data, but
25 that's assuming, you know, smooth parallel plates.

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1 Like I just said, this core is not smooth. Once you
2 get past about here, you have something that's very
3 chaotic, lots of waves, very agitated structure. So,
4 that's not surprising that turbulent would undercut it
5 as well.

6 So, what are we going to do to develop a
7 model? Okay, well, this is a Nusselt number
8 definition I'm going to use. It's no magic. Two
9 times the film thickness. It's just, you know, the
10 hydraulic diameter for parallel plates, if you will.

11 What I'd like to do is correlate this heat
12 transfer coefficient as a function of vapor Reynolds
13 number, and what I'm talking about now is the heat
14 transfer coefficient from the wall through the vapor
15 to the saturated interface.

16 I know it's a function of the vapor
17 Reynolds number, but I had no idea what the Reynolds
18 number is.

19 MR. WALLIS: Because the vapor is going
20 very much faster than the liquid?

21 MR. KELLY: Right.

22 MR. WALLIS: But you don't know how much -
23 - do you know how much heat transfer -- you're down to
24 the split between subcooling and vaporizing?

25 MR. KELLY: Exactly. So there's no way to

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1 know what your vapor velocity is because you don't
2 know how much of the heat was absorbed into the liquid
3 cord.

4 So what do you do? Here's where I borrow
5 an idea come up with by CATHARE, the work at PSI, and
6 we got this through the camp program as a NUREG-IA.
7 What we said is we don't know the vapor Reynolds
8 number. Let's instead use the film thickness and
9 correlate it based on that, and through an analytical
10 solution, you know, for laminar, you can show the
11 relationship between the film thickness and the
12 Reynolds number.

13 MR. WALLIS: Just like fudging the
14 friction factor and annular flow as a function of film
15 thickness.

16 MR. KELLY: Exactly, exactly. So, I'm
17 going to use the nondimensional film thickness where
18 this is a, you know, viscous gravitational link scale
19 which if in the condensation world, that would be
20 called a Nusselt link scale, and we use that to
21 correlate the Fung data. This is it. It's very
22 simple.

23 The Nusselt number is equal to two, is a
24 smooth laminar film. So this added part is due to the
25 wave enhancement.

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1 MR. WALLIS: This .1098 is --

2 MR. KELLY: It should have been .11. I
3 saw that last night, and I went oh, you idiot. Why
4 did you do that?

5 MR. WALLIS: That's what you got from
6 correlating data. You didn't get that from CATHARE?

7 MR. KELLY: No, I did the curve fit, and
8 I put the four digits there, and that's wrong. I
9 apologize. That's wrong.

10 MR. WALLIS: Well, I wasn't criticizing
11 that. I was just saying you got it rather than
12 CATHARE, but it's okay.

13 MR. KELLY: No, I did that, but I mean,
14 it's silly.

15 So, this is the result with you do that.
16 Nusselt number versus non-dimensional film thickness,
17 and it does a better job that I ever thought it would,
18 to be such a simple model.

19 MR. WALLIS: Well, you could have done it
20 versus alpha presumably. You could have said two plus
21 something times alpha.

22 MR. KELLY: And I'll show you exactly why
23 I don't --

24 MR. WALLIS: Because you and the row don't
25 change all that much, do they?

1 MR. KELLY: They don't.

2 MR. WALLIS: Delta is a measure of alpha.

3 MR. KELLY: That's true, they don't,
4 unless you go to high pressures.

5 MR. WALLIS: Right, so that's the test.
6 You have to go to a different pressure.

7 MR. KELLY: And at Winfrith, they did a
8 series, a very similar kind of experiment, not as much
9 data, however. So, what I've got here again is the
10 heat transfer coefficient versus void fraction. I'm
11 sorry you can't read this very well, but at five
12 different pressures. You notice at five bar, there's
13 a number of data points, and you get about the same
14 kind of behavior we saw with Fung.

15 A couple of points, at 20 bar, 40 bar, and
16 one at 70 bar. If I just correlated it with respect
17 to alpha, I wouldn't be able to do this, but having
18 the nondimensional film thickness in here which has
19 basically the vapor density, the delta row term,
20 that's what gives you this, and it does -- I mean,
21 it's not perfect by any means. That point is probably
22 in a different regime.

23 MR. WALLIS: Well, dimensionless delta is
24 gravity versus viscosity.

25 MR. KELLY: Right, and the delta row in

1 that is what gives you a lot of the pressure scaling.

2 MR. BANERJEE: But if it's turbulent, why
3 would viscosity enter that? Or is that the wall
4 effect? You know, George Galligher developed a
5 mechanistic model for this many years ago where he
6 partitioned the -- he actually took the amount of heat
7 that went into the liquid film, dissolution of the
8 liquid region. What was wrong with his model?

9 MR. KELLY: Trying to put it into TRACE.
10 If we're talking about the same thing, maybe I'm even
11 thinking of one of your papers, the one where he --

12 MR. BANERJEE: I never developed a model.

13 MR. KELLY: No, this one, it was a model
14 for inverted annular, but you had a two pressure
15 solution and looked at the ways.

16 MR. BANERJEE: It was a two fluid model.

17 MR. KELLY: Yes, but it's --

18 MR. BANERJEE: With the surface tension
19 because he wanted to take into account that if you
20 have different surface tension, say you did liquid
21 nitrogen boiling or liquid water, but it just fell out
22 of the two fluid model.

23 We didn't make a correlation. We just did
24 it.

25 MR. KELLY: Right.

1 MR. BANERJEE: It was a pure two fluid
2 model, and the instability of the interface was
3 predicted simply based on the two-fluid model which
4 gave you the wave lengths.

5 MR. KELLY: Right.

6 MR. BANERJEE: But George actually took
7 this, and he made a mechanistic model.

8 MR. KELLY: I looked at, you know, more
9 than 100 papers easily trying to find a model that I
10 thought would fit well, and I compared a lot of them
11 to this data, and none of them came out as well as
12 this, because I didn't start out saying I'm going to
13 develop a model. I started out saying I'm going to
14 select a model, but this is how I ended up.

15 MR. BANERJEE: For example, in this model,
16 there's no surface tension dependence. Now, clearly,
17 even with water, as the pressure changes, you're going
18 to get an effect because surface tension has an
19 important effect on the waves.

20 MR. KELLY: On the waves, that's right.

21 MR. BANERJEE: As does the density
22 difference.

23 MR. KELLY: Yes.

24 MR. BANERJEE: So, I mean, I wonder if
25 this model will work over a wide range of parameters

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1 or not because it's not very mechanistic.

2 MR. KELLY: No, but I do have one point
3 here at 70 bar.

4 MR. BANERJEE: Why is G in there? You'd
5 think if it was an experiment in space, you'd still
6 have inverted annular.

7 MR. KELLY: Yes, but this, the vapor film
8 is buoyancy driven. You know, the force balance
9 between the vapor film and the liquid.

10 MR. WALLIS: Buoyancy driven, okay.

11 MR. BANERJEE: You know, you get the same
12 thing in a horizontal pipe where G acts 90 degrees to
13 this.

14 MR. KELLY: Right, but now it's the film
15 flowing up underneath the liquid pool, and so you do
16 have the gravity.

17 MR. WALLIS: Okay, so now you're going to
18 tell us how to predict delta. Maybe you need to do
19 that.

20 MR. KELLY: Well, even before we get to
21 that, we now have a model for wall heat transfer.

22 MR. WALLIS: You don't know what delta is
23 except from the experiment. You don't have void
24 fraction.

25 MR. KELLY: Right, but before we get

1 there, we've talked about wall heat transfer through
2 the wall through the vapor film.

3 MR. WALLIS: This is K over δ times
4 δ . The second is a constant, the second term is
5 a constant. δ is cancelled, the second term.
6 δ over δ .

7 MR. KELLY: That's basically true.

8 MR. BANERJEE: So it's just a density
9 correction.

10 MR. KELLY: Yes. I didn't realize that,
11 but you're exactly right. See, that's why we need
12 peer review.

13 We have this wall correlation, but it's
14 across the vapor film. In the code, that encompasses
15 two heat transfer models, wall to vapor and vapor to
16 interface. So how on earth am I going to get that?
17 I don't know how hot the vapor is. I know it's
18 somewhere between T_{sat} and T_{wall} . I'm just going to
19 partition it equally.

20 Say that the vapor is exactly halfway
21 between the temperatures, and set the resistance to
22 heat transfer the same between the wall to the vapor
23 and the vapor to the interface. I know it's not
24 right, but it gives me the same -- you know, I'm
25 saying these two heat fluxes are equal, and then I'm

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1 just setting these two coefficients.

2 MR. WALLIS: Well, you could do a
3 parametric thing where you couch this into different
4 ways and so I sensed that the answer was to it.

5 MR. KELLY: Right, and you know, I would
6 just be causing myself more trouble, and this is --

7 MR. BANERJEE: In the two-fluid model,
8 doesn't this all sort of get calculated? You have a
9 temperature --

10 MR. KELLY: The vapor temperature does.

11 MR. BANERJEE: Yes.

12 MR. KELLY: But I need these interfacial
13 heat -- well, this is a wall heat transfer
14 coefficient, and this is an interfacial. That's what
15 I'm saying, what do I use for the interfacial?

16 MR. BANERJEE: But that would depend on I
17 guess whatever you calculate as the interfacial
18 roughness, right?

19 MR. KELLY: Right, and what I'm saying is
20 I don't have enough knowledge to do that. I know the
21 total resistance to heat transfer across the film, and
22 I'm just splitting it into two equal resistances.

23 MR. WALLIS: How do you know the total
24 resistance?

25 MR. KELLY: That's this model. Turn this

1 heat transfer coefficient into resistance.

2 MR. WALLIS: Delta, okay. So, it's all
3 going to be tied together in the end?

4 MR. KELLY: Yes. Well, what I've done is
5 put together a model where if --

6 MR. WALLIS: An interim model?

7 MR. KELLY: Yes, where if we have the
8 right film thickness, and therefore the right void
9 fraction, I get the right heat transfer. The previous
10 incarnation of the ACRS highly criticized TRAC-P F1
11 Mod2 in doing CSA use study for quite often doing a
12 pretty good job on the heat transfer, but being out to
13 lunch on the void fraction. They're saying you can't
14 have the heat transfer right and the void fraction
15 wrong.

16 So here, if we have the right void
fraction, that's an if, we'll get the right

18 transfer.

19 MR. WALLIS: We are an incarnation?

20 MR. KELLY: Okay, we reconstituted. Okay,
21 now I developed this model based upon tubes because I
22 had good quality, steady state tube data. It's very
23 hard to do steady state film boiling tests in a rod
24 bundle, especially under these low quality conditions.

25 So, is it applicable? You got to ask that

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1 question. Basically rods and tubes, rod bundles and
2 tubes are very, very different.

3 So what I did is something I call a frozen
4 quench front approach. So, I take a reflood test and
5 take one point in time and look at an axial snapshot
6 of the conditions downstream of the quench front. So,
7 I'm going to look at the axial profile of those wall
8 heat transfer coefficients, but I want void fractions
9 as well.

10 We don't have gamma densitometers on
11 these, unfortunately. Instead we have DP cells. So
12 what I'm going to have to do is infer void fractions
13 from the DP cells, interpolate them in the axial
14 direction to the locations of the thermocouples, in
15 order to generate a heat transfer coefficient versus
16 void fraction.

17 I'm going to use data from two FLECHT-
18 SEASET tests. I reduce these, a six-inch per second
19 test, a three-inch per second test, and three PERICLES
20 tests. This dates from the time when I worked as a
21 member of the CATHARE team in France.

22 We develop the same model --

23 MR. WALLIS: Except it's not point three?

24 MR. KELLY: Right. It went from .11 to
25 .3, and that's really not surprising that it's higher

1 in rod bundles. It's even higher in rod bundles than
2 force convective flow.

3 This is what it looks like. This is a
4 FLECHT-SEASET run. This is a Pericles run. What I've
5 done is looked at snapshots at four different points
6 in time when the quench front is just downstream of a
7 grid spacer so that I have almost two feet before I
8 hit the next grid spacer and the flow is completely
9 disrupted.

10 So, I have all of the thermocouples here,
11 and what you'll see is that as you get farther away
12 from the quench front and the void fraction goes up,
13 the film thickens. At some point when this
14 nondimensional film thickness is around 35 to 40, you
15 go through a regime change, and you go from something
16 that looked like inverted annular to something that's,
17 you know, whether it's a distorted slug --

18 MR. WALLIS: It's a lower heat transfer
19 coefficient, though.

20 MR. KELLY: Right.

21 MR. WALLIS: It's got to be worse than
22 annular.

23 MR. KELLY: Right.

24 MR. WALLIS: How could that be?

25 MR. KELLY: Well, because you're breaking

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1 up to things like dispersed floor film boiling. You
2 no longer have that liquid smack up close to the wall.
3 It's now dispersed.

4 MR. WALLIS: I think dispersed will make
5 it better because the droplets would come closer to
6 the wall. The furthest it can be away is when it's
7 concentrated.

8 MR. BANERJEE: It's inverted annular thing
9 actually, this goes looping around, you know.

10 MR. KELLY: So that's what's happening
11 here. This is when you do a regime transition.

12 This was a model I developed for tubes,
13 and that's -- I hate -- I wouldn't call it a
14 correlation. It's more of a co-fit, but you see it
15 worked pretty well for the Pericles test at 30 psi and
16 the FLECHT-SEASET at 40.

17 MR. WALLIS: Okay.

18 MR. BANERJEE: What's the dark blue stuff
19 in Pericles?

20 MR. KELLY: You mean here?

21 MR. BANERJEE: Yes.

22 MR. KELLY: Well, if you could see it,
23 you'll notice there's these points down in here, too.

24 MR. WALLIS: It goes around.

25 MR. KELLY: So this again is the point

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1 where, you know, there's some kind of flow regime
2 change.

3 MR. BANERJEE: That's at a lower pressure
4 or something?

5 MR. KELLY: Yes, this is at 30 psi and
6 this is at 40. So, it's not perfect, believe me, but
7 at least I looked at dry bundle data.

8 MR. WALLIS: It suppresses the turbulence
9 somehow or something. Okay, you'd invent some
10 concept.

11 MR. KELLY: So back to my little cartoon.
12 We've now taken care of the wall to vapor heat
13 transfer and the vapor to interface. The next thing,
14 remember what I said the controlling process was, was
15 the interfacial heat transfer from the saturated
16 liquid interface into the subcooled liquid core.
17 That's the controlling process, and that's what we're
18 going to talk about now.

19 We had a discussion about the definition
20 of

21 MR. WALLIS: That's how the subcooling
22 exerts an influence.

23 MR. KELLY: Right. Vic and I had a
24 discussion at one of these meetings about the
25 definition of ad hoc and whether or not it's bad.

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1 This is where you can go towards being an ad hoc
2 model, but I'm going to do my best to base it on data

3 MR. RANSOM: Ad hoc means special purpose.

4 MR. KELLY: Exactly. I actually did go
5 back and look that up from the dictionary after our
6 discussion, and you were right. If my Latin weren't
7 so rusty, I'd say it means to this or something.

8 So, we're going to talk about interfacial
9 heat transfer between the saturated interface and the
10 subcooled liquid core. So first what I want to do is
11 make an observation, and that is that when the liquid
12 is significantly subcooled, most of the wall heat
13 transfer just simply goes across the vapor film and
14 then vents into the liquid core. So, it's primarily
15 increasing the sensible heat of that liquid core.

16 The thickness of this vapor film is going
17 to be self-regulating, if you will. It's going to
18 adjust itself so that the heat transfer across it
19 matches what is possible for this subcooled liquid
20 core to absorb.

21 So, you know, leap of faith here. What
22 I'm saying is the wall heat flux, which I've said is
23 equal to this heat transfer coefficient times T_{wall}
24 minus T_{sat} , is approximately equal to the heat flux
25 going into the subcooled nuclear core.

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1 MR. WALLIS: There's no vaporization
2 occurring at all?

3 MR. KELLY: I'm saying it's small.

4 MR. WALLIS: It's small. You could
5 probably estimate it and show it's small. It would be
6 useful.

7 MR. KELLY: Yes, well, you're going to see
8 in just a second when it isn't small. That's very
9 much supposed to be approximate.

10 What I'm going to try to do is take this
11 database and infer what this interfacial heat transfer
12 coefficient might be.

13 MR. WALLIS: So are you saying essentially
14 that the vapor is formed there, but it doesn't really
15 do very much except that the main thing is that
16 there's a space there?

17 MR. KELLY: Exactly.

18 MR. WALLIS: The velocity of the vapor
19 doesn't matter very much?

20 MR. KELLY: Not too much. The waviness of
21 the liquid film does, but the main thing is what
22 happens in the liquid core.

23 MR. WALLIS: There's nothing in your slide
24 that indicates what the delta is of the vapor film or
25 anything?

1 MR. KELLY: None whatsoever.

2 MR. WALLIS: That makes it a little
3 suspect. It works just as well for downflow?

4 MR. KELLY: Haven't tested that yet, but
5 that's something that needs to be done.

6 So, what I'm going to do is get an
7 estimate of this, and I have to emphasize estimate a
8 priori. I don't even know the order of magnitude of
9 that, and if you go and look at the literature, people
10 do all kinds of things. You know, from using Dittus-
11 Boeter, saying that well, you know, with this
12 turbulent liquid, and we're just going to pretend the
13 interface is a wall. Well, I know that's not right
14 because the wall --

15 MR. WALLIS: Well, the turbulence is
16 created at the wall. It is not touching the wall. I
17 don't see how it can be turbulent in the same sense it
18 would be if it filled a pipe.

19 MR. KELLY: Well, what they're saying is
20 that before you got to the quench front because, you
21 know.

22 MR. WALLIS: Okay, then it retains the
23 turbulence it had?

24 MR. KELLY: Right, and so they'll use the
25 Dittus-Boeter model for this.

1 MR. BANERJEE: Or the alternative is when
2 you have high vaporization with drag on the interface
3 generates.

4 MR. KELLY: Right, that's another one, but
5 you don't see models really in the literature doing
6 that. The other thing people will do is they'll say
7 it's a transient --

8 MR. WALLIS: There must be something to
9 stop the liquid slowing down and falling back down
10 again. There must be something pulling it up there.

11 MR. KELLY: That's the interfacial drag.

12 MR. WALLIS: That comes from gravity.
13 That's the delta row part.

14 MR. KELLY: Right.

15 MR. WALLIS: So at least you know that the
16 vapor holds up, keeps the liquid going.

17 MR. KELLY: Exactly, but you have to have
18 enough vapor to do that, and that's when we get --

19 MR. WALLIS: It's where your delta row G
20 comes from maybe.

21 MR. KELLY: Exactly.

22 MR. WALLIS: It's a measure of interfacial
23 share which is also a measure of the creation of
24 turbulence and mixing.

25 MR. BANERJEE: But then if you have down

1 fluid which changes.

2 MR. KELLY: Yes, but I mean, I can go in
3 the literature, and people do transient conduction
4 solutions. You know, developing boundary layers and
5 flag plates, all kinds of things.

6 Like I said, I don't even know the order
7 of magnitude of this thing. So, what I'm going to try
8 to do is figure it out, you know, in a very
9 approximate way.

10 So, what I'm going to simply say is, based
11 upon this approximation, it's equal to the wall heat
12 transfer over T_{sat} minus T liquid.

13 MR. WALLIS: Well, you're going to take
14 where it's going to and get some way of interpolating
15 between the two, essentially.

16 MR. KELLY: Well, first I'm going to get
17 an estimate of what it is.

18 MR. WALLIS: Yes, but you're going to get
19 where it's going to and then you've got the other
20 part, and you can add them together.

21 MR. KELLY: Right. So, again, I took all
22 of the subcool data, and I got what I'll call an
23 inferred Nusselt number for this interfacial heat
24 transfer.

25 MR. WALLIS: Well, that's the constant

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1 we're adding. This is the constant you want, isn't
2 it? You take the curve which is coming down like this
3 and you add a constant to it. It goes up to --M R .

4 KELLY: Yes, but this is a very different curve.

5 MR. WALLIS: Different curve than what we
6 saw before?

7 MR. KELLY: Yes, this is completely
8 different. That's why I was befuddled for a second.
9 This, I'm now taking the wall heat flux and dividing
10 it by T_{sat} minus T_{liquid} , where T_{liquid} comes from
11 an energy balance, or basically my equilibrium
12 quality, coming up from the bottom of the test
13 section. I'm turning that into a Nusselt number. So,
14 this is interfacial now, is what I'm trying to do.

15 The reason for this tail has very little
16 to do with the film thickness because it's turned
17 around. The highly subcooled cases out here, this is
18 when the void fraction is ten percent, is out here.
19 This is where the liquid has almost reached
20 saturation. This is void fraction of 70 percent. So,
21 in a sense, exactly flipped around.

22 MR. WALLIS: Okay.

23 MR. KELLY: My approximation that I made
24 is reasonable out here, and the approximation is that
25 almost all of the wall heat flux makes its way into

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1 the liquid core with very little vapor generation. As
2 the liquid subcooling goes towards zero, that
3 assumption falls apart.

4 I mean, obviously when the liquid
5 saturated, all of the wall heat transfer is generating
6 vapor, and none of it is going in. So, what I'm doing
7 is dividing my denominator is going to zero, and
8 that's the main reason you get this exponential shape.

9 The point of this is that over a pretty
10 wide range where I think my model, that assumption is
11 more or less valid, it almost comes to a constant
12 value where the Nusselt number equals 200.

13 Now, and that's similar to what Saha and
14 Zuber got for subcooled nuclear boiling in the
15 conduction control regime where they came up with a
16 Nusselt number of 455. Is this absolutely right? No,
17 but is it a whole lot better than guessing something?
18 Yes.

19 So, this is what I'm going with, and
20 again, there's no noticeable mass flux effect, and
21 within the assumptions, it does a pretty reasonable
22 job.

23 MR. WALLIS: Well this number 200 means
24 there's a characteristic length which is much shorter
25 than one percent of the actual length.

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1 MR. BANERJEE: It suggests its turbulent.

2 MR. WALLIS: Where is it coming from if
3 it's not coming from turbulence, and why should it be
4 constant? It should depend on some mechanism of some
5 sort unless it's a surface tension. Anyway, you
6 should proceed. This is very interesting.

7 You're getting towards the end, I think.

8 MR. KELLY: Right.

9 MR. WALLIS: Because we need to finish.

10 MR. KELLY: So, I'm going to compare it to
11 the Winfrith data so I can look at the effect of
12 different pressures and also it's always better, if
13 you can, to use more than one experiment.

14 MR. WALLIS: Okay, so you're going to pull
15 all of this together.

16 MR. KELLY: And that has the same trends
17 and comes to about the same value.

18 MR. BANERJEE: But the only points there
19 are at the lowest pressure, right?

20 MR. KELLY: Right, that's true. But this
21 is five bar and Fung was one bar. So, at least that
22 helps a little, but you're exactly right.

23 Wall to liquid radiation, we can dispense
24 with that. We have no way of knowing what it is, so
25 I'm just going to use concentric cylinders.

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1 MR. WALLIS: That's probably what it is.

2 MR. KELLY: And that's as close as I can
3 guess.

4 MR. WALLIS: Liquid is a pretty good
5 absorber.

6 MR. KELLY: We've gotten through
7 everything except interfacial drag. I'm not going to
8 talk about the break-up criteria, although I already
9 did some.

10 How are we going to get the interfacial
11 drag? Well, we have a problem, one of many problems.
12 This is where ad hoc comes from.

13 MR. WALLIS: Adjust to enough to keep the
14 liquid going.

15 MR. KELLY: Yes.

16 MR. BANERJEE: Why don't you just use
17 Graham's?

18 MR. WALLIS: No, it's inverted.

19 MR. KELLY: I'm going to talk about that
20 in the condensation presentation. The fact velocities
21 are unknown. The liquid is subcooled, so even in
22 these very simple, steady state experiments, I have no
23 way of knowing what the actual vapor floor rate is.
24 So, I don't know what my relative velocity is.

25 I know the void fraction, so I can know

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1 what the buoyancy force, what is, and consequently
2 what the interfacial drag force was, but since I don't
3 know the relative, I can't get the interfacial drag
4 coefficient.

5 MR. BANERJEE: Doesn't your two-fluid
6 model give you the velocities at the end?

7 MR. KELLY: Well, yes, but I'm trying to
8 do this from data, okay?

9 MR. WALLIS: It seems to me that that's
10 subliquids there, the liquids in the middle. If you
11 don't have enough drag on it, it's going to slump down
12 within the film.

13 MR. KELLY: Exactly.

14 MR. WALLIS: So that the drag -- you've
15 got a kind of adjust it in order to keep the liquid
16 going.

17 MR. KELLY: Exactly, and so what --

18 MR. WALLIS: Make it enough to keep the
19 liquid going.

20 MR. KELLY: Well, what is that?

21 MR. WALLIS: It's the weight of the
22 liquid.

23 MR. KELLY: That's the force.

24 MR. WALLIS: Because it's not changing.

25 It's not accelerating.

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1 MR. KELLY: Right, and that's what I just
2 said, is I know the buoyancy force needed, so that
3 gives me the -- I need the F's of I that I'm going to
4 -- and I don't know -- I know the --

5 MR. WALLIS: It adjusts itself in order to
6 keep the thing going.

7 MR. KELLY: I know the force, but I don't
8 know the REL, so I can't get the coefficient.

9 MR. WALLIS: You don't need the
10 coefficient. You just need the force.

11 MR. KELLY: In the code, I can't say, you
12 know --

13 MR. BANERJEE: But you can put $Tow W$ per
14 unit area there.

15 MR. KELLY: Yes, but if I say $Tow W$ is
16 equal to α , one minus α --

17 MR. WALLIS: That's what you need, yes, do
18 that.

19 MR. KELLY: G delta row, that means no
20 matter what amount of liquid it is, I'm going to have
21 enough force to hold it there.

22 MR. WALLIS: That's right. That's right.

23 MR. KELLY: Well --

24 MR. WALLIS: It adjusts itself. I mean,
25 it doesn't change -- the α doesn't change.

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1 MR. KELLY: Physically, you're speaking
2 truth.

3 MR. BANERJEE: It sounds like drip flux
4 models.

5 MR. KELLY: In numerical space, we're
6 talking loads of problems.

7 MR. WALLIS: Okay, let's move.

8 MR. BANERJEE: Isn't that how you get your
9 coefficients for the drip flux model? I mean, it's
10 the same thing.

11 MR. KELLY: Yes, but they're applied to a
12 Vrel. I don't just stick a force in. I use the
13 actual Vrel calculate by the code in computing the
14 force.

15 MR. WALLIS: The force is what you need to
16 fight the buoyancy of the bubbles.

17 MR. KELLY: Right, yes. So, I don't have
18 any way of calculating these from the data. So, what
19 am I going to do? Again, I want to make some
20 observations.

21 So, I'm going to go out and look at some
22 single phase, you know, pressure drop tests and ducts
23 with either grooves or wavy walls. I'm talking about
24 grooves that are orthogonal to the flow so it kind of
25 sort of looks like waves. This is the friction factor

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1 follows that for its move parallel plates for Reynolds
2 numbers. Reynolds number is between 200 and 400. It
3 looks like the smooth laminar flow.

4 When you've got a higher Reynolds numbers,
5 the friction factors approach a constant value, like
6 a fully rough turbulent number where that's a function
7 of the amplitude to the wavelength ratio of, you know,
8 whether the ridges or the waves.

9 Well, that helps. I know an expected
10 behavior, but it doesn't give me any numbers yet, and
11 then I went and looked at some horizontal stratified
12 flow data from Andritsos and Hanratty. Again, they
13 came up with the interfacial friction factor being a
14 function of the wave amplitude.

15 Okay, well, I could have guessed that, but
16 of course, I don't have models for the wave amplitude,
17 and nothing that I know would justify trying to put
18 something like that in.

19 They went further, and they showed that at
20 least for their case, the interfacial friction factor
21 ended up being proportional to the vapor Reynolds
22 number. So, what they're saying is the vapor velocity
23 has something to do with forming these waves, and that
24 takes you to this fully rough turbulent condition.

25 So, I'm going to propose a model, and this

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1 is what I want it to do. I want it to reduce to the
2 smooth parallel plate for low values of the vapor
3 Reynolds number, okay? I want it to be linearly
4 proportional to the vapor Reynolds number at high
5 Reynolds numbers. You know, when I expect it to be in
6 this fully rough turbulent condition where surface
7 waves are what are important.

8 These next two conditions fall out by me
9 looking at other models. What I want is for the vapor
10 Reynolds number to monotonically increase the film
11 thickness. There are some models that don't meet that
12 condition. I want to avoid unrealistically high vapor
13 Reynolds numbers like you would get if you just
14 assumed it was smooth, parallel plates.

15 So, this is again, you hate to call it a
16 model. This is what I'm using. It's a maximum of,
17 you know, 24 over the Reynolds number. That's a
18 smooth parallel plate, and the simple function of a
19 non-dimensional film thickness.

20 MR. WALLIS: Where did that function come
21 from? Comparison with data or something?

22 MR. KELLY: I'm going to tell you.

23 MR. WALLIS: The next figure. I was
24 trying to figure out. I'm on the next slide.

25 MR. KELLY: Yes, well, don't go there yet.

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1 MR. WALLIS: Okay.

2 MR. KELLY: The .7, the power, came about
3 because that's the power that gives me a linear, the
4 interfacial friction factor increasing linearly with
5 Reynolds number, and I'll explain how that comes about
6 in a second. This coefficient --

7 MR. WALLIS: Has to do with the one-third
8 power and all that stuff?

9 MR. KELLY: No. It's much simpler than
10 that. It matched the interfacial drag at the point
11 where I expect this liquid column to break up and go
12 into the next regime. That was my degree of freedom
13 that I chose in order to get me a smooth transition.
14 This is what results when you do that.

15 MR. WALLIS: Now, these are data points
16 here?

17 MR. KELLY: Yes and no. Each one of these
18 points is one of Fung's tests.

19 MR. WALLIS: It is, okay, based on the
20 data, based on a test.

21 MR. KELLY: Yes, now it should, on the
22 next slide, you'll see an inferred in front of this
23 Reynolds number, because you remember we don't know
24 the vapor Reynolds number. If I did, I could have
25 calculated these things, but now I have a model for

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1 interfacial drag.

2 I can go and solve my two fluid equations
3 given the void fraction that was measured in these
4 tests. So, like you were saying, I know the buoyancy
5 force, so I know the interfacial friction force. I
6 have this model for interfacial friction.

7 MR. WALLIS: That's the .72 power that's
8 on there?

9 MR. KELLY: The .72 power on the non-
10 dimensional film thickness makes this be Reynolds
11 number to the one, okay? So, what I did is I back-
12 solved from the momentum equations for a given film
13 thickness, what the vapor velocity would be using my
14 model. So, I solved for these Reynolds numbers and
15 then plotted what the interfacial friction factor was.

16 MR. WALLIS: That's right. That's why
17 it's such a straight curve, I guess.

18 MR. KELLY: This is the 24 over RE, which
19 is exactly what you expect. This is where that max
20 kicks in, and it becomes a function of the film
21 thickness. The derivative of this with respect to the
22 Reynolds number gives you a slope of one. I mean,
23 it's linearly in proportion. That's what I'm trying
24 to say.

25 The same kind of plot, except here I was

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1 more truthful, or at least more careful, and said
2 inferred Reynolds number. So, I'm back-calculating
3 that Reynolds number based upon my model and plotting
4 it versus non-dimensional film thickness.

5 MR. WALLIS: And all this is what went
6 into the code that gave the results that you showed at
7 the very beginning?

8 MR. KELLY: Yes, this is all that went
9 into that one regime, and that's just one of many
10 regimes in reflood.

11 MR. WALLIS: This is why it took so long
12 to grind one point?

13 MR. KELLY: Yes, and it's also why it's,
14 you know, something that hasn't yet truly been solved,
15 even though we've been working in the reactor safety
16 area since the ECCS hearings, '73.

17 MR. WALLIS: All this is based on your
18 fantasy about what's happening?

19 MR. KELLY: Right, but in a two-fluid
20 framework.

21 MR. WALLIS: It's sounds nice, nice story.

22 MR. KELLY: So, that's what we have, and
23 you know, basically what I'm saying is we're going to
24 do some future model development.

25 MR. WALLIS: Since this is so perfect, we

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1 should stop the Penn State tests because they might
2 disprove it.

3 MR. KELLY: Well, they deal with some of
4 the other regimes, which are even more uncertain than
5 this, and the regime that comes in between.

6 MR. WALLIS: Now, this is the one where
7 the quench front is. This is the most important part
8 to get right, isn't it?

9 MR. KELLY: It's hard to say.

10 MR. WALLIS: Isn't that why you were doing
11 it?

12 MR. KELLY: Yes, because it does help
13 drive the velocity of the quench front, and that gives
14 you your vapor source, but if you mess up the
15 dispersed flow film boiling by a lot, then your PCT is
16 directly affected by that one.

17 MR. WALLIS: Has this been written up in
18 a form that can be peer reviewed?

19 MR. KELLY: Not quite. Actually, I didn't
20 put this model in the code. Weidong did for me. What
21 I did, I wrote up a fairly brief description of all
22 the models and handed that off to Weidong, and Weidong
23 implemented it for me.

24 MR. WALLIS: Yes, but it's going to be
25 written up as a NUREG or something?

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1 MR. KELLY: Yes.

2 MR. BANERJEE: Well, before that, a draft
3 should come to us, I think.

4 MR. WALLIS: I don't know. We don't have
5 to do a peer review for everything.

6 MR. KELLY: I agree, that's exactly what
7 I want to do.

8 MR. BANERJEE: This is the sort of thing
9 that you could publish, so the best peer review is to
10 send it to Journal of Heat Transfer and see what they
11 say.

12 MR. KELLY: And I will. It's just, you
13 know, this is one regime out of many, and as you can
14 see, I'm already working on tube condensation, and you
15 know, so we're balancing time here.

16 But this work is just about at the end,
17 and one of the main things I have left to do is the
18 documentation, and that's where I will try to publish
19 something from this.

20 MR. BANERJEE: There is a lot of stuff
21 beginning to come out of direct numerical simulation
22 with the formable interfaces. Clearly, of course,
23 these are coming out of JFM. There are a couple of
24 papers in JFM and so on.

25 There's a group in the AETH 5 as well.

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1 We're looking at condensation with George. So, many
2 of the issues, assumptions you are making here will be
3 directly available from DNS. Their actual direct
4 solution of the stuff is not approximations anyway.
5 So, it would be useful to see whether any of this
6 actually falls up because you can't measure these
7 things easily. Certainly you can calculate them in
8 codes.

9 MR. KELLY: When I look at how chaotic the
10 structure is --

11 MR. BANERJEE: Well, they're fully
12 turbulent.

13 MR. KELLY: Yes.

14 MR. BANERJEE: I mean, just for the
15 regimes where you have interfacial waves, not when
16 they're breaking up. Even that can be done now by
17 DNS, but certainly the regime with interfacial waves
18 are being calculated and being published after peer
19 review in DFM.

20 MR. KELLY: Yes.

21 MR. BANERJEE: So we should look at that.

22 MR. KELLY: Okay.

23 MR. WALLIS: Is there any further data
24 that you can use to check your model?

25 MR. KELLY: Well --

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1 MR. WALLIS: Besides what may come out of
2 Penn State? Maybe the Penn State results are the
3 answer.

4 MR. KELLY: One of the things, when we,
5 you know, decided to do the Penn State test, one of
6 the things I insisted upon was trying to measure the
7 void fraction more accurately, and so we did this with
8 delta P cells every three inches over about three to
9 four feet in the middle of the bundle, so that we can
10 have a little bit better idea of the axial profile of
11 the void fraction.

12 So, that ought to at least give us heat
13 transfer coefficient versus void fraction in this
14 regime whereas now I'm having to interpolate over one
15 foot delta P cells, which is insufficient.
16 Unfortunately, we didn't have enough money to put a
17 gamma densitometer on that test because that would
18 have been better, and would have helped support it.

19 MR. WALLIS: I was thinking about that
20 because the DP cell measures pressure drop, and
21 there's a friction. There's a wall of friction term
22 in there. That interface friction is enough to hold
23 up the liquid, which is the hydrostatic term you want
24 to get. Presumably, the wall friction is the same
25 order of magnitude. So, you may have trouble taking

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1 void fraction directly from DP cell.

2 MR. KELLY: Yes, they're not too bad when
3 you're in a highly subcooled, low void fraction
4 regime, and you're in a place where there's no grid
5 spacer.

6 MR. WALLIS: But now since you have a way
7 of calculating pressure drop with your model.

8 MR. KELLY: You can compare that.

9 MR. WALLIS: You can put that with the DP
10 cell.

11 MR. KELLY: Right.

12 MR. WALLIS: That will make the day feel
13 even better.

14 MR. KELLY: Yes. So, RBHT will help, but
15 one of the big -- I mean, the model, there are two
16 models in here that are most uncertain. That's the
17 interfacial drag, which we just went through, which I
18 think has the right behavior, but I wouldn't swear to
19 the magnitude, and the interfacial heat transfer for
20 the saturated interface to the liquid core. That's
21 the one I really pulled out of the air, remember?

22 That one I would love to have some data
23 for. I am going, when we get the RBHT data in house,
24 I'm going to look for it, and what I mean is I can
25 make the same kind of assumptions, but I don't know

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1 what the liquid temperature is because I can't do, you
2 know, the easy integration of the test section.

3 We have fluid thermocouples hanging down
4 from the grid spacers. If those fluid thermocouples
5 can measure liquid subcooling while it's in film
6 boiling, then I can at least check this estimate of
7 the magnitude of the interfacial heat transfer, but
8 this is an area where I would like to do a smaller
9 separate effects test, and we just have to see where
10 the agency priorities are and whether this is
11 something we can spend more money on or not.

12 MR. WALLIS: Okay.

13 MR. KELLY: And believe it or not, because
14 I started 15 minutes late, we got lucky.

15 MR. WALLIS: I was just going to say, you
16 have done extraordinarily well in terms of my
17 experience with you. You've taken exactly the time
18 allotted.

19 MR. KELLY: I can always talk more.

20 MR. WALLIS: In spite of having a lot to
21 say. That's very good.

22 MR. KELLY: Thank you.

23 MR. WALLIS: And you're going to do the
24 same thing this afternoon. You're going to be on
25 time, right?

1 MR. KELLY: Yes.

2 MR. WALLIS: Good. So it's now time to
3 take a break unless my colleagues have a great desire
4 to say something.

5 We'll take a break until 1:30. Thank you.

6 (Whereupon, the foregoing
7 matter went off the record at
8 12:31 p.m. and went back on the
9 record at 1:32 p.m.)

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A-F-T-E-R-N-O-O-N S-E-S-S-I-O-N

(1:32 p.m.)

MR. WALLIS: We'll come back in session, and we'll hear the next presentation by Joe Kelly. Looking forward to it, as always.

MR. KELLY: And I'll be speaking about the tube condensation model in TRACE, and my coworker on this is Birol Aktas of ISL.

I'm going to split it into, again, three parts. The first part is going to be fairly brief. There's going to be one slide showing you what the diagram of the ESBWR is. There's a reason for this, is the need for tube condensation is to model the intube condensation for the isolation condenser and the passive containment cooling systems of the ESBWR.

I'm going to try to briefly explain what's in TRACE now, and these are the legacy models from TRAC/PF1-Mod2. Then before you do any model development, you always have to answer your question, do you need to. So, the first thing I'm going to do is what I'll call an investigatory assessment where I try to determine if the current models are good enough.

Of course, if they were, you wouldn't see this other topic, and that's where I'm going to

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1 describe the model development effort. This is a work
2 in progress. I just started this not long ago, and so
3 you're only going to see a partial description of the
4 following models.

5 This to some extent is the inverse of what
6 I was talking about in the last presentation.

7 MR. WALLIS: I was just going to say,
8 you're such an expert in modeling wall friction,
9 interfacial shear, wall fluid heat transfer,
10 interfacial heat transfer. With those four models,
11 you could fit almost anything.

12 MR. KELLY: Right. You could also not fit
13 just about anything, too. So, you're familiar with
14 the ESBWR design. Just to show you, ICS, again
15 they're basically vertical tubes, heat exchangers,
16 sitting in a pool of water. We're going to be talking
17 about the condensation in the inside of the tubes.
18 The ICS tends to be more at higher pressure and pure
19 steam driven from the reactor pressure vessel,
20 delivering the condensate back to the pressure vessel.

21 The PCCS system, the same design heat
22 exchanger except for a non-condensable gas vent. It
23 takes its intake from the dry wall in the containment.
24 So here, you're primarily talking about condensation
25 with non-condensables.

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1 Air normally, but in case of a severe
2 accident, you would have a hydrogen steam mix. So,
3 driven by the pressure difference between the dry well
4 and the wet well, you have the noncondensable steam
5 gas mixture driven through the condenser.

6 The condensate feeds back to the
7 suppression pool -- excuse me, the condensate comes to
8 this little holding tank back to the vessel. It's the
9 old design where it was drained to the GDCS pool.
10 That was an SBWR design.

11 This line is a vent path for non-
12 condensables. It kind of burps the noncondensables
13 out periodically.

14 MR. WALLIS: So presumably there's very
15 little pressure drop between the containment and the
16 suppression pool?

17 MR. KELLY: Right. So now we're going to
18 talk about the current models in the TRACE code. So,
19 when you go to the condensation regime, the effective
20 wall heat flux is the super position at two heat
21 fluxes, one from the wall to the vapor and one from
22 the wall to the liquid. This is just the way it's
23 currently done, and if you're in condensation, it ends
24 up using the sync temperature being T_{sat} instead of
25 the vapor temperature for what I'll call the wall to

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1 vapor component.

2 MR. WALLIS: Why do the two components if
3 only one component is on the wall?

4 MR. KELLY: Good question, and in the
5 model development, there will only be one. This is
6 what's in the code now.

7 MR. WALLIS: So one of these H's is zero,
8 presumably?

9 MR. KELLY: No.

10 MR. WALLIS: No?

11 MR. KELLY: No.

12 MR. BANERJEE: Except for drop
13 condensation.

14 MR. KELLY: Right, which this isn't.

15 MR. WALLIS: I don't get that.

16 MR. KELLY: This isn't at all. It adds
17 the two. Here's the wall to vapor and here's the wall
18 to liquid. It uses this waiting factor which is a
19 function of quality, and I'll explain this in a
20 second.

21 You can pretty much forget about the vapor
22 convective term. This is very, very small. The vapor
23 condensation term, this tends to be a large number.

24 MR. WALLIS: This doesn't make sense to me
25 at all.

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1 MR. KELLY: I'm not going to defend this.
2 This is what's there now.

3 MR. WALLIS: What? Why is this in there?

4 MR. KRESS: That's just the way the guy
5 decided to do it because he didn't know how else to do
6 it.

7 MR. WALLIS: Didn't know how else to do
8 it, okay.

9 MR. KELLY: This H liquid convective, that
10 will end up being, if you will, a two-phase convected
11 heat transfer coefficient, and so this, if it were
12 right, this is all you would need, but what they use
13 for that model --

14 MR. WALLIS: It's like the Chen
15 correlation for boiling. So, adding a boiling effect
16 to a convective effect. Here you're adding a
17 condensation effect to a convective effect.

18 MR. KELLY: Kind of but not really because
19 this is ramping between them.

20 MR. WALLIS: That's not really what's
21 happening.

22 MR. KELLY: But it's funny --

23 MR. WALLIS: This is the interface and the
24 convection is at the wall.

25 MR. KELLY: I agree. I agree completely.

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1 MR. WALLIS: Okay.

2 MR. KELLY: But it's funny you should
3 mention the Chen correlation.

4 MR. WALLIS: Chen is a subscript here.

5 MR. KELLY: Yes, because that's what's
6 going to be used for this convective heat transfer.

7 MR. WALLIS: He just borrows anything from
8 anywhere and uses it.

9 MR. KELLY: And in this waiting factor,
10 the quality here, that Chen, the .71, that's according
11 to the database, that's the highest quality that
12 you're supposed to use that model at. That's why --

13 MR. WALLIS: The boiling model or the --

14 MR. KELLY: No, the forced convective
15 part, what I guess they'll call the macro term.

16 MR. WALLIS: For boiling?

17 MR. KELLY: Well, it's for forced
18 convection evaporation.

19 MR. WALLIS: It's evaporation. It's not
20 condensed.

21 MR. KELLY: Right.

22 MR. WALLIS: So they've got the same
23 condensing as for boiling, the X Chen?

24 MR. KELLY: Well, this they used, they say
25 we won't use the correlation at a quality higher than

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1 this because that would exceed its database, and
2 that's where this ramp comes from. So, if the quality
3 is one, give it pure condensation to the vapor, and
4 I'll show you the models for that.

5 If the quality is between one and .71, you
6 ramp between these two, where this is a two-phase
7 conductive term. Below .71, this is all you get.
8 Then it's even funny, because if you look at the
9 definition of quality, it uses a quality that they
10 take a static mixture enthalpy and convert that to a
11 quality. It's now a flow-in quality.

12 That's actually not a bad idea because a
13 flow quality in these transient to fluid codes can go
14 between zero and one, time step to time step,
15 especially in low flow conditions.

16 MR. WALLIS: They're extraordinarily
17 different.

18 MR. KELLY: Yes.

19 MR. WALLIS: Going much faster than the
20 liquid, and the influx quality, which is a bad use of
21 the term, is nothing like the same as the flow-in
22 quality.

23 MR. KELLY: Exactly, and here it's being
24 used as a weighting factor between these two.

25 MR. WALLIS: Why won't these guys show the

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1 view?

2 MR. KELLY: Now, that I don't know. I
3 wasn't at the NRC when this work was done.

4 But now let's talk about the wall to vapor
5 condensation heat transfer coefficient, the HV
6 subscript conv that I have. This made up of two
7 correlations with a weighting factor. The first, and
8 I'm just using the terminology that's straight from
9 the theory manual, is the good old Nusselt formula for
10 laminate film condensation.

11 You know, it's an analytical solution for
12 condensation on a plate where the L, the denominator
13 here, is the length of the entire plate. So, this is
14 for laminate film condensation.

15 They did realize that that was not
16 applicable to turbulent films, and they found an
17 empirical formula which I had trouble tracking down.
18 I now know it's by Grigull, and it's from several,
19 like maybe the fourth edition.

20 MR. WALLIS: Reliable, right.

21 MR. KELLY: Of Creef's book. So, it's the
22 same kind of formula except, you know, the L and delta
23 T's in the numerator instead of the denominator.
24 Again, this is the characteristic link scale. It
25 should be the entire --

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1 MR. WALLIS: Is this the condensation
2 drive only by gravity?

3 MR. KELLY: That's correct. No effective
4 interfacial shear.

5 MR. BANERJEE: On a vertical plate.

6 MR. KELLY: On a vertical plate, and we're
7 going to make it even more interesting. This is
8 supposed to be the length of the entire heat transfer
9 surface. We use a node length.

10 MR. WALLIS: Oh, come on.

11 MR. KELLY: No, that's true. It's exactly
12 what's done in TRACE, and until --

13 MR. WALLIS: Everything gets re-
14 established every node?

15 MR. KELLY: Yes.

16 MR. WALLIS: This is what's done in TRACE?

17 MR. KELLY: Yes.

18 MR. BANERJEE: It's from the surface
19 renewal model.

20 MR. KELLY: That's not bad, and until 1996
21 or something, and we started doing AP600 and SPWR,
22 this was what was in RELAP, too.

23 MR. KRESS: It changes every time we
24 change their node size.

25 MR. KELLY: Yes.

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1 MR. WALLIS: That's okay. You can tune it
2 then.

3 MR. KELLY: I mean, they try to do some
4 physics in a sense, so they wanted to wrap between a
5 laminar to a turbulent correlation as the heat
6 transfer surface. You don't ever get nodes. To be
7 fully turbulent, this has --

8 MR. WALLIS: Maybe the H was so big, it
9 really didn't matter too much what it was? H was so
10 big without condensers, it really didn't matter what
11 it was.

12 MR. KELLY: That's probably true, and you
13 know, it wasn't the mission of the TRACE code when it
14 was a large break LOCA code only to look at this kind
15 of stuff.

16 MR. WALLIS: Just like ATT.

17 MR. KELLY: It doesn't completely excuse
18 bad physical models, but you're right. In RELAP now,
19 they have replaced this, but it's a user input. You
20 tell it the length of the surface.

21 MR. WALLIS: But it's not condensation
22 that you care about in a break, in a typical PWR. You
23 don't get condensation. It's flashing and boiling.

24 MR. BANERJEE: Well, you get a
25 condensation on the --

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1 MR. KELLY: On the ejected ECC.

2 MR. BANERJEE: The ECC.

3 MR. WALLIS: But that's so big, it
4 probably doesn't matter too much.

5 MR. KELLY: This is wall condensation.
6 You're right. For a large break loca, this isn't --

7 MR. WALLIS: This is the danger of having
8 a bad model which doesn't make any difference for
9 certain purposes which you accept, and then you
10 inherit it and use it for a reactor which depends upon
11 condensation to work.

12 MR. KELLY: That's right. Now the other
13 term was the wall convective stuff, and that's where
14 we talked about Chen, which is really this Dittus-
15 Boeter in this flow factor. The flow factor is a
16 function of the Martinelli parameter. What it really
17 is is nothing more than the ratio of the hydraulic
18 diameter of the film thickness.

19 Okay, so physically this is not a bad
20 model, and it does somehow put interfacial shear in,
21 but only in a round-about way. It takes a maximum of
22 naturally two natural convection correlations, which
23 have a Grashof number, which once again end up using
24 the node sizes of characteristic length.

25 Now we're going to talk about interfacial

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1 heat transfer.

2 MR. WALLIS: But you can't do that.
3 What's the length in the Nusselt number?

4 MR. KELLY: Well, if I remember, for the
5 natural convection models, they end up using the node
6 size as well. So, for the turbulent when it cancels
7 and for the laminar one that almost cancels, but I
8 mean --

9 MR. WALLIS: You have the same dimension
10 in the Nusselt numbers and the Grahof numbers.

11 MR. KELLY: Right, and that's what they
12 do.

13 MR. WALLIS: They don't. They have the
14 hydraulic diameter of the Nusselt number, and they
15 have a length for the Grashof number.

16 MR. KELLY: Ah, you're right. I'm sorry.
17 See, I get these codes mixed up. We just had the L's,
18 so they cancel.

19 MR. WALLIS: Yes.

20 MR. KELLY: And I copied this out of the
21 theory manual, so unless I copied it wrong, that's
22 completely wrong.

23 MR. WALLIS: I seems to be.

24 MR. KELLY: Yes.

25 MR. WALLIS: Okay, so you're going to

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1 replace it with something good, right?

2 MR. KELLY: Well, we're going to try.
3 Now, I'm not going to explain the entire interfacial
4 heat transfer package, for the same reason, that we'd
5 be here, you know, forever, but I am going to show
6 what the code has currently for the non-condensable
7 gas effect.

8 It uses an empirical model by Skover and
9 Rodivilin, and it's developed for a cross-flow of an
10 air-steam mixture on a liquid jet, okay? This has
11 nothing to do with wall condensation whatsoever.

12 Here's the formula. What it does, it
13 decrements the normal liquid interface heat transfer
14 coefficient, and there's lots of limits on these
15 things because obviously if you have a liquid mass
16 flux in the denominator, that can go to zero.

17 So, this does introduce a non-condensable
18 gas effect by putting it on the interfacial heat
19 transfer coefficient between the liquid and the
20 interface, but that only affects the condensation if
21 the condensation is drive by heat transfer from the
22 liquid to the wall. If condensation is driven by the
23 H, the con term, what I'll call the wall of the vapor
24 condensation in this model --

25 MR. WALLIS: There isn't any. There isn't

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1 any direct condensation.

2 MR. KELLY: Well, there shouldn't be, but
3 there is in the TRACE model.

4 MR. WALLIS: I see, okay.

5 MR. KELLY: Then in that case, --

6 MR. WALLIS: There's nothing real with
7 this. This is so bizarre.

8 MR. KELLY: See, if I set the bar low
9 enough, I can make it over it.

10 MR. WALLIS: This bar is buried.

11 MR. BANERJEE: Maybe we should look at the
12 whole heat transfer packet.

13 MR. KELLY: Yes.

14 MR. WALLIS: Okay.

15 MR. BANERJEE: In TRACE.

16 MR. KELLY: Well, we're going to get
17 there. You know, eventually, and that's why I don't
18 want to spend my time rewriting the entire
19 constitutive models in the theory manual, when I have
20 the expectation the bulk of them will. We're just
21 going to try to change them in an ordered way.

22 I think this model is overly complicated
23 and unphysical. I found, when I'm looking at the
24 assessment results, I found it was difficult to even
25 be able to tell which model was being used.

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1 MR. WALLIS: You sound like the ACRS
2 reviewing some of the models we've seen.

3 MR. KELLY: Well, I should be. I should
4 be here. My responsibility has changed in the group,
5 and my responsibility is for the physical models, and
6 I'd better be skeptical or they're going to be bad.

7 The analytical models, you know, applied
8 inappropriately by using the link scale of the node
9 size. There's no effective interfacial shear in the
10 condensation heat transfer. That's plain wrong. The
11 non-condensable gas effect, it's a model that would be
12 questionable to condensation at best, and it's only
13 applied to the wall to liquid part where I had the
14 water vapor part, does not affect it at all.

15 MR. WALLIS: What about the wall to liquid
16 part? There's no gas in the liquid. I mean, the wall
17 to liquid has nothing to do with the vapor.

18 MR. KELLY: We'll have to talk about this
19 some other time, about how they --

20 MR. BANERJEE: The vapor to liquid.

21 MR. KELLY: It's a mass transfer model.

22 MR. WALLIS: It's being killed about ten
23 times over now, so maybe we should move on to
24 something that's alive.

25 MR. KELLY: This is the assessment matrix

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1 I used, okay. I wanted to look at laminar film
2 condensation. I took the pure steam tests that were
3 done at UCV by Kunz. That was the last series of
4 tests.

5 For turbulent film, I just looked at one
6 test from the NASA series. There's a lot of them to
7 do, and for non-condensable gas tests and tests done
8 at MIT by Siddique. What I have are the pressure --
9 you'll notice I did a nice little parametric on
10 pressure from one to five bar.

11 The gas Reynolds numbers at the inlet, the
12 Film Reynolds number is at the outlet. So, this just
13 shows you what the conditions are.

14 MR. WALLIS: Dorse or something had a lot
15 of data on condensation in tubes.

16 MR. KELLY: Well, I only put one here
17 because that's all I need to show how bad the model
18 is.

19 This is the noncondensable gas mass
20 fraction, and I'm going to be using a lot of that data
21 in selecting a revised model.

22 This is for laminar film condensation.
23 The calculated heat transfer coefficient versus
24 measured. Again, this would be perfect agreement. A
25 few points are not bad. A few of the all pressure

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1 ones look reasonable.

2 Most of them are greatly underpredicted,
3 and the trend worsens as the pressure gets higher. I
4 was actually surprised any of these were anywhere
5 close.

6 Now we're going to look at one of these
7 tests, the one in three bar, I have heat flux versus
8 position and heat transfer coefficient versus
9 position. This is the data. You know, it's a nice,
10 almost linear decrease in heat flux as you go down the
11 tube.

12 TRACE underpredicts it but also has a
13 rather strange behavior. This is almost pure vapor
14 condensation so it's using like the Nusselt formula.
15 This is where it's switching between two. This is the
16 ramp down.

17 MR. WALLIS: You start off from the same
18 point when it's all vapor.

19 MR. KELLY: Pretty much, yes. And there,
20 must accept the characteristics of the scale being the
21 node size. That wouldn't be so bad.

22 This is the ramp down to two-phase
23 conduction, and this is the pure two-phase conduction.

24 MR. BANERJEE: Well, it's conservative.

25 MR. KELLY: It won't be when we get to

1 non-condensable gases.

2 The same test. What I'm plotting now, by
3 phase velocity versus axial position. The blue curve
4 is the vapor velocity, and it does decrease as you
5 condense the vapor. Guess what? Here's the liquid
6 film. This is at five meters a second.

7 MR. WALLIS: It's going faster? This is
8 a TRACE prediction?

9 MR. KELLY: Yes.

10 MR. WALLIS: Gravity is pulling it.

11 MR. KELLY: Gravity is pulling it, and the
12 wall is not. This results from the partitioning of
13 the wall friction factor. Now, what people try to do
14 -- well, actually in TRACE it's not as sophisticated
15 as what they try to do in RELAP. Basically almost no
16 wall drag here because the liquid just falls. It's
17 wrong, and this is the result of it. This is the film
18 thickness, and I think that's supposed to be microns
19 versus -- let me think.

20 MR. WALLIS: It's millimeters.

21 MR. KELLY: No, this is millimeters,
22 that's right.

23 MR. WALLIS: Is there any measure of the
24 film thickness?

25 MR. KELLY: No.

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1 MR. BANERJEE: Is the Nusselts solution?

2 MR. KELLY: Not in any of these, exactly.

3 I plotted the Nusselt solution, which for this test
4 should slightly overpredict because this doesn't have
5 interfacial shear. So, laminate film with no
6 interfacial shear.

7 MR. WALLIS: How about the interfacial
8 shear due to mass transfer? By enough condensation
9 rate --

10 MR. KELLY: Oh, you're very right. So, it
11 would be thinner than this, but it's up here. It's
12 not down where TRACE is calculating it.

13 MR. BANERJEE: Yes, but they overestimated
14 the velocity.

15 MR. KELLY: Exactly, because there's no
16 wall drag. So now we're going to talk about --

17 MR. WALLIS: Isn't this being contact with
18 vapor or something?

19 MR. KELLY: Yes. The way TRACE does it,
20 it calculates a friction factor and applies that
21 friction factor to each phase using the phasic
22 momentum flux. So, for the liquid, instead of one-
23 half row V squared, it's one-half one minus alpha row
24 V squared. It's that one minus alpha that kills the
25 wall drag because with these thin films, the void

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1 fraction is, you know, .999, you know.

2 This is turbulent film condensation. It's
3 one of the tests of Goodykoontz. Heat transfer
4 coefficient versus axial position. You get a decrease
5 as the vapor condenses and you have less interfacial
6 shear, and the film thickens.

7 You don't see that in TRACE. TRACE gives
8 an almost constant value, and that's a factor of
9 seven.

10 MR. WALLIS: You shouldn't call it TRACE.
11 You should call it TRAC or something.

12 MR. KELLY: Well, I was trying not to do
13 that, but yes. But if you took the code today and ran
14 this test, that's what you'd get.

15 Well, blowing this up so I can look at the
16 TRACE result, you have the heat transfer coefficient
17 that has this little funny dip in it. Plot the node
18 length. Where this heat transfer coefficient went
19 down, it's because the node size went up.

20 MR. WALLIS: Why is the node size varying
21 so much?

22 MR. KELLY: Because I select, rather than
23 a uniform node size, I picked a node size to match
24 thermocouple locations. So, I could do, you know,
25 easy comparisons to the data.

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1 MR. WALLIS: So if you choose equal nodes,
2 you can have a reasonable curve then?

3 MR. BANERJEE: No, you would be flat.

4 MR. KELLY: Yes. I wouldn't have seen
5 this.

6 MR. WALLIS: Right.

7 MR. KELLY: Okay, now let's go to the non-
8 condensable gas effect. Calculated heat flux versus
9 measured heat flux, and the full test -- now let's
10 look at just one, this run 24. So this would be near
11 the two, the first measurement station.

12 MR. WALLIS: Which data set is this?

13 MR. KELLY: It's MIT.

14 MR. WALLIS: MIT.

15 MR. KELLY: Actually, the use of
16 Goodykoontz is probably better data, and I will be
17 using that primarily in the assessment, but I'll have
18 some of these tests as well.

19 MR. WALLIS: Is this Berkeley, you mean,
20 UCB?

21 MR. KELLY: Yes, because they went through
22 four different graduate students, learning as they
23 went along and making the experiment better every
24 time, whereas this was the first graduate student
25 doing this at MIT.

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1 So, if we look at this one test, it's
2 here. The second point here, third, fourth, all
3 overpredicting the condensation rate, and then you
4 underpredict.

5 MR. WALLIS: By a lot.

6 MR. KELLY: But you underpredict because
7 you've condensed all the steam, okay? That's the one
8 thing that's kind of nice about, you know,
9 condensation with non-condensables. Once you get rid
10 of the steam, you can't do more than that.

11 This isn't very good. I was surprised it
12 was as close as it is, given the models that we saw,
13 that don't make much sense, but it is non-
14 conservative, and it's not very good. Those errors
15 are unacceptable.

16 This just shows, you know, an axial
17 profile of the heat transfer coefficient. Here's the
18 data during a nice linear decrease, and here's a TRACE
19 calculation. In this particular case, this node was
20 the vapor condensation formula, a Nusselt. This was
21 natural convection to liquid, and this was a two-phase
22 forced convection. So, not very good.

23 I pretty much said everything on this. I
24 don't think I need to repeat it.

25 MR. WALLIS: I'm not quite -- I would

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1 think that the effects of vapor shield were much
2 bigger at the beginnings, and this wouldn't be very
3 good at the very beginning of the pipe.

4 MR. KELLY: In this case, you know,
5 there's not any real film to drag that.

6 MR. WALLIS: I think if you were using a
7 real two-fluid model, you wouldn't use missile at the
8 beginning because the interfacial shear is bigger
9 then.

10 MR. KELLY: That's right.

11 MR. WALLIS: Thanks.

12 MR. KELLY: So, I judged the models to be
13 deficient, and we need to develop or at least
14 implement a new model, and that may mean just
15 selecting current models when you can.

16 The reason is again to do an M2
17 condensation that's applicable to the ICS and PCCS
18 systems, the approach. It should work within a two-
19 fluid framework. That's very important. When you try
20 to shoehorn something in, you can really come up with
21 things that don't make a lot of sense.

22 My opinion is the model should take
23 advantage of the quantities that TRACE calculates. If
24 you're going to use Nusselt, which makes sense if you
25 have a laminar film. Well, the code calculates the

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1 film thickness. So, if you can calculate the film
2 thickness correctly, a Nusselt heat transfer
3 coefficient is this. The liquid conductivity over the
4 film thickness. You don't need to evaluate this, you
5 know, group of physical properties with, you know, the
6 conductivity cube and a reg scale in it, which you
7 don't know, because the code is integrating the
8 conservation equations down the length of the
9 condenser tube.

10 Why throw that solution away? Use it, but
11 use it in a sensible way.

12 The model is going to first be implemented
13 as a specialized package, which will be available to
14 pipes that are labeled or have an attribute car
15 condenser tubes. One of the reasons for doing this is
16 I can put this set of constitutive models is without
17 changing all of the TRACE results in every calculation
18 that's ever done. That gets me out of trouble with
19 Chris.

20 But, as I'm doing this, what I want to do
21 is look for the models that could be generically
22 applicable, and when those models have been proved to
23 do so, they'll be migrated over to the normal
24 constitutive package.

25 MR. RANSOM: John, a little bit of defense

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1 of the models that they did put in there. A lot of
2 that was envisioned to be drop-wise condensation on
3 horizontal tubes and, you know, things of that type.

4 MR. KELLY: Not this stuff, though.

5 MR. RANSOM: No, well, not the
6 application, but the model --

7 MR. KELLY: The model is the film
8 condensation. There are models for drop-wise. This
9 ain't them.

10 MR. RANSOM: Well, you know, the only
11 application in the past is primarily the condenser
12 itself. You know, balance it with the components.
13 I'm wondering if that isn't where a lot of that came
14 from.

15 MR. KELLY: I don't know.

16 MR. RANSOM: There's no write-up or
17 history of this in the TRAC manuals or theory manuals?

18 MR. KELLY: They try to explain what the
19 models are, but they don't say why. They do talk
20 about following films, and they don't say a word about
21 condenser tubes. Of course, if it were a condenser
22 tube, your length would be the diameter of the tube.

23 MR. RANSOM: Sure.

24 MR. KELLY: Certainly not the node length.

25 Back to my little cartoon. Just like we

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1 had before, except now I have the liquid against the
2 wall and the vapor out here. In the normal
3 presentation and when we open the heat transfer
4 textbook and you look at a condensation heat flux,
5 it's a condensation coefficient times T_{wall} minus
6 T_{sat} . That's with the definition of the heat flux
7 being negative when it comes into the wall.

8 Two fluid model, it's a little different.
9 Now the wall heat flux is the wall to liquid heat
10 transfer coefficient times T_{liquid} minus T_{wall} . I
11 mean, it actually comes from the interface to the
12 liquid, liquid to the wall. If this is the wall heat
13 flux, the vapor generation or in this case
14 condensation rate, is the sum of the two interfacial
15 heat transfers divided by the latent heat, and I'll do
16 a mea culpa for doing HFG when it's really the, you
17 know, the delta H stars that John talked about
18 yesterday.

19 MR. BANERJEE: Which we still don't
20 understand completely.

21 MR. KELLY: Right.

22 MR. WALLIS: Well, this is like what we
23 talked about yesterday. You've got the different
24 temperatures you need for your energy balance than you
25 need for your heat transfer, and you can get some

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1 weird things.

2 MR. KELLY: Right.

3 MR. BANERJEE: But as you've written it,
4 it's correct here.

5 MR. KELLY: Right, and I wrote it this way
6 just so we wouldn't go off in a long discussion that
7 I thought would be secondary to what I'm trying to
8 say. We can address that another time. These are
9 just the interfacial heat fluxes.

10 So, you have the possibility here, if you
11 have a cold wall, saturated interface, you pull heat
12 from the interface to the liquid to the wall, and
13 condense vapor here, the vapor on the other hand can
14 be either subcooled or superheated. If it's
15 subcooled, then the vapor will condense on the
16 interface by itself from this interfacial heat
17 transfer.

18 If the vapor is superheated, it would be
19 trying to evaporate some of the liquid, and it would
20 be the sum of these two that determines whether it's
21 a condensation process or an evaporation process.

22 MR. BANERJEE: But that's correct, what
23 you just said.

24 MR. KELLY: Yes, and that's the
25 mechanistic part of the two-fluid that gives you the

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1 possibility to model something, but it's only correct
2 if you have halfway reasonable models for these.

3 MR. WALLIS: Well, these heat transfer
4 coefficients are affected by the simultaneous mass
5 transfer.

6 MR. KELLY: Yes.

7 MR. WALLIS: It's not in here at all.

8 MR. BANERJEE: Yes, well, that would show
9 up in whatever correlation they write for the heat
10 transfer. We'll have to wait and see that.

11 MR. KELLY: Yes, this one.

12 MR. BANERJEE: Yes.

13 MR. KELLY: And likewise when you get to
14 the effective non-condensables and you turn this into
15 a mass transfer process here. Then the suction of the
16 effect of the condensation of the liquid film affects
17 the mass transfer rate.

18 MR. WALLIS: We know that if you have a
19 cold enough film, you can get condensation at mach
20 one.

21 MR. KELLY: Unfortunately, I'm not doing
22 condensation with liquid metals, because I'm always
23 getting the question about the accommodation
24 coefficient.

25 MR. WALLIS: Right.

1 MR. KELLY: We don't have that in the
2 code.

3 MR. WALLIS: You don't, no.

4 MR. KELLY: No. One other further thing
5 I want to say is that this interface temperature, the
6 assumption in the two-fluid code, at least all the
7 two-fluid codes I'm acquainted with, is that this is
8 saturation at the bulk vapor partial pressure, which
9 is fine if there are no non-condensables.

10 MR. WALLIS: That's right.

11 MR. KELLY: You know, it's just the total
12 pressure. If there are non-condensables, you know
13 there's a distribution of non-condensables as you go
14 towards the interface, and the interface is actually
15 at a lower temperature because the partial pressure is
16 lower there.

17 I had to think, did I say that right? But
18 that's not the way the numerics in the code works.
19 The code is always going to assume that this interface
20 that drives these interfacial heat transfers, is at
21 the saturation at the bulk partial pressure.

22 MR. WALLIS: Are you always going to
23 assume that?

24 MR. KELLY: Unless we make drastic surgery
25 to the code.

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1 MR. WALLIS: We did assume that, but
2 you'll have to investigate whether you can cobble up
3 things to represent it this way.

4 MR. KELLY: And that's what you do.
5 That's why, for the moment, let's pretend we don't
6 have this, okay? We've only got wall condensation.
7 All we have to worry about is this one.

8 Now, if you have non-condensables, that
9 weight is going to be decreased by the mass transfer
10 that goes on here. That's going to be the limiting
11 rate process.

12 So, what you end up doing is coming up
13 with what the rate limiting to the mass transfer is
14 and giving it a modifier that you stick here. You
15 increase the heat transfer resistance between this
16 interface and the liquid.

17 MR. WALLIS: So rather than dropping TI ,
18 you change the H ?

19 MR. KELLY: Right, because that works
20 within the current numerical framework. You could
21 switch the code to spread solves for this, but that's
22 rather major surgery to the code.

23 MR. BANERJEE: Even more difficult than
24 that because you'd have to actually calculate the
25 local concentration.

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1 MR. KELLY: Yes.

2 MR. BANERJEE: That's really difficult.

3 MR. WALLIS: Well, you'd probably use some
4 kind of film theory or something.

5 MR. RANSOM: You're getting counter-
6 current diffusion there as well.

7 MR. WALLIS: The noncondensibles to the
8 bulk and the vapor has to diffuse through.

9 MR. KELLY: Right, There's a series of
10 papers on the interface temperature model by Ghiassian
11 at George Tech, if you're interested, but that would
12 be fairly major surgery to the code. I can't do that
13 within this timeframe.

14 So, if we're going to develop a model for
15 film condensation, what do we -- we need to apply both
16 pure steam and non-condensable steam gas mixtures for
17 both following and sheared films. So, these are the
18 models that are needed, and they're the same ones that
19 we talked about before except now we have the addition
20 of a non-condensable gas effect.

21 So, let's talk about a relatively easy one
22 first, that's film thickness. What you need in order
23 to be able to calculate the film thickness is if it's
24 a falling film, all you need is wall friction. We're
25 assuming the code can do gravity right.

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1 MR. WALLIS: There's no pressure gradient
2 in the masses?

3 MR. KELLY: Well, you end up, you know,
4 the pressure gradient, if it's a falling film, we're
5 talking about a wall and heat volume. So, it's just
6 wall drag.

7 MR. WALLIS: For interfacial shear here?

8 MR. KELLY: Yes, here it's just wall drag.
9 If it's a sheared film, then you have the pressure
10 gradient, and also there is the balance between the
11 wall and interface and buoyancy terms.

12 MR. BANERJEE: This is just a Nusselt
13 solution.

14 MR. KELLY: Right. I'm just doing this
15 because I'm going to use it in a second. So this is
16 actually from a two-fluid momentum equation, and I'm
17 just reducing it down, using the thin film assumption,
18 and getting the solution that you're very familiar in
19 getting the Nusselt result.

20 MR. WALLIS: Well, we know that when the
21 film is thin, the interfacial shear dominates gravity.
22 So, you're going to have to stop this somewhere down
23 the pipe. It's certainly not valid with the top.

24 MR. KELLY: Right, but at the moment, all
25 I'm talking about is a falling film. I'm going to

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1 make the leap to sheared film first, but I want to
2 solve an easy problem first, get that solution, and
3 start adding a complexity.

4 Okay, the reason I showed that is because
5 of this. I put together a film thickness database,
6 okay? So it's got a non-dimensional film thickness
7 where a non-dimensional buys the Nusselt link scale
8 which was on a previous slide, versus film Reynolds
9 number, and a corrected data from a variety of
10 sources. Then you have this pretty characteristic
11 behavior. It's turbulent out here and laminar down
12 here.

13 MR. RANSOM: Is the length scale in the
14 Reynolds number the length of the tube?

15 MR. BANERJEE: No, it must be the
16 thickness.

17 MR. RANSOM: The diameter.

18 MR. KELLY: Actually, it's --

19 MR. BANERJEE: It has to be the thickness.

20 MR. KELLY: Yes, it's four times gamma
21 over new. Where gamma is the condensate for film
22 floor rate divided by the weighted perimeter.

23 MR. WALLIS: Well, yes.

24 MR. KELLY: Okay, and if you use that --

25 MR. WALLIS: This is classical stuff.

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1 MR. KELLY: Yes, if you use that
2 definition, then the film Reynolds number becomes the
3 same as the liquid Reynolds number, which is the
4 liquid mass flux times the hydraulic diameter over
5 viscosity.

6 MR. WALLIS: Hewitt and Wallis, whoever
7 they were, '63, show exactly the same curve with
8 exactly the same theory.

9 MR. KELLY: And now what I do is take
10 those wall drip, film thickness measurements, and
11 using what I talked, the previous derivation, convert
12 it to a wall friction factor versus Reynolds number,
13 okay?

14 MR. WALLIS: You can do that, too.

15 MR. KELLY: That's easy enough. It's just
16 straight algebra.

17 MR. WALLIS: Who is that line there?

18 MR. KELLY: Oh, the ones --

19 MR. BANERJEE: These are all wavy.

20 MR. KELLY: That's some data by Chen from
21 his thesis, and I haven't tracked down why those
22 points are so far off, but I'll note it.

23 So, this is the model I'm going to
24 propose. When it's a smooth laminar film, 24 over the
25 Reynolds number, okay, it's easy enough. Flat plate

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1 stuff. I know that this is going to slightly
2 overpredict the film thickness because it doesn't take
3 account of ripples.

4 I know that the ripples affect the heat
5 transfer because they effectively thin the film. So,
6 when I go to the heat transfer model, I'm going to do
7 something to cover ripples.

8 For turbulent, a simple, explicit
9 approximation to Colebrook-White. This term doesn't
10 really matter very much, but I'm using this because
11 I'm hoping to eventually replace the wall drag model
12 and track with it. You know, generically. What we
13 have here now is not as good as this. This is a
14 better approximation than what's in the code
15 presently, and use a power combination.

16 MR. WALLIS: Well, how big is interfacial
17 shear in the real device here compared with these?
18 Are you going to show us that, because this whole
19 thing is all very well if you just have a pretty
20 quiescent vapor.

21 MR. KELLY: But we're starting somewhere.
22 We're going to add where there's a complexity as we
23 go, okay?

24 The answer is if you look at the UCF Kunz,
25 the pure steam condensation ones, the interfacial

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1 shear from the standpoint of actually shear, is
2 relatively small.

3 MR. WALLIS: What I mean is an ESBW, what
4 sort of steam velocities do you get, and there's the
5 interfacial shear report, because that's your
6 application.

7 MR. KELLY: It's for the passive
8 containment cooling system, which is with non-
9 condensables where the condensation rates are not so
10 high. There the interfacial drag is relatively small.
11 okay? It's not negligible, but it's relatively small,
12 and a lot of it would be the mass transfer part.

13 MR. WALLIS: I think it's something like
14 Goodykoontz. Goodykoontz have very high velocities.
15 I think his interfacial drag may have been dominant.

16 MR. KELLY: Definitely, and that's where
17 in the isolation condenser system, which is pure steam
18 and higher pressure, higher flows, that's where you
19 might move more towards that regime, but now I'm also
20 trying to put something in that won't -- where you
21 won't fall off the end of the earth, if you go just a
22 little bit outside of the bounds.

23 So, this is the wall friction factor
24 versus film Reynolds number. The laminar model, the
25 turbulent, and the power wall combination, and it

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1 looks pretty good. But so far, I've done all of this
2 on a spread sheet and pen and paper. What about the
3 code?

4 So Bill implemented it for me and tested
5 it for me, and so this is a non-condensable film
6 thickness versus film Reynolds number again. The blue
7 curve is the TRACE we have today, and you see it
8 greatly underpredicts the film thickness, and that's
9 because of the wall drag partitioning.

10 Somehow it goes through some kind of
11 laminar turbulent transition and wanders around, and
12 heaven knows where it is. The black line is when
13 Birol implemented the correlations I had on the
14 previous slide, and there are actually a couple of
15 glitches that we have to look at. He told me just a
16 little while before my presentation that oh, he found
17 a mistake, and the results get better, but I didn't
18 have time to change the slide.

19 MR. WALLIS: In the laminar region, you're
20 not going to present a kink like that.

21 MR. KELLY: No, there's an implementation,
22 something wrong, and we'll figure that out. These are
23 pretty much hot off the press. This is what I'm
24 working on, you know, as we speak.

25 Now we're going to talk about sheared

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1 films. What I want to do is somehow select an
2 interfacial friction model applicable to co-current
3 downflow. I had one database that I could easily get
4 to cover that, and that was by Andreussi and Zanelli.

5 Now, what's nice about their test, they
6 measured the film thickness. They measured the axial
7 pressure gradient, so they were able to back out the
8 interfacial shear. They also measured the entrainment
9 fraction. So, I know which tests have entrainment and
10 which don't.

11 Then they reduced the data to give values
12 of the interfacial friction coefficient. So, I didn't
13 even have to do that. I could just take their data
14 and plot it, and that's what I did, and I compared it
15 to these various models.

16 I started with Wallis and Wright, but it's
17 a good place to start because it's simple. It's not
18 simple minded. It's simple. Simple is a virtue,
19 believe me, but it's also the model that's currently
20 in TRACE for the annual mist flow regime.

21 MR. WALLIS: I know there's a motion
22 models in these codes, very crude things developed in
23 the 60's, and haven't evolved since.

24 MR. KELLY: Well, and the Bromley
25 correlation is the 50's.

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1 MR. WALLIS: Yes. It's always puzzled me
2 why they haven't evolved to something better.

3 MR. KELLY: Well, we're trying. What I'll
4 call modified Wallis because a lot of people will say
5 oh, you should take the friction factor in front of it
6 and actually use it as a function of the Reynolds
7 number. A model by Henstock and Hanratty, Professor
8 Hanratty from the University of Illinois. Bharathan,
9 which is developed for countercurrent swell. I didn't
10 expect it to be very good, but you know, I may end up
11 using this for countercurrent flow some day, so I
12 wanted to check it here.

13 Professor Hanratty again, with a graduate
14 student named Asali, two models, one with entrainment
15 and one without. The most recent one is by Jayanti
16 and Hewitt. Again two models, one for ripple waves
17 and one for disturbance waves.

18 What do they look like? Well, this is
19 Wallis, and it's amazingly good, actually. This is
20 not bad.

21 MR. WALLIS: For the ultra-simple model.

22 MR. KELLY: This is interfacial friction
23 predicted versus measured, and you'll notice the blue
24 --

25 MR. WALLIS: But you have to get the

1 entrainment right. That's right.

2 MR. KELLY: The blue, actually there's no
3 fancy things here with entrainment. It just uses the
4 film thickness, and it works quite well.

5 For the data without entrainment, which
6 actually is closer to my condensing, it overpredicts.

7 MR. WALLIS: But it's a smooth film.

8 MR. KELLY: Yes.

9 MR. WALLIS: It has to be a rough thing.

10 MR. KELLY: This is the best comparison.
11 It's the model by Asali and Hanratty with entrainment.
12 They gave two correlations, as far with entrainment,
13 did a better fit to the data. It's not too surprising
14 it does well because this data is in its database.
15 So, it should fit this.

16 There's even another trick which I'll tell
17 you in a minute, but this looks pretty good, and this
18 is the model I'm going to use.

19 MR. BANERJEE: What happens if you take
20 their own data out?

21 MR. KELLY: I don't know because, you
22 know, it's hard to get this kind of data. There's not
23 that much, and if you correlate all of it, you know.

24 This was the Jayanti and Hewitt,
25 disturbance wave model. Very small scatter, which I

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1 liked, and again, this is a simplistic model in the
2 sense that it's a turbulent wall friction coefficient
3 with a roughness parameter in it, and the roughness
4 factor they used it five times the film thickness.
5 So, I like how simple it is, but it does underpredict
6 significantly.

7 Then I tabulated the results from all
8 eight different models, and these are very relative
9 error. It's on average value, the maximum and the
10 RMS, and you can see this model --

11 MR. WALLIS: This is in what units?
12 Relative error?

13 MR. KELLY: Yes, so it's delta F over F.

14 MR. WALLIS: Okay.

15 MR. KELLY: So this is actually quite
16 good, and that's what I'm going to go with, but again,
17 this doesn't look very complicated, fairly simple.
18 It's the ratio of interfacial to a smooth tube
19 friction factor. The function of a gas Reynolds
20 number and a non-dimensional film thickness. I
21 apologize. I'm using M here for the film thickness,
22 which you get from the chemical industry where delta
23 comes from the heat transfer people.

24 This is the way it's nondimensionalized.

25 MR. BANERJEE: By the wall interface?

1 MR. KELLY: Now, interfacial, that's the
2 trick that helps make it so good.

3 MR. WALLIS: Because it speaks for itself.

4 MR. KELLY: Yes, you have the answer on
5 both sides of it. I actually used the measured values
6 of this when I evaluated the correlation. So, no
7 wonder it fit the data, you know, or it should have.

8 Well, that gives me a problem because now
9 this is implicit. So what I did is substitute for
10 this --

11 MR. WALLIS: Now, wait a minute. FI over
12 F is squared, so it's correlating against itself.

13 MR. KELLY: Right.

14 MR. WALLIS: X equals X.

15 MR. KELLY: Exactly.

16 MR. WALLIS: Well, Hanratty ought to know
17 better than that.

18 MR. BANERJEE: He probably knew.

19 MR. KELLY: It certainly helps when you
20 have the answer on the right-hand side.

21 MR. WALLIS: Oh, yes, that's right.

22 MR. BANERJEE: So what happens when you
23 solve it for --

24 MR. KELLY: Well, that's what you're going
25 to see. That's the next two slides. So, that's

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1 exactly what I did. I substituted for this, turned it
2 into a quadratic equation for the square root of FI
3 and solve it, and I bet I've gotten the quadratic
4 formula, right? Where this is the definition of the
5 two coefficients.

6 MR. WALLIS: Well, why is it quadratic?
7 Isn't that square root --

8 MR. BANERJEE: Square root of F5 --

9 MR. WALLIS: It is the square root, you're
10 right.

11 MR. KELLY: Yes.

12 MR. WALLIS: That's right, it's quadratic.

13 MR. KRESS: It's assuming A is equal to
14 one.

15 MR. KELLY: And so then I did the data
16 comparison with the explicit formulation where I don't
17 --

18 MR. WALLIS: That's no better than that
19 Wallis correlation, is it, for the blue one.

20 MR. KELLY: Actually, the RMS error is
21 still better than any of the other correlations.

22 MR. WALLIS: Okay, all right.

23 MR. KELLY: Because I did check that.

24 MR. WALLIS: To the untrained eye, they
25 look equivalent.

1 MR. KELLY: Well, that's why we have to
2 have quantitative figures.

3 Okay, again, so far I did all that on the
4 spread sheet. Now let's stick it into TRACE and see
5 what happens. So, this is the calculated film
6 thickness and this is the one in microns, versus the
7 measured film thickness.

8 This is what you get with TRACE today,
9 grossly underestimating the film thickness. For two
10 reasons, for overpredicting interfacial drag or
11 underpredicting wall friction because of the
12 partitioning.

13 With the models that I've given Bill, this
14 what he got. It works very good for these points. We
15 underpredict the film thickness here, and what he told
16 me was that those points go up when he makes a
17 correction.

18 MR. BANERJEE: What correction.

19 MR. KELLY: I don't know. He did the
20 implementation with TRACE, and he called me just
21 before my presentation and said I made an error. It
22 gets better.

23 MR. WALLIS: Let's go back to the sheared
24 films here. You didn't give us an equation. Are
25 these sheared films with condensation and gravity or

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1 just pure sheared?

2 MR. KELLY: This is with gravity, but air
3 water.

4 MR. WALLIS: Air water and a vertical
5 pipe?

6 MR. KELLY: Right.

7 MR. WALLIS: No condensation?

8 MR. KELLY: Co-current downflow.

9 MR. BANERJEE: What happens if there's an
10 angle?

11 MR. KELLY: And there is an entrance and
12 exit of those tubes.

13 MR. BANERJEE: Well, just because, you
14 know, this isn't a very scientific thing. The waves
15 are caught implicitly. So, I mean, the wave structure
16 completely changes with angle. So, since it's not
17 mechanistic, you expect it to change with angle.

18 MR. KELLY: Well, and that's why you
19 should have empirical models for all those kind of
20 things, and we don't. Like when we were talking about
21 the effect of the virtual mass term, and I mean, I
22 know that TRAC will not do two-phase flow through a
23 nozzle correctly because we don't have that term.

24 MR. BANERJEE: Right.

25 MR. KELLY: But on the other hand, do any

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1 of you believe that interfacial drag correlations
2 developed for vertical pipes work as you accelerate a
3 two-phase flow through a nozzle? Of course they
4 don't, and that will swamp anything having to do with
5 the added mass. Now, whether the added mass term
6 gives you numerical stability and a more reasonable
7 answer, that's another question.

8 As far as accuracy goes, what happens to
9 the structure of the two-phase interface as you go
10 through that nozzle is a lot more dramatic than
11 anything else. You're right, we don't have models for
12 interfacial drag as you go around corners.

13 MR. BANERJEE: Right.

14 MR. KELLY: I'm just trying to get them
15 right in a straight pipe because they're not right for
16 that yet, which is a little bit humbling. I mean,
17 this is 2003, and this isn't really difficult stuff.
18 I just make it look difficult sometimes.

19 So back to my cartoon, the things that
20 were grayed out were the wall friction interfacial
21 shear. We've selected models for those, and now we're
22 going to talk about wall heat transfer, and we're
23 going to talk really about condensation heat transfer.
24 So, what it's going to involve is both the wall to
25 liquid and then the liquid to interface part.

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1 So, we're going to talk about the total
2 heat transfer and how it gets split between those two.

3 MR. BANERJEE: You know, the friction
4 factor has to be a function of the fluid number in
5 some way.

6 MR. KELLY: Oh, certainly if it's incline,
7 yes.

8 MR. BANERJEE: Yes, so I mean, if you look
9 at the way these things, it's never just a function of
10 the Reynolds number, in this case. It's worrying that
11 they don't come out that way. I'll have to think
12 about it.

13 MR. KELLY: Okay. We're going to talk
14 about film condensation now. I'm going to start out
15 talking about falling films. We're going to start out
16 simple and add complexity.

17 I assembled a database and the flaw in the
18 database is that it only includes condensation heat
19 transfer coefficients that are averaged over the
20 entire surface because that's how the experiments are
21 done. You can't, you know, control your power that
22 you're pulling out of a specific area.

23 So, almost all of the data I could find
24 for condensation is this way. The data are presented
25 in terms of non-dimensional Nusselt numbers, which is

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1 very simple. It's the heat transfer coefficient
2 averaged over the surface times the Nusselt link scale
3 over the connectivity. And this just shows you, if
4 you do the Nusselt solution in these terms, the local
5 value is 1.1 over the Reynolds number to the one-third
6 power. The surface average value is 1.47 over that.

7 The data are going to show an enhancement
8 to this through a course of the ripples. So, this is
9 some of the water data. This is some of the freon.
10 They're slightly different panel numbers. The non-
11 dimensional Nusselt number averaged over the surface
12 versus the Reynolds number, and as expected, it's 15
13 to 20 percent low.

14 You have a laminar region and a turbulent
15 region, but the data in the turbulent region again are
16 averaged over the whole plate, so they cooled part of
17 the plate and maybe most of the plate, being in a
18 laminar flow, and that's part of the reason for this
19 broad minimum here.

20 MR. WALLIS: So the data are both there
21 because the shear has an effect? Is that what it is?

22 MR. KELLY: Oh, no, these are falling
23 films.

24 MR. WALLIS: There are no shear at all?

25 MR. KELLY: No shear at all. It's

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1 waviness.

2 MR. BANERJEE: Well, it's turbulenced.

3 MR. WALLIS: Waviness.

4 MR. KELLY: Well, if it's very, very low,
5 it's the little ripples. They decrease the film
6 thickness, and they may induce, you know, velocity
7 normal.

8 MR. BANERJEE: Submixing.

9 MR. KELLY: Submixing, right. Here's
10 Nusselt, one of the other well known ones is by
11 Kutateladze, so it shows some enhancement over
12 Nusselt, and there's another one by Nozhat, and we'll
13 just show these on that data.

14 MR. WALLIS: How does it show enhancement
15 over Nusselt?

16 MR. KELLY: Well, if you divide this by
17 Nusselt, what you'll end up getting is an enhancement
18 factor that's a function of the Reynolds number, and
19 in this case, it's --

20 MR. WALLIS: Can you get your Reynolds
21 number small enough?

22 MR. KELLY: Yes, it's a Reynolds number to
23 the .07.

24 Here we are. This is Nusselt, Katateladze

25 --

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1 MR. WALLIS: This is almost beginning to
2 look like materials data here.

3 MR. KELLY: Yes, you can draw -- I mean,
4 that's the long scale, too, you know. So, for now
5 --

6 MR. SIEBER: There's a pattern to it.

7 MR. KELLY: This is the one I'm going to
8 pick, the one by Nozhat.

9 MR. WALLIS: And why is that?

10 MR. KELLY: Well, Kutateladze is a little
11 high, Nusselt is low. This one's in between. When
12 you average it with something in regard to turbulence
13 --

14 MR. WALLIS: I don't like the way that the
15 data scatters so much, though.

16 MR. KELLY: Well, if I can raise it to a
17 level of importance high enough -- no, actually, I
18 already have the UCB data, and that's prototypic tube
19 size and stuff. So, I don't need to do a separate
20 effects test for wall film condensation.

21 This is what you find out there.

22 MR. WALLIS: I would want to know if the
23 UCB data are near Nozhat or whether they're near one
24 of the other extremes of these data.

25 MR. KELLY: We won't get that far in this

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1 presentation, but you'll see it.

2 MR. WALLIS: I'll see it one day?

3 MR. KELLY: Yes.

4 MR. BANERJEE: But they have shear, right?

5 MR. KELLY: Yes. The shear is not very
6 large, and actually most of it comes out through the
7 mass transfer effect. I've started reducing some of
8 that data now. I just haven't finished it.

9 MR. BANERJEE: Because you have non-
10 condensables.

11 MR. KELLY: Well, they did 42 lines with
12 pure steam, which is nice.

13 MR. WALLIS: The interfacial shear due to
14 mass transfer, just the momentum transfer then?

15 MR. KELLY: That's much larger than the
16 actual -- normally call interfacial shear.

17 MR. BANERJEE: And what you call gamma and
18 to UG roughly?

19 MR. KELLY: Right. That's exactly what's
20 in the code, and that probably overpredicts it a
21 little. The interface velocity should be less than
22 that, but how much less is hard to say. We run into
23 the same thing we did with the H primes.

24 MR. WALLIS: It films the boundary there
25 anyway, and that's the way it increases the facial

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1 shear.

2 MR. KELLY: Yes.

3 MR. RANSOM: When you say UCB data, you're
4 referring to Schrock's data, I guess, what he did for
5 GE?

6 MR. KELLY: The fourth series of tests,
7 the ones done by Kunz.

8 MR. WALLIS: I think the effect is about
9 half, is the mass transfer and the friction and the
10 mixing and the turbulence. It's about half, from just
11 adding it simply.

12 MR. KELLY: Yes. You see papers that say
13 .6, 19.

14 MR. WALLIS: Whatever, yes.

15 MR. KELLY: The code uses all of it. If
16 you take the momentum out of the vapor phase, you'd
17 better put it somewhere.

18 MR. BANERJEE: There is a set of data
19 which is not extreme, which is horizontal. Do you
20 know, George Bankoff did a lot of experiments on
21 horizontal.

22 MR. KELLY: And I'm going to look at
23 those, too.

24 MR. BANERJEE: Right.

25 MR. KELLY: Especially for the interfacial

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1 part.

2 MR. BANERJEE: You'll find that the models
3 that work there are purely turbulent centered. They
4 have to be because it's all shear driven with the mass
5 transfer.

6 MR. KELLY: Right, and when we get to the
7 interfacial part, that's one of the ones I'm going to
8 look at. I haven't yet, but I'm going to.

9 MR. WALLIS: I think Bankoff is a very
10 extensive piece of work, isn't it?

11 MR. BANERJEE: Yes, very.

12 MR. KELLY: And I have the NUREGS.

13 MR. WALLIS: It's in the NUREG. Isn't it
14 a fairly fat NUREG?

15 MR. KELLY: Several NUREGS.

16 MR. WALLIS: Oh, several NUREGS, right.

17 MR. KELLY: Okay, I selected a laminar
18 film mode, but it was for the condensation rate. So,
19 just like we talked about before, this is now the heat
20 transfer coefficient across the film. What I really
21 need is the heat transfer coefficient between the wall
22 and the film, an interfacial one between the film and
23 between the liquid and the interface.

24 Well, how am I going to do that? You can
25 do a straightforward energy balance, saying that the

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1 condensation heat flux has to equal the wall to
2 liquid, which in turn has to equal to the interfacial
3 one. We're talking about just straight shot through
4 those resistances.

5 MR. WALLIS: There's no subcooling of the
6 liquid film or anything like that that comes into the
7 energy balance?

8 MR. KELLY: It does, but --

9 MR. WALLIS: There's a correction.

10 MR. SIEBER: Not there.

11 MR. KELLY: Yes. Now what I'm saying is
12 I know this one. How am I going to split it between
13 these two? If you do this, and I guess I shouldn't
14 have called it an energy balance just because what
15 you're saying. Then you can do a resistance kind of
16 thing, and this is what you come up with.

17 MR. BANERJEE: What is that now?

18 MR. KELLY: I'm basically taking the two
19 resistances. I'm solving for HOI --

20 MR. WALLIS: You're solving the
21 temperatures from those two equations?

22 MR. KELLY: Exactly, and solving for HOI
23 in terms of the wall to liquid and the condensation
24 heat transfer coefficient.

25 MR. WALLIS: You mean one over H?

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1 MR. KELLY: Yes, one over H minus one over
2 H.

3 MR. WALLIS: Yes.

4 MR. KELLY: And now I happen to -- this
5 one, wall to liquid, I don't have any local
6 condensation data, but I do have a lot of the local
7 heating data. Okay, now we're talking about just wall
8 to liquid. So, the only difference is the direction
9 of the directional flow of the heat, and that's kind
10 of a second order effect.

11 MR. WALLIS: What you've done here is
12 really evaluating resistances in series.

13 MR. KELLY: Right, exactly. So, what I'm
14 going to say is I have this heating data. Let's use
15 it to help me pick a model that is wall to liquid. In
16 a laminar one, if you go to the loca model, it's 1.88.

17 MR. BANERJEE: I guess the way it's coming
18 out is because of the way you define HC. It's T_{sat}
19 minus T_W .

20 MR. KELLY: Exactly.

21 MR. BANERJEE: The T_G minus T_W , you'd get
22 a different thing.

23 MR. KELLY: Yes.

24 MR. BANERJEE: Okay.

25 MR. KELLY: Now, this is if you look at

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1 film heating data. It's a lot of Wilke's data and
2 some by Ueda and Tanaka. I want to look at the
3 laminar part, and it fits that beautifully, okay? Of
4 course, it was developed from that data, but it was
5 basically an analytical solution. So, I could do
6 that, and what I'm talking about is taking this and
7 taking the nose-out model for that and coming up with
8 this.

9 One problem. The problem is those two
10 models intersect, and I'm subtracting them in the
11 denominator. My denominator goes to zero, which would
12 imply my interfacial heat transfer coefficient goes to
13 infinity, and I don't want to go there, okay? So,
14 back up and try again.

15 If I had a smooth laminar film, this is
16 something I can solve. I can take the parabolic
17 velocity profile, the linear temperature profile, and
18 this is what I get for the bulk liquid temperatures.
19 Five-eighths time T_{sat} , $3/8$ times the wall. It's
20 closer to the interface temperature because that's
21 where most of the liquid is because the liquid is
22 moving slower next to the wall.

23 If you then convert that into these
24 Nusselt numbers, you get the wall to liquid being $8/5$
25 times, the condensation in the interfacial, $89/3$ times

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1 the condensation.

2 Okay, that's a fair enough way to split it
3 out, and that's exactly what I'm going to do. So,
4 again, it's adding up the resistance of things.

5 MR. BANERJEE: But this is just a laminar
6 force.

7 MR. KELLY: Right, but that's all I'm
8 talking about right now, is a laminar falling film.

9 MR. WALLIS: Does this get rid of your
10 infinity?

11 MR. KELLY: Yes. I'm going to split them
12 this way rather than what I did on the other plot.

13 MR. WALLIS: So you always end up with
14 something which is finite?

15 MR. KELLY: Exactly. We did the easy
16 problem. We did laminar falling films, okay?

17 MR. WALLIS: Yes, but when you do this
18 thing, does it still give as good a correlation as you
19 showed in the previous slide?

20 MR. KELLY: Yes. The correlation was for
21 what we use in Nozhat, which is for the condensation
22 rate, or the heat transfer across the film. How I
23 apportion it, that total heat resistance to heat
24 transfer, between wall to liquid and liquid to
25 interface? The only thing that effects is the

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1 condensate temperature. It just moves where that
2 temperature is between T wall and Tsat, and I picked
3 it to be where it would be for the laminar solution,
4 you know, and being ignorant of where it should
5 actually be. That's what I chose as being reasonable.

6 MR. WALLIS: Well, no condensables,
7 because they affect one of these coefficients and not
8 the other, presumably.

9 MR. KELLY: Right. I talked about non-
10 condensables briefly on my last slide.

11 MR. WALLIS: You haven't done that,
12 though.

13 MR. KELLY: We're not going to get into it
14 today. Okay, that will be next time because remember,
15 this is work I'm doing now, as we speak. So, you're
16 seeing where I am, not what I've done.

17 MR. WALLIS: This is a homework
18 assignment, and it's due next week.

19 MR. KELLY: Well, that's what my boss
20 keeps telling me.

21 Okay, we did a laminar falling film.
22 That's the easy problem. Let's make it a little bit
23 more difficult and go to turbulent falling film.

24 The first problem is the database. I
25 simply don't have turbulent falling film data except

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1 ones that have been met, averaged over an entire
2 surface.

3 MR. WALLIS: That's why I've seen curves
4 like the one on your slide 48, many, many, many times
5 in the literature.

6 MR. KELLY: Slide 48?

7 MR. WALLIS: It's a standard thing, the
8 Nusselt number versus Reynolds number.

9 MR. KELLY: Yes.

10 MR. WALLIS: Condensation.

11 MR. KELLY: Yes, there's no --

12 MR. WALLIS: It's in all the textbooks.

13 MR. KELLY: I'm not making a big advance
14 to the science here. What I'm doing is trying to take
15 something that's known and put it inside a two-fluid
16 card and get it to work in a rational way, not
17 developing models from scratch really. I'm trying to
18 select models that I can implement.

19 So, I don't have local turbulent falling
20 film data. I only have stuff that's averaged, and
21 then it is polluted, if you will, by so much of the
22 plate being in laminar.

23 So, what I'm going to try to do is take a
24 turbulent heating data in order to select a
25 correlation to work with, because I have that data.

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1 I'm going to look at interfacial heat transfer models,
2 and the one due to Bankoff is one of the ones I'm
3 going to look at.

4 When you add these two together, you then
5 can predict the condensation rate, but I don't have a
6 database to really compare it to. So what I'm going
7 to do is take what I'll say is a well established
8 turbulent falling film condensation correlation and
9 use that as my discriminator, and the one I'm going to
10 pick, or at least I think I'm going to pick is by
11 Labuntsov. But I just said, I'm going to use a well
12 established model, and now I'm just going to show you
13 there's no such thing.

14 Here's a laundry list for condensation
15 correlations in time, okay, from 1933 to '87. They
16 are all the non-dimensional Nusselt number in terms of
17 Reynolds and Fandall. Notice that Reynolds dependence
18 goes from .2 --

19 MR. WALLIS: Don't you have anything done
20 by Germans, or just probably thorough?

21 MR. KELLY: By who?

22 MR. WALLIS: Don't you have Grober, Erk,
23 and Grigull, or someone who's done a really thorough
24 job and investigate everything under the sun, and it
25 works? That's what it looks like, as if these are all

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1 just looking at partial data. Actually, there's
2 somebody who's done a really thorough job and pull it
3 all together. It's amazing to me. It's such a simple
4 problem, has so many authors. Then when you plot
5 them, they're so different.

6 MR. KELLY: Right, and you're right. Part
7 of it is because they look at different pieces,
8 instead of comprehensive. Now, if we talk about film
9 heating, Wilke has a correlation that stands the
10 entire range, but there are two things here. One is
11 the Reynolds number dependence varying so much, and my
12 expectation. Now, these are non-dimensional, so we
13 can actually multiply it by the film thickness.
14 You're going to end up changing this Reynolds number
15 dependence.

16 You're basically going to multiply by
17 about .58 to .6. So, you expect something a little
18 bit greater than .2.

19 MR. WALLIS: Yes, but if you look at the
20 next slide, you've got these plotted?

21 MR. KELLY: They're everywhere.

22 MR. WALLIS: Well, there's an error factor
23 of three between the correlations?

24 MR. KELLY: Yes.

25 MR. WALLIS: It's a very, very simple

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1 problem.

2 MR. KELLY: I agree.

3 MR. WALLIS: It's not such a simple
4 problem, unfortunately.

5 MR. KELLY: Actually, one of my favorite
6 papers is one I read just recently. It's by Palen,
7 and it's entitled, "What We Still Don't Know About
8 Condensation." I enjoyed it enormously.

9 MR. WALLIS: But, you know, you've got a
10 scatter here which is 50 percent or something.

11 MR. KELLY: Yes.

12 MR. WALLIS: And yet --

13 MR. KELLY: And go pick up a textbook.
14 One will tell you to use this. One will tell you to
15 use this. Another one will tell you to use this.

16 MR. WALLIS: In a two-phase flow, you'd
17 expect things to be worse. This is a single phase,
18 isn't it?

19 MR. KELLY: This is relatively simple,
20 right.

21 MR. WALLIS: Well, it's a free surface.

22 MR. KELLY: And that's where some of this
23 comes in.

24 MR. WALLIS: So if the lab is vibrating to
25 shaking, it makes a difference, doesn't it, because

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1 you get waves.

2 MR. BANERJEE: Well, to begin with,
3 surface tension has to enter. It's called waves,
4 right.

5 MR. KELLY: And that's exactly where we're
6 going. You don't -- let me move on to the number
7 dependence, and I'll talk about just what Professor
8 Banerjee mentioned. The number dependence, well
9 Colburn doesn't have it, but he looked at a fairly
10 small range of panel numbers. This is empirical.
11 This is to the one-third, .4, one-half, .65, okay, and
12 that's a pretty large variation.

13 What you expect from cooling data, like
14 you did that kind of stuff, you expect about .4. So,
15 film heating is well correlated by .34. He expects
16 something of that order.

17 If he had mass transfer problems, and
18 you're talking about gas absorption into liquid film,
19 the Schmidt number dependence normally comes out to be
20 one-half. Where on earth do these things come from,
21 these .65?

22 Well, and if you look at the data that
23 they correlated, you need that in order to fit it. I
24 just read a paper. It's by Al Hussein, Tuzla, and
25 Chen, and they put together a model actually for

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1 evaporation of liquid films. It's one where you model
2 the boundary layers, and in your integrated crossing
3 to end up with a very complicated looking heat
4 transfer correlation. Wall boundary layer effect and
5 core turbulence, and then a free surface effect.

6 What they said is the reason these panel
7 number dependents are all over the map is because
8 they're not modeling the right thing. It isn't a
9 Prandtl number dependant that's separating the data.
10 Instead, it's a wave effect. What you're doing, you
11 know, some of these are comparing evaporation of water
12 to evaporation of oils, which are very thick and
13 viscous. What you really need to do is use a Kapitza
14 number.

15 You know, panel number for the thermal
16 stuff, a Kapitza number for the wave effects, and
17 that's not what's being done.

18 MR. WALLIS: This is a liquid methyl data
19 in there, too?

20 MR. KELLY: No, not in this. So, that's
21 what I'm going to look at when I go to an interfacial
22 heat transfer part.

23 It turns out, if you look at heating data
24 where you don't worry about the film surface, you end
25 up with a Prandtl number dependence about .34, which

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1 is about what you expect, and you don't have this wide
2 scatter.

3 Like you said, this shows where the
4 correlations are, and these are all, you know, --

5 MR. WALLIS: Well, if it depends on
6 waviness, it's going to depend on the length of the
7 performance.

8 MR. KELLY: That's true as well.

9 MR. WALLIS: Because if waves are
10 developing.

11 MR. KELLY: Now, these are all models that
12 people recommend you use, and they're all over the
13 map. So, for the moment, in trying to pick one to use
14 as a benchmark to guide my development, I'm going to
15 pick the one that's kind of in the middle, the one by
16 Labuntsov.

17 I could probably pick Soliman just as
18 well, and it's kind of in the middle. I've got, you
19 know, Prandtl number one and Prandtl number two here.
20 It's not a wide variation, that that kind of brackets
21 the water applications I'm looking at. You know, two
22 is basically saturated water, one atmosphere, and one
23 covers saturated water, a whole range.

24 So what I said I was going to do is take
25 the condensation correlation, use that as a benchmark,

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1 use heating data to select a wall to liquid heat
2 transfer correlation, go to the literature, find some
3 models for interfacial heat transfer, add those two
4 together, and then compare them to condensation data.

5 So, what I'm doing now is trying to pick
6 a model for a convection from the wall to the liquid
7 film, and we use heating data to do that. This is an
8 example of Bay's data. The Wilke correlation has four
9 piece-wise pieces, and it's kind of a standard in all
10 of this. It's pretty accurate, and that's the broken
11 blue line.

12 Gnielinski is one of the more recent, more
13 modern ones. It's much more accurate than Dittus-
14 Boeter, and in fact, it's what I use in the reflood
15 model for --

16 MR. WALLIS: It's forced convection? I
17 mean, we're talking here about a falling film.

18 MR. KELLY: Right.

19 MR. BANERJEE: But the wall.

20 MR. KELLY: Yes, and what I'm using now is
21 a characteristic of something like full scale as a
22 film thickness. When you do that, what we talked
23 about, like when we were talking about Chen, about the
24 ratio and the hydraulic diameter of the film
25 thickness.

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1 MR. WALLIS: Labuntsov looks just like the
2 close convection.

3 MR. BANERJEE: Yes, except the battles to
4 the half.

5 MR. KELLY: Right, exactly. So,
6 Gnielinski does a pretty good job. It's not quite as
7 accurate, but I think the behavior is actually better,
8 and I actually looked at a lot more data than this,
9 and again, remember I said I want to when I can pick
10 models that I want to migrate over to the normal
11 constitiute models. So, Gnielinski fits right in with
12 that. So, as long as I know the film thickness, I can
13 use that and do just as well as a model developed for
14 heating.

15 MR. WALLIS: It seems to me that the
16 regulator has a problem here, that you develop all
17 this stuff and you choose Labuntsov and Gnielinski,
18 and some vendor is going to come along and say we're
19 using Colburn and Nickelgruber or somebody, and what
20 do they do?

21 MR. KELLY: They'd better. When you see
22 the next few viewgraphs, I'm going to say, and the
23 assessment will be. Remember what I said the other
24 day? Never believe one of these codes for a new
25 application, unless you sat down, and whether you want

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1 to call it a PERT or whatever, that you figured out
2 what the important phenomena are, when they're
3 important, and what range of parameters import and
4 over.

5 MR. WALLIS: Which will cost in
6 experiments which are something like full scale.
7 Perhaps we're getting there.

8 MR. BANERJEE: In this case, there are.

9 MR. KELLY: Exactly.

10 MR. WALLIS: The giraffes and pandas and
11 the whole menagerie.

12 MR. KELLY: Well, and panthers.

13 MR. BANERJEE: And panthers.

14 MR. KELLY: Which was done in Piacensa.
15 It's actually the real, full-scale thing. Now, you
16 don't have the detailed measurements from it necessary
17 for model resolvment, but you can assess your model
18 against it.

19 MR. WALLIS: It will be interesting to see
20 how all these animals fit on your --

21 MR. KELLY: We'll get there. This is a --

22 MR. WALLIS: Not today, though.

23 MR. KELLY: Actually, I did that once a
24 long time ago, but I need to, you know, this is deja
25 vu here. When I first joined the agency in '93, my

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1 very first ACRS presentation was on this stuff.

2 MR. WALLIS: You've come full circle.

3 MR. KELLY: So I dusted it all off.

4 MR. WALLIS: Has there been any progress
5 since then?

6 MR. KELLY: Just a little. I've gotten a
7 little bit smarter, and a little more cynical.

8 MR. WALLIS: You got smarter, but is the
9 result any better?

10 MR. KELLY: We'll see. So, at any rate,
11 this is Nusselt, non-dimensional versus film Reynolds
12 number. The orange line is the Labuntsov correlation.
13 That's for condensation.

14 The blue line is Gnielinski, which is just
15 from the wall to the liquid. When you then add an
16 interfacial correlation to it, and the one I added
17 here is by Al Hussein, Tuzla, and Chen. That's from
18 Lehigh University.

19 That produces the black curve, which
20 amazingly enough comes somewhere close to this, that
21 actually surprised me. So, when it's fully turbulent,
22 it's pretty close.

23 When you go towards the laminar
24 transition, it nets down, actually as it should. So,
25 I'm not too unhappy with this.

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1 MR. WALLIS: This is just a turbulent
2 falling film.

3 MR. KELLY: Yes, it's a simple problem.

4 MR. WALLIS: This is step number one.

5 MR. KELLY: It's a simple -- well, step
6 number two. Laminar was the first step.

7 MR. WALLIS: Okay.

8 MR. KELLY: Well, actually, step number
9 one was getting the film thickness right. So, this is
10 just the very first one I looked at. I'm going to
11 look at others and then try to pick one, but this
12 isn't bad, considering what I've done to get there.

13 Then of course it's going to have to be
14 assessed. Before we do the assessment, because the
15 assessment that I'm going to look at is all sheared
16 films. That's the condensation data I have that makes
17 some sense, particularly the UCB test done by Kunz,
18 which at lower vapor Reynolds numbers, and in a NASA
19 Goodykoontz data.

20 I have some others by Ueda and Blangetti
21 and Schlunder, where they actually measured the film
22 thickness and the pressure drop and tried to back out
23 where the interfacial friction was. I can actually do
24 these guys on a spread sheet where these I'm going to
25 have to end up doing on a card.

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1 Okay, so where are we? When you look at
2 a sheared film, the first observation you make is that
3 the heat transfer is hot. It goes way up, and the
4 reason, what seems to me and to others, is that the
5 main reason it gets a lot higher is the film just
6 simply gets thinner. If you thin the film down to
7 next to nothing, your heat transfer rate goes way up.

8 So, what I'm proposing to do --

9 MR. BANERJEE: But you also enhanced your
10 turbulence. You get turbulence at the interface and
11 at the wall model.

12 MR. KELLY: Yes.

13 MR. BANERJEE: Whereas previously, you
14 only guarded the walls.

15 MR. KELLY: And you were damping it at the
16 interface. Yes, that's true, but as a first shot,
17 what we're going to do is use heat transfer models
18 developed from the following film data, and then
19 translated to a sheared film by using the calculated
20 film thickness.

21 MR. WALLIS: I think that Collier and
22 Hewitt and people way back in '69 or something. Did
23 a lot of experiments with annular flow, and the heat
24 transfer as well. They found they had approached
25 something like this, but they had to fudge it by a

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1 factor of about two to get the missile number right.

2 MR. KELLY: And that's what we're going to
3 find out.

4 MR. WALLIS: A long study of that.

5 MR. KELLY: Yes, you know, and typically
6 the approach is to go off and use the Martinelli
7 parameter into some kind of multiplier. I don't want
8 to do that because I'm already calculating the film
9 thickness. What I remember is something like a two-
10 phase heat transfer coefficient ratio is like one over
11 one minus alpha to the .8. So, we're going to see
12 where this takes us, okay?

13 So, this is the approach I'm going to use.

14 MR. WALLIS: How many years do you have?

15 MR. KELLY: I've only got a couple more
16 months. This is the assessment I'm going to do, so
17 I've got to get busy and pump some stuff to Birol, and
18 he's got to get it in the code and test it. Remember,
19 I'm coming to the end of the presentation, and this is
20 the work I'm doing now. So, you're getting what I'm
21 planning on doing.

22 MR. WALLIS: That's not very far with the
23 real problem.

24 MR. KELLY: That's true. On the other
25 hand, we've corrected the wall drag models and the

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1 interfacial models.

2 MR. WALLIS: You're going to show us the
3 next slide.

4 MR. KELLY: Yes. So, this is an example
5 of the approach. This is the data from the Ueda, and
6 it's the Nusselt number, non-dimensional Nusselt
7 number versus film Reynolds number. What they did is
8 they were able to back out or infer the level of
9 interfacial friction. Actually, these are non-
10 dimensional values.

11 So as you go from a value of 10 to 40 to
12 70 to 120, on up to 300, of course the films got
13 thinner, and the heat transfer rates got higher.

14 Yet instead of plotting it as a non-
15 dimensional Nusselt number, we use a Nusselt number
16 we're a little more familiar with, which is a heat
17 transfer coefficient times the film thickness over the
18 conductivity. It's unfortunate that I used an
19 asterisk for times here, because it looks like it's
20 the non-dimensional.

21 So, if you use the standard definition of
22 the Nusselt number --

23 MR. BANERJEE: Whose film thickness is
24 that? From them or --

25 MR. KELLY: Measured.

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1 MR. BANERJEE: Measured.

2 MR. WALLIS: So the other Nusselt number
3 was in terms of this dimensionless length?

4 MR. KELLY: Right, because that's how you
5 find condensation data. The rate scale used is the
6 Nusselt one, the viscous gravitational one.

7 MR. WALLIS: Right.

8 MR. KELLY: So here I'm using the actual
9 measured film thickness.

10 MR. WALLIS: Because you've got a sheared
11 flow rather than the gravity flow.

12 MR. KELLY: Right. Now, what that does is
13 it collapses the data down rather remarkably, given
14 this scatter you've seen in condensation data. Now
15 not only do they have condensation data. They have
16 film thickness measurements, which are not the most
17 accurate thing in the world either.

18 Then what I did on this plot was I went
19 ahead and plotted Gnielinski, and the Gnielinski plus
20 the ATC interfacial. So, this is what I would have
21 expected the condensation heat transfer to be, and
22 you'll notice this data overpredicts it. For some
23 reason, that line happens to go right smack dab
24 through the middle of it, which it shouldn't, because
25 I was saying there's no interface resistance.

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1 MR. BANERJEE: Right. The lower, of
2 course, all your heat transfer is coming from the
3 shear at the wall, right? It's without shear.

4 MR. WALLIS: I'm puzzled here.

5 MR. BANERJEE: The dotted line is without
6 shear.

7 MR. KELLY: No, in both of these, I'm
8 using the measured -- well, I'm just using the film
9 Reynolds number.

10 MR. BANERJEE: Right.

11 MR. KELLY: Okay.

12 MR. BANERJEE: But the other one is
13 without shear.

14 MR. KELLY: Right.

15 MR. BANERJEE: I don't know what the black
16 line is. Where does that come from?

17 MR. KELLY: Okay, the black line is the
18 heat transfer coefficient, or Nusselt number, from the
19 wall to the liquid. This is wall to liquid plus the
20 interfacial effect.

21 MR. BANERJEE: Because you sheared the
22 interface.

23 MR. KELLY: I've removed the shear by
24 plotting it this way.

25 MR. BANERJEE: Yes, but the correlation

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1 that was developed, the one you showed us before, was
2 for turbulent falling liquid without shear.

3 MR. KELLY: That's correct.

4 MR. BANERJEE: So that's what that -- and
5 you can plot that against the film Reynolds number.

6 MR. KELLY: Right.

7 MR. BANERJEE: Okay, and that's what
8 you've done there?

9 MR. KELLY: That's what I've done.

10 MR. BANERJEE: Now, when you put shear, of
11 course, you bring additional turbulence in addition to
12 tending the film.

13 MR. KELLY: Okay.

14 MR. BANERJEE: So, you've got the real
15 film thickness down there, but that has to move up.

16 MR. KELLY: Well, that's a good point.
17 Thank you. I appreciate that. I hadn't thought of
18 that. In fact, I just put these curves on here last
19 night, which is why it's not in your handout, but yes,
20 I think you're right. The caveat to that is there's
21 some other data by Blangetti and Schlunder where they
22 do this same kind of thing. I didn't put the plot up
23 here, but if these points are about 35 percent higher
24 than theirs.

25 MR. BANERJEE: Could be many things.

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1 MR. KELLY: And that's why I got --

2 MR. BANERJEE: Did they measure the film
3 thickness as well?

4 MR. KELLY: I don't remember.

5 MR. BANERJEE: Because this is a measured
6 thickness.

7 MR. KELLY: Right.

8 MR. BANERJEE: So you have to check that.

9 MR. KELLY: Right, but I'm going to keep
10 your comment in mind because one of the next things
11 I'm going to do is start comparing this to the UCB
12 data with pure steam condensation, and then also the
13 NASA Goodykoontz and see where this comes, and also
14 try other models like the Bankoff one and see what I
15 get.

16 MR. BANERJEE: Because opposite, you'll
17 find with the Bankoff model, it's all driven by
18 interfacial shear. The wall shear is not very
19 important.

20 MR. KELLY: No.

21 MR. WALLIS: What's the message with this
22 ATC thing? You add the ATC and the correlation gets
23 worse?

24 MR. KELLY: For this set of data, yes. I
25 probably shouldn't have even shown it, but you know,

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1 I put it on --

2 MR. BANERJEE: Why don't you go back to
3 your previous slide where you showed these -- yes,
4 that one.

5 MR. KELLY: So for this, it
6 underpredicted, but for the shear driven one, it
7 underpredicted, and you may be exactly right, that
8 this model, because it doesn't take account of
9 interfacial shear, overpredicts the resistance to heat
10 transfer at the interface.

11 MR. WALLIS: Right.

12 MR. BANERJEE: Now, what is that other
13 blue line coming from? That's just a forced
14 convection heat transfer, is it?

15 MR. KELLY: Which I'm using for the wall
16 to the liquid. In this line is the resistance from
17 this plus the resistance to the interface. If I
18 applied these as resistances, you would see them
19 adding up to this, and that would make more sense,
20 yes.

21 MR. WALLIS: Parallel.

22 MR. BANERJEE: Well, in series.

23 MR. KELLY: Series, right. So, this is
24 just the approach I'm going to try to follow, and
25 we're going to see where it leads next time, which may

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1 be a couple of months from now.

2 The next to the last slide, noncondensable
3 gas effect, which is actually one of the main things
4 for all of this, and if you go to the final report of
5 the UCB project, they go through a lot of models, and
6 in the end, they look at a fusion layer model and what
7 they call a mechanistic approach using a mass transfer
8 conductance model. They show that for their own data,
9 that is more accurate than the empirical models they
10 develop from their data.

11 So, this is the approach I'm going to try
12 to follow and implement, and then this is the
13 assessment cases. Now, I'm going to do a number of
14 all of these and see how good it is.

15 So in summary, I looked at the original
16 TRACE models. They do a poor job. They overpredict
17 condensation with noncondensables present. They
18 underpredicted for pure steam. So, I started the
19 development of a constitutive package to be
20 applicable for ICS and PCCS condenser tubes.

21 We've made improvements to the wall drag
22 and interfacial friction. I've started looking at
23 condensation and laminar falling films. I've chosen
24 them all for that. I'm looking at turbulent films
25 now, and I'm going to be looking at sheared films and

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1 then use a mass transfer approach for the
2 noncondensable gas, and then do a relatively large
3 amount of assessment and then have quantitative
4 metrics.

5 These are nice as far as quantitative
6 metrics.

7 MR. WALLIS: Are you going to look at
8 Diraf and Pendar and all that sort of thing, too, and
9 panthers?

10 MR. KELLY: In the development of the
11 model, I'll use the simple, separate effects test, and
12 if you will, the validation model. That's when we
13 start expanding it out to the larger, more interval
14 facilities.

15 MR. WALLIS: You've given us a couple of
16 examples here where the codes were not doing a very
17 good job. You started to try to figure out how to
18 improve.

19 MR. KELLY: Right.

20 MR. WALLIS: And you've made some steps
21 forward, but you've got some way to go.

22 MR. KELLY: That's true.

23 MR. WALLIS: So one has to wonder how many
24 other parts of these codes are in the same state.

25 MR. KELLY: Yes.

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1 MR. WALLIS: Now, is it that the rest of
2 the codes are in fine shape and these are just some
3 odd things that weren't done too well because they
4 didn't matter at the time, or do we have to look at a
5 lot of parts of the code as well?

6 MR. KELLY: My intent is to look at all
7 the other parts of the code. I mean, like if we're
8 talking about small break loca, for example, which is
9 a nontraditional application of TRACE. Now,
10 unfortunately, it doesn't even apparently do large
11 break loca very well. That's why I had to do the
12 reflood stuff.

13 There's a lot of things important in small
14 break loca that TRAC had never been assessed against.
15 Loop seal clearing, reflux condensation. You know,
16 all these things have to be looked at, and we're going
17 to do them one at a time.

18 In most cases, we'll be doing comparisons
19 from TRACE versus RELAP5, and if the models in RELAP5
20 are significantly better, we'll just port the model
21 over, but talking about small break loca, one of the
22 things you know is important is the level swell. We
23 already know from our assessment that the interfacial
24 drag model in TRACE was not adequate, and we've made
25 the decision to go ahead and replace it.

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1 MR. WALLIS: So that's another example
2 where you had to look at fundamentals and you had to
3 make a significant change in the interfacial drag
4 model.

5 MR. KELLY: Yes.

6 MR. WALLIS: It was a factor of --

7 MR. KELLY: Oh, interfacial drag
8 coefficient, you know, that can be an order of
9 magnitude real easy.

10 MR. WALLIS: Or major different from what
11 was assumed before.

12 MR. RANSOM: Did I hear that stratified
13 flow models have not been put into TRACE yet?

14 MR. KELLY: No, there is a horizontal
15 stratification criteria. How good it is --

16 MR. RANSOM: I'm thinking of the counter
17 current flow modeling.

18 MR. KELLY: Yes, I haven't looked at the
19 interfacial drag and countercurrent flow in a
20 horizontal pipe yet, so who knows. I don't know.

21 MR. BANERJEE: I think he means even the
22 terms and the equations which are missing.

23 MR. KELLY: Oh, no, no, no. That is here.
24 Yes, the gravitational head due to a void fraction
25 profile, that's there, so water does run more level --

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1 seek its own level in a pipe.

2 MR. RANSOM: Okay.

3 MR. KELLY: Yes, if it didn't have that,
4 you know, that's there, but I mean, these codes have
5 hundreds of constitutive models in them. Some good
6 and some not so good. They're terrible. You have to
7 address the application, and I'm talking about TRACE
8 here, but it's true of RELAP5. It's true of the
9 vendor codes. It's true of any code, and you have to
10 assess it for your application, and you have to do a
11 very good job, and whoever is in charge of that code
12 better be just as inquisitive as you guys are. You'd
13 better ask the tough questions.

14 MR. WALLIS: Of course if you'd done this
15 for 40 or 50 years, and you seem to be rediscovering
16 things that we did a long time ago. I'm trying to
17 figure out why the steps haven't been taken before.
18 Conceivably it's because the regulatory framework is
19 that an applicant gets some young engineer out of
20 college and says put together some models for our
21 code. He or she puts together whatever they can to
22 make something work that seems sort of reasonable, and
23 if it gives good enough results for the regulatory --

24 MR. KELLY: You move on.

25 MR. WALLIS: -- argument that they want to

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1 make about large break loca or something, they get it
2 approved by the NRC and they don't want ever to look
3 at it again. So no one has any incentive to do
4 anything about it.

5 MR. KELLY: I won't speak to the vendors
6 in here but I can speak about myself and my own
7 experience because most of my career was spent in a
8 national lab, and most of that as a contractor to the
9 NRC. What happens is the development deadlines tend
10 to be aggressive because you want results now. You
11 don't want them a couple of years from now.

12 Contractors are relatively expensive. NRC
13 research budgets, these days, are not that large, and
14 so you have to do a very lot with very little staff
15 power, and if I were a contractor right now and
16 someone came to me and said we want you to put a tube
17 condensation model to handle noncondensables into
18 TRACE, chances are they would give me one or two staff
19 months of effort, because that's already big bucks.
20 Two staff months is 50, \$60,000, okay? If you're
21 going to give me two months to do this work, and that
22 includes putting it in the code, documenting it,
23 changing the stuff in the manual, how much time does
24 that leave for intellectual curiosity? Not much.

25 You're going to go to the first textbook

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1 or first journal paper you can find, and you're going
2 to see a correlation that someone has referenced and
3 recommend it, and you're going to try to find some way
4 to shoehorn it into that code and get your work done
5 so you meet your milestone. I mean, you're going to
6 do your work as best you can, but you do not have the
7 luxury to sit there and read a couple hundred
8 technical papers and educate yourself on one of these
9 topics. There simply is no time, and time is money.

10 MR. WALLIS: Then there's some manager
11 saying that's good enough, and trying to convince the
12 agency that that's good enough.

13 MR. KELLY: Now, I'm speaking from the NRC
14 perspective. I was an NRC contractor for most of my
15 career.

16 MR. WALLIS: You speak from that side, but
17 I think it's very true of industry as well. The
18 pressure to produce something now is probably even
19 greater.

20 MR. KELLY: There it's real money. It's
21 bottom line.

22 MR. WALLIS: I look at some of the people
23 who I know produce some of the work, and they really
24 didn't know very much, and you can see that they put
25 together things based on what they knew, which is a

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1 good start, but the thing is they prostelize at the
2 start. No one goes back and says that was a pretty
3 poor model. It's not really good enough for this
4 thing. Let's do something about it. It doesn't seem
5 to be an incentive to do that.

6 MR. KELLY: Well, that's because --

7 MR. WALLIS: I'm talking about the vendors
8 now.

9 MR. RANSOM: Yes, but hasn't a lot of that
10 been driven by the appendix K where we're simply to be
11 super conservative, and as long as you're under
12 whatever the NRC with audit and come up with, why
13 that's good enough.

14 MR. KELLY: But even when you move into
15 best estimate space, and I mean people try. Most
16 people out there are honest and hard working and want
17 to do a good job, but there is no time. Right now, I
18 am in a very nice position with the Agency. My
19 management has given me the job to look at these
20 models, and they're giving me time to spend to go
21 assemble these databases, go check models out, try to
22 make some rational decisions instead of just grabbing
23 the first thing I can find and sticking it in the
24 code.

25 I'm very, very appreciative of that, and

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1 I'm learning a lot, and that's what makes my job fun
2 right now.

3 MR. WALLIS: It looks as if there's going
4 to be a pay-off because you're getting results which
5 are significantly different from what was predicted
6 before, and will influence decisions made about
7 something like the ESBWR probably. So, it's not that
8 it's just interesting work. I mean, it has a real
9 pay-off for the Agency.

10 MR. KELLY: Right.

11 MR. WALLIS: Which may not have been
12 appreciate before. You know, that letting you do this
13 would have a pay-off for the Agency.

14 MR. RANSOM: I think the one thing that
15 seems still kind of disturbing is, and I'm not
16 pointing at anybody in particular, but you know, after
17 six years of being at this, you still won't have an
18 ability to use it in the NRC licensing sense. The
19 question that comes up to me is how much longer will
20 it be before you actually achieve that goal.

21 MR. KELLY: And I would say that depends
22 upon the application. No, I agree with you
23 completely. The first few years of the project were
24 taken up by things like trying to modernize the
25 architecture and trying to bring in TRAC-B models,

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1 things like the heater component, the Chan component
2 with the radiation model, the jet pumps, et cetera.
3 That was the first few years of the project.

4 Then where we really got bogged down was
5 when we went to be able to do RELAP5 input decks. As
6 you very well know, the philosophy behind the
7 interconnectivity of the components and the type
8 components are different in the codes. In trying to
9 do that --

10 MR. RANSOM: Was that not recognized at
11 the outset?

12 MR. KELLY: None of us realized it was
13 going to be as hard a job as it was. I mean, it's
14 much, much harder than I'm saying. When you try to
15 map one of these components, even a pipe or a valve,
16 they don't quite go one to one. Now, put a control
17 system on top of this, and you're going to map the
18 control system as well. That control system expects
19 it to be this junction in this pipe. That doesn't
20 exist after you've mapped it.

21 So, you have to map it, redo the control
22 system. I mean, it gets very complicated.

23 MR. RANSOM: The thing that bothers me is
24 the NRC should have realized this because actually,
25 most of that framework goes back to the 60's. It

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1 started out at General Electric and you know, through
2 the INELE, and so there's an awful lot of history
3 behind that, and probably no real good reason to
4 change that view of the world.

5 MR. KELLY: When we first started this,
6 the idea of the consolidated code, one of the metrics
7 was not going to be able to re-use the RELAP input
8 decks.

9 MR. RANSOM: Oh, really?

10 MR. KELLY: Not six years ago. That came
11 along after one or two years, and we realized that we
12 wanted to keep the investment in input models. That
13 raises --

14 MR. CARUSO: I'm going to disagree.

15 MR. STAUDENMEIER: No, the original intent
16 wasn't to map everything directly. The original
17 intent was map what you could easily, which would be
18 1D components, pipes, and things like that. Then SNAP
19 would give the user a message on things it couldn't
20 map and tell it you have to do this on your own, and
21 this is how we think you should do it. We can't do it
22 -- I can't automate it for you, but then it was turned
23 into -- that would get you probably 90 percent of the
24 stuff, 90 to 95 percent, but when it was turned into
25 100 percent type of thing, that's where the work just

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1 multiplied by a lot.

2 MR. CARUSO: The message was that the
3 existing decks should not have to be redone. You
4 should not have to pay a zillion bucks to recreate all
5 those data decks, and if it required a little bit of
6 tweaking, that was all right, but there were, just
7 before the decision was made to consolidate the code,
8 there was a bad example of going from one version of
9 RELAP to another version of RELAP that meant that some
10 decks that had just been delivered by a national
11 laboratory were not able to run in the new version of
12 the code, and a substantial amount of money had to be
13 spent to get those decks run on the next version of
14 the code.

15 MR. KELLY: Yes, I remember that.

16 MR. CARUSO: That caused some
17 unpleasantness.

18 MR. KELLY: And I don't recall it quite
19 the same way because I recall more of a discussion
20 about, you know, new code versus re-using one of our
21 codes, and if we're going to re-use one of the codes,
22 which one. It turned out that TRAC at that time,
23 there was a project by the Office of Naval Reactors to
24 modernize the architecture of the 1D components in
25 TRAC.

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1 MR. WALLIS: I remember that.

2 MR. KELLY: And that, together with what
3 we believe was a more modular structure in TRAC,
4 helped drive -- and the 3D vessel -- helped drive the
5 decision that way. That turns out to have really been
6 a difficult problem to be able to re-sue RELAP5 input
7 decks.

8 MR. RANSOM: I imagine, yes.

9 MR. KELLY: And with lots of fitful starts
10 along the way. You hear us talk about things like the
11 TPR file. That didn't just be perfect in this first
12 inclination. A whole lot has been done there. We
13 have not advanced the state of the art as far as our
14 computational capabilities. I mean, zero, okay,
15 except for bug fixes.

16 But what we now have --

17 MR. RANSOM: What's your estimate? How
18 long will it take to produce this, put this code into
19 the licensing arena?

20 MR. KELLY: Well, if we're talking about
21 large break LOCA, okay, that may be within the next
22 year. See how the assessment goes.

23 Small break LOCA, maybe another year after
24 that. As you saw with Steve's presentation about his
25 plans for the assessment of the code, this code will

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1 end up being better assessed than any of the vendor
2 codes, but as we start down that path, we're going to
3 identify deficiencies, and we're going to have to
4 rectify them.

5 The one thing in our favor now is the code
6 really is much, much more modern and easier to go in
7 and make changes than it's ever been in the past.
8 Compared to the TRAC code we started with, it's more
9 than an order of magnitude. There are no pointers.
10 There's no test on bits. All that archaic stuff is
11 gone.

12 It's relatively straightforward, easy to
13 read Fortran, and you can go in and do your work. We
14 have the automated testing tools. Much, much better
15 quality assurance than we've ever had before, and so
16 yes, we haven't made the answers better yet, but we've
17 gotten ourselves in a position where we can.

18 MR. RANSOM: Well, I think one difficulty
19 that may be faced too, and this is somewhat new to me,
20 too, but licensing is now moving towards its first
21 conformed regulations, which means a slightly
22 different way in which codes are going to be used. I
23 think that will still be very important, don't you?

24 You know, good physical models will be
25 important in that framework, too, because that will

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1 tend to reduce the amount of uncertainty that's
2 involved in any one of these calculations.

3 I think that research is going to have to
4 you know, bring these codes into that arena, too,
5 which is a new thing.

6 MR. KELLY: And Steve just walked in the
7 door, and that certainly is -- he worked as part of
8 the best estimate team at Westinghouse, and has a lot
9 of experience in that area, and that's where he's
10 pushing us.

11 MR. WALLIS: I'm just going to call a
12 break, not because Steve walked in the door. We'll
13 take a break until 3:30. Thank you very much, Joe.

14 (Whereupon, the foregoing
15 matter went off the record at
16 3:15 p.m. and went back on the
17 record at 3:34 p.m.)

18 MR. KROTIUK: I'm Bill Krotiuk, and I work
19 in research. At Joe's request, Joe Staudenmeier's
20 request, I'm sort of presenting some of the
21 applications that I have done, specifically using
22 TRACE, and this pertains to the development of load
23 inside the steam generator, and following a rupture of
24 a main steam line or a feedwater line.

25 The specific guidelines were to use TRACE

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1 for this analysis, but one of the things that I found
2 it to do is because of the questions about the
3 applicability and everything, I wanted to run some
4 sensitivity studies with the code and also to do some
5 comparisons with appropriate tests that would be
6 representative of the type of phenomena that I would
7 be seeing inside the steam generator.

8 So, what I ended up doing was that I
9 wanted to use specific test comparisons to look at
10 test data that would test the code regarding its
11 ability to follow the acoustic wave transmission
12 through the depressurization process, and also to
13 assess pool swell effects that could occur inside the
14 steam generator following the rupture.

15 The codes that I specifically looked at
16 were Edwards, the very simple comparison, a LOFT
17 Semiscale blowdown test. Then the more specific tests
18 that were more complicated were the GE vessel blowdown
19 and the Westinghouse MB-2 testing.

20 MR. WALLIS: All of these tests measured
21 pressure wave propagation?

22 MR. KROTIUK: Okay, these first two did,
23 Edwards and the LOFT Semiscale did. The GE vessel and
24 the MB-2 were more attuned to the pool swell
25 phenomena, and specifically, the MB-2 actually was a

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1 Westinghouse steam generator with two support plates
2 and the pressure measurements requested, and tube
3 support plates.

4 MR. WALLIS: And will the pressure wave
5 propagation is very early after the break, presumably.

6 MR. KROTIUK: Right.

7 MR. WALLIS: And the pool swell is
8 something that happens later?

9 MR. KROTIUK: Later on.

10 MR. WALLIS: Later on, because it's
11 different times altogether?

12 MR. KROTIUK: Yes, there's different time
13 scales on that, and well, I'll show you that it turns
14 out one is dominant over the other.

15 MR. WALLIS: Okay. Does he have to start
16 again?

17 MR. KROTIUK: Okay. This is just a slide
18 just summarizing the Edwards pipe blowdown problem,
19 and what I did to try to look at sensitivity, I did
20 divide the problem into different number of nodings,
21 and also did look at the two numerical schemes, the
22 sets and the nonsets type of situation.

23 I have, you know, numerous comparisons,
24 and I just chose two points here. With regard to the
25 pipe blowdown, these were two positions near the

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1 coldest end of the pipe, and this is for pressure and
2 this is for basically void fraction. One finding that
3 I did in doing this sensitivity study was that the
4 NOSETS equals zero, which means using the SETS option
5 actually provided results that were closer to test
6 data. Then this was just some indication of the type
7 of node size that I needed to follow that acoustic
8 wave.

9 MR. WALLIS: Now, the acoustic wave is
10 over in a very short time.

11 MR. KROTIUK: That's correct. Yes, this
12 problem is within the second acoustic wave is over.

13 MR. WALLIS: Isn't it much shorter than
14 that? Four meters long, and you open the end of it,
15 and the wave rushes from one end to the other and
16 bounces off?

17 MR. KROTIUK: Right.

18 MR. BANERJEE: It's the first wave --

19 MR. KROTIUK: But don't forget, there are
20 reflections back and forth, so --

21 MR. WALLIS: But isn't the sort of
22 millisecond time range at the beginning?

23 MR. KROTIUK: Yes, you get a lot of time
24 right here, yes.

25 MR. WALLIS: All right.

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1 MR. KROTIUK: But you are getting
2 reflections.

3 MR. WALLIS: Are you interested for loads?
4 Are you interested in --

5 MR. RANSOM: Between that very early phase
6 range. The long terms of the weight propagation. Are
7 you interested in the loads on the steam generator?

8 MR. WALLIS: Are you interested in that
9 very short part with millisecond time scale, or are
10 you interested in --

11 MR. KROTIUK: No, I'm interested more in
12 the one second time scale.

13 MR. WALLIS: You are?

14 MR. KROTIUK: Right.

15 MR. WALLIS: Isn't it the wave that hits
16 the steam generator that you're concerned about?

17 MR. KROTIUK: No, when you get the pipe
18 break on say the steam line, which turns out to be the
19 worst case, you get a depressurization rate of
20 traveling back and instead depressurization wave
21 that's going back that gives you the forces on the two
22 support pieces.

23 MR. WALLIS: That's over way in the --

24 MR. KROTIUK: Don't' forget, the time
25 scale on this is very small. I mean, yes, you're

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1 right, and I do have another problem which would --

2 MR. RANSOM: Comparing an eight meter pipe
3 with one that, I don't know, is probably 40 or 50
4 meters long.

5 MR. KROTIUK: Agreed.

6 MR. RANSOM: While the time scale cannot
7 be compared directly as far as what's important.

8 MR. KROTIUK: Right, and this is the first
9 problem. I'm just trying to get some sensitivity of
10 the ability of the code to predict this, and then I'll
11 go to the next one.

12 MR. WALLIS: My concern was that NOSETS,
13 whatever it is, that this solution from the code
14 predicts what happens after a few milliseconds fairly
15 well, but it doesn't predict the acoustic wave
16 propagation, does it? Or does it?

17 MR. KROTIUK: It does, and the next case
18 I show will show you specifically acoustic wave.

19 MR. WALLIS: Okay, thank you.

20 MR. BANERJEE: Can I ask you a question?

21 MR. KROTIUK: Yes.

22 MR. BANERJEE: In let's say something like
23 the feedwater line break.

24 MR. KROTIUK: Right.

25 MR. BANERJEE: It's subcooled water like

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1 the Edwards situation here. In the Edwards
2 experiment, you don't show it, but I remember, since
3 I know Tony Edwards. There was an incredibly large
4 pressure undershoot. It almost went down to somewhere
5 between around 1.5 on your scale, before the pressure
6 came back up. That happened in the first few
7 milliseconds.

8 MR. RANSOM: That's at the closed end.

9 MR. BANERJEE: This is at the closed end,
10 he said.

11 MR. KROTIUK: Well, this is at the closed
12 end, but that is --

13 MR. RANSOM: Oh, that is the closed end?

14 MR. KROTIUK: Yes, that is the closed end.
15 There is, and I'm just looking at, and as I say, I
16 didn't make copies of all of the test points. There
17 is an undershoot at position 7, which is --

18 MR. BANERJEE: There was an undershoot at
19 a number of points.

20 MR. KROTIUK: Yes, there is an undershoot,
21 yes.

22 MR. BANERJEE: Where is that undershoot?

23 MR. KROTIUK: It doesn't show up on that
24 particular set of data, but it does show up on some of
25 the other ones.

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1 MR. BANERJEE: Did you predict that
2 undershoot?

3 MR. KROTIUK: Let me just look very
4 quickly. I don't remember --

5 MR. WALLIS: It's just the reflection of
6 a decompression wave, isn't it?

7 MR. BANERJEE: No, it's the subcooled wave
8 that goes through --

9 MR. KROTIUK: No, it does --

10 MR. BANERJEE: For bubbles nucleate, and
11 it takes a certain time to nucleate the pressure
12 drops.

13 MR. KROTIUK: Right. Now, the code is not
14 predicting that undershoot.

15 MR. WALLIS: What you would get with a
16 reflected wave in just pure water.

17 MR. BANERJEE: Right, but a feedwater line
18 break is that, right? I mean, it's water.

19 MR. RANSOM: If you didn't get
20 vaporization, you'd double down, actually. So, it
21 becomes very low, but vaporization actually keeps it
22 from getting --

23 MR. BANERJEE: Yes, but the feedwater line
24 is water.

25 MR. RANSOM: Sure, sure.

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1 MR. BANERJEE: And it will hit that.
2 There will be an undershoot before you start
3 vaporization.

4 MR. RANSOM: Absolutely.

5 MR. WALLIS: It's a bit like a water
6 hammer where the reflected wave wants to go down to
7 pressures which are subatmospheric, but it creates
8 vapor, and it doesn't go down, sub-atmospheric.

9 MR. KROTIUK: It's almost like a vapor
10 formation followed by a collapse, something of that
11 nature.

12 MR. BANERJEE: So, what happens? Do you
13 feel that the wave that comes from the rarefaction
14 wave in its reflection for the feedwater line break is
15 not important?

16 MR. KROTIUK: It turns out the feedwater
17 line is not the design case. So, it's not important
18 in terms of the analysis that I performed. The steam
19 line break turns out to be most severe.

20 But just to elaborate on what you said,
21 I've done other work with TRACE, and that the problem
22 you're alluding to, I have noticed in doing some of
23 the other test comparisons, and that problem still has
24 to be addressed. It has to do with, as you're saying,
25 the flashing of subcooled liquid as the pressure drops

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1 and things of that nature.

2 There are some situations that that --
3 well, there are problems with the code that it doesn't
4 exactly handle that situation.

5 MR. BANERJEE: Well, the reason I'm saying
6 that is that I'm aware of a situation where in Sweden,
7 we had to consider the feedwater line breakers being
8 very important, and look at the pressure undershoot.
9 So, I'm surprised you're able to do that without
10 considering it.

11 MR. WALLIS: Does this pressure undershoot
12 actually yank the end of the pipe? I mean, it pulls
13 on it?

14 MR. KROTIUK: For the Edwards problem?

15 MR. WALLIS: Yes.

16 MR. KROTIUK: Yes, it will, over a short
17 time frame, but whether the pipe responds at all is
18 another thing. It's a dynamic response. I mean, you
19 know.

20 MR. WALLIS: It's over so quickly that
21 nothing much happens?

22 MR. KROTIUK: That's what I've, you know,
23 working over the years with dynamic stress analysis
24 codes, lots of times it doesn't. Of course, you have
25 a dynamic amplification factor that many times you

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1 apply to static analyses to approach that type of
2 calculation, and lots of times it's very small. It's
3 close to one, basically.

4 MR. RANSOM: In fact, it's very difficult
5 for these kind of codes to predict that because
6 they're driven by heat transfer to interfacial area,
7 and when you're in a pure fluid, you have no
8 interfacial area. So, you have to use some kind of
9 seating in order to get the process started.

10 That's been a issue with TRAC because they
11 used to use seating that remained all the time, and so
12 you'd see waves propagating at more nearly the ATM
13 speed, you know, rather than a pure liquid speed.
14 This came up in the Savannah River water, and I don't
15 know whether that's been retained in the latest
16 versions of TRAC. It was called like dirty water or
17 spongy water. That was the word that was used.

18 MR. BANERJEE: There are two separate
19 waves that go. One is the subcooled wave.

20 MR. RANSOM: Right, that's going through
21 the liquid.

22 MR. BANERJEE: And the two-phase wave,
23 which is the --

24 MR. RANSOM: Acoustic sound of the water,
25 5,000 feet a second.

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1 MR. BANERJEE: Right.

2 MR. RANSOM: Meters per second.

3 MR. BANERJEE: I mean, that's like water
4 hammer.

5 MR. RANSOM: Sure.

6 MR. BANERJEE: So I mean, when you break
7 this, you get something like water hammer.

8 MR. RANSOM: Oh, absolutely.

9 MR. KROTIUK: It is. I'm calling it
10 acoustic phenomena really, and if you have your water,
11 it's going to be a water hammer.

12 MR. RANSOM: But the interesting thing is
13 that if you have spongy water, the wave propagates at
14 about less than 500 meters per second, you know. You
15 know, 500 compared to 1000. So, it arrives, and in
16 fact, if you look at those two curves, it looks like
17 it maybe takes twice as long for the wave to arrive as
18 it does in the data, and I don't know whether that's
19 true or not. You'd have to blow up that region to
20 find out.

21 MR. BANERJEE: So are you telling us that
22 basically you're considering here the steam line break
23 where the phenomena is not likely to be important but
24 for the feedwater line break, it's likely to be
25 important, and that will be talked about later, or

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1 what?

2 MR. KROTIUK: The steamwater line breaks
3 and feedwater line breaks, but when you -- you'll see
4 when I back calculate the loadings on the tube support
5 plates, that the loadings that come from a steam line
6 break are substantially higher than anything that
7 would be developed by a feedwater line break. So,
8 it's not of an immediate concern, even if you have
9 this deficiency.

10 MR. BANERJEE: Why is that? Is that the
11 back of the envelope calculation, or what?

12 MR. KROTIUK: That I will address
13 specifically.

14 MR. BANERJEE: You will address it?

15 MR. KROTIUK: Yes, if you just --

16 MR. BANERJEE: The raptures and so on are
17 not aggravated by these things? I mean, is the whole
18 plate that's moving?

19 MR. KROTIUK: The whole, there's a force -
20 - yes, there's a force that builds on the entire tube
21 support plate.

22 MR. BANERJEE: Due to the imbalance of
23 --

24 MR. KROTIUK: Due to the imbalance of the
25 pressure across the plate.

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1 MR. BANERJEE: And what happens to -- is
2 there no possibility of ruptures of the steam
3 generator tubes?

4 MR. KROTIUK: That was the purpose for
5 doing this because ultimately what I did is that after
6 developing these forces on the tube support plates,
7 the loadings was transmitted to basically people doing
8 stress analysis who would look at the stress on the
9 tube support plate and transmitted stresses to tubes,
10 and they would make assumptions about, you know, was
11 there a tube that maybe was possibly ruptured or ready
12 slightly, or whatever, and would that aggravate the
13 situation.

14 So, that's done -- the effects of that is
15 done on the stress analysis portion. My main task was
16 to develop the loadings for the stress analysts.

17 MR. SIEBER: There was a situation where
18 a couple of licensees rolled the tubes into the tube
19 support plate that locked in there.

20 MR. KROTIUK: Yes.

21 MR. SIEBER: And that becomes a erious
22 problem when a steam line breaks because as the tube
23 support plate acts as a membrane, it puts tremendous
24 tensile stress on the tube because it's locked there.
25 Ordinarily there's enough clearance so that the tube

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1 support plate can go up and down, more or less free of
2 the tube except for the chemical crud that's sitting
3 in there.

4 MR. KROTIUK: But again, I won't be
5 addressing that part of this. I'm mainly concerned
6 with just the forces developed, you know.

7 MR. SIEBER: Did you consider that the
8 membrane may have a couple of nodes in it?

9 MR. KROTIUK: Excuse me?

10 MR. SIEBER: The tube support plate? You
11 know, some calculations I have seen shows that --

12 MR. KROTIUK: No, because I'm not doing
13 any of the stress analyses. I'm not doing that for
14 part of this. This is just addressing the development
15 of the thermal hydraulic forces on --

16 MR. SIEBER: This is just to get the
17 forces.

18 MR. KROTIUK: This is just to get the
19 forces, correct.

20 MR. SIEBER: All right.

21 MR. BANERJEE: But without the pressure
22 undershoot.

23 MR. KROTIUK: Right, without the pressure
24 undershoot that would exist.

25 MR. BANERJEE: In reality.

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1 MR. KROTIUK: In the feedwater. I think
2 this following one is kind of a nice problem that I
3 like to use as a real example of more of what you
4 would call almost like a water hammer type of an
5 effect because this is a test that I had found a
6 number of years ago of the semiscale blowdown test,
7 and it's basically a tank that has a rupture starting
8 on it. This is the initial conditions. Let me just
9 show you the figure.

10 What it is is that we have a rupture at
11 this location, and unfortunately there were only two
12 points that the data was taken. One was near the
13 rupture at this location and one at the end over here.
14 This was initially filled with liquid, as I said, and
15 then ruptured at this location. You could follow the
16 transmission of the wave back and forth, and you could
17 actually see the initial wave with a reflection, and
18 so on.

19 I've chosen, I've done a number of
20 comparisons.

21 MR. WALLIS: So now we're looking at
22 milliseconds?

23 MR. KROTIUK: No, we're looking at very
24 short time frames.

25 MR. WALLIS: Right.

1 MR. KROTIUK: And what I also did is that
2 a number of years ago, I'd written characteristics
3 codes to look at this specifically. It was modified
4 to include the two-phase effects. So, I have that
5 data plotted here, and let's see, that's in blue,
6 compared to the predictions from TRACE and then the
7 solid line is the test data.

8 MR. WALLIS: Now, is there any two-phase
9 flow going on here, or it's all single phase water?

10 MR. KROTIUK: Let me just remember
11 quickly. With this, it's towards the -- I think there
12 was --

13 MR. WALLIS: It's all single phase water,
14 isn't it?

15 MR. KROTIUK: There was primarily single
16 phase, but I believe there was some vaporization
17 towards the end of the problem. Let me just see if I
18 can find that. Oh, here we go.

19 Yes, towards the end of the problem, and
20 this was at what location? Again, I don't have
21 everything, but towards the end of the problem, I was
22 coming up with void fractions, and at this particular
23 location that I see here is maybe between 30 and 40
24 percent. So, there was some two-phase effects towards
25 the end of the problem.

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1 MR. WALLIS: Well, if you're going to get
2 that higher void fraction, then you must have some
3 flow out of the break to make space for the voids to
4 form in the vessel.

5 MR. KROTIUK: Yes. This was shown to, you
6 know, yes, you would get some flashing as the liquid
7 is coming out.

8 MR. BANERJEE: So if it gets pressure
9 undershoot here in the single phase region, why do you
10 say you don't see it in the Edwards case?

11 MR. KROTIUK: I didn't see it in the
12 Edwards case, and to tell you the truth, I didn't look
13 specifically at it, and maybe I should have looked
14 more closely, but I don't know why at this point.
15 This did predict this initial undershoot.

16 MR. RANSOM: Those are not necessarily
17 undershoot at that point.

18 MR. KROTIUK: Well, it's a
19 depressurization wave coming back.

20 MR. RANSOM: You mean undershoot compared
21 to the saturation or --

22 MR. KROTIUK: The undershoot according to
23 the depressurization.

24 MR. BANERJEE: Well, one is going through
25 the subcooled liquid initially. Is this subcooled?

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1 MR. KROTIUK: This is subcooled
2 liquidation.

3 MR. BANERJEE: What happens is that, and
4 this is well understood now, is it depressurizes
5 things to below saturation, in fact, and bubbles start
6 to nucleate, and as they grow, you start to get a two-
7 phase wave. In order to catch that, of course, we
8 have to have some way to look at bubble growth and
9 nucleation as we were saying.

10 MR. RANSOM: Right.

11 MR. BANERJEE: I mean, many people have
12 done work on this.

13 MR. RANSOM: What you might want to
14 consider here is he's depressurizing from a small
15 break into a rather large vessel, so the wave is
16 already made smaller, attenuated, I guess to a certain
17 extent as it spreads out and passes down the vessel.
18 I would guess also you have all of the surface area,
19 you know, the vessel too, which is creating
20 nucleation. The combination of that, I don't think
21 you really see much undershoot in this kind of
22 experiment.

23 MR. BANERJEE: It's less than in the
24 Edwards one.

25 MR. RANSOM: The Edwards was a whole pipe.

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1 MR. KROTIUK: It was just a straight pipe,
2 yes.

3 MR. BANERJEE: Where the undershoot was
4 much larger than this.

5 MR. RANSOM: Right.

6 MR. BANERJEE: But he's also doing the
7 calculation with a method of characteristics,
8 presumably initially for single phase flow, right?

9 MR. KROTIUK: No, I tell you, that code
10 that I used for that was initially a single phase
11 code, but I had modified it myself and came up with a
12 two-phase MOC code.

13 MR. BANERJEE: So how did you do that
14 without an undershoot and so on? I mean, did you have
15 a bubble nucleation model?

16 MR. KROTIUK: Yes, I did.

17 MR. BANERJEE: Okay, so where does the two
18 phase flow start in this time frame?

19 MR. KROTIUK: Probably something of the
20 order around this location here.

21 MR. BANERJEE: Okay, so you're still
22 sustaining an undershoot in the single phase liquid.

23 MR. KROTIUK: Yes.

24 MR. BANERJEE: I'm just confused that you
25 don't see it in there with the experiment, but you see

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1 it here. You know, we need to rationalize this.

2 MR. KROTIUK: Yes, I think that that's a
3 valid concern, and it might be my fault for not just
4 looking closely at it enough either.

5 MR. BANERJEE: But also, to get this
6 undershoot, you need a bubble nucleation model. It
7 just doesn't happen spontaneously. So, how do you get
8 the void forming? Did you have a nucleation model of
9 sorts, or does TRACE have one?

10 MR. KROTIUK: TRACE does approach that,
11 and to some degree, but I don't know the details on
12 that. That's what I was saying, that other problems
13 that I have show that this model does not, you know,
14 just some work needs to be done on that model.

15 MR. STAUDENMEIER: The TRACE model is
16 undershooting the break flow, and that's how it
17 computes. It has an undershoot model in computing its
18 subcooled break flow. Then the flashing model in
19 TRACE, which is, as Joe Kelly said before, isn't
20 really physically based on anything as far as he could
21 tell, is I guess the nucleation model for both cells
22 as they get superheated. But in the break flow
23 itself, the subcooled break flow model, does model
24 that undershoot that you're talking about. I think
25 it's a Lienhard-Jones or something like that.

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1 MR. BANERJEE: So, that's the model which
2 is used?

3 MR. KROTIUK: Yes.

4 MR. FORD: Could you say something about
5 the scaling on this? I notice you say semiscale here,
6 and yet it's nothing like the scale of a steam
7 generator.

8 MR. KROTIUK: No, I know, but this is the
9 LOFT -- it's called the LOFT semiscale facility, and
10 this was a --

11 MR. RANSOM: Okay, well, it's just a tank.

12 MR. KROTIUK: It's just a tank.

13 MR. FORD: Okay, well --

14 MR. KROTIUK: It's not scaled --

15 MR. FORD: What uncertainties do I have in
16 going from this test, which you've very successfully
17 predicted, to a much larger problem? I'm not a
18 thermal hydraulicist, so lead me through the thought
19 process.

20 MR. KROTIUK: Well, my thought process on
21 this was that I wanted to look at some applications
22 that are more acoustically dominated and then look at
23 some test data that had longer time frames so that I
24 could see the effects longer out in time after the
25 acoustical portion.

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1 When you're talking about pool swell
2 phenomena with the liquid on the bottom of the steam
3 generator vaporizing. So, it was done in two stages,
4 you know, looking at two different facts separately.

5 MR. FORD: Okay.

6 MR. KROTIUK: Okay. This was some testing
7 using the GE vessel blowdown tests. Initially, this
8 one had tanks, and this shows the nodalization that
9 used in TRACE, and this was another tank with the
10 nodalization. This gives you dimensions and pressures
11 and temperatures.

12 What I've chosen to do is to just show
13 -- this was done actually by ISL, this work. I just
14 chose two points here to show the void fraction at
15 different elevations within the vessel for one of the
16 tests, and showing the test data versus the TRACE
17 predictions.

18 MR. BANERJEE: What TRACE?

19 MR. KROTIUK: At the time I did this, it
20 was called TRAC-M, and so the labeling is TRAC right
21 now, but it was just an earlier version of TRACE.

22 MR. SIEBER: Before it was an engine.

23 MR. KROTIUK: Before it was an engine,
24 right.

25 One interesting thing about this one, when

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1 Birol did the analysis, he did this analysis with a
2 level tracking model and without the level tracking
3 model. Basically the level tracking model did produce
4 some better results than without the level tracking
5 model included.

6 Basically the comparisons, though, were
7 pretty decent, with or without the level tracking
8 model for this particular problem. It wasn't a major
9 concern. Then this is just two points that I chose to
10 show.

11 MR. BANERJEE: You're not really
12 interested in the long time scales here. You're
13 looking at the very rapid --

14 MR. KROTIUK: Well, relatively rapid. I
15 mean, you know, --

16 MR. KROTIUK: This goes out to 200
17 seconds, but that's, you know, definitely shorter time
18 scales.

19 MR. RANSOM: Which test are you showing
20 here, the 1004-3?

21 MR. KROTIUK: It's the 1004-3, correct.

22 MR. WALLIS: This is different. The break
23 is in the steam region.

24 MR. KROTIUK: The break is in the steam
25 region, correct. It's more likely steam line break.

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1 MR. WALLIS: And the time scale we're
2 talking about here is very different from the
3 milliseconds we talked about.

4 MR. KROTIUK: Right. We're looking at
5 different things.

6 MR. WALLIS: Right.

7 MR. RANSOM: The most interesting part of
8 this occurs in the early time when the level actually
9 swells up, and even some goes out the break, as a
10 matter of fact. So, there's a void distribution going
11 up the vessel, which you can't see by just looking at
12 two points. Apparently the bottom is -- this is near
13 the bottom, I guess, at about .25. That's the bubbly
14 regime.

15 MR. WALLIS: This is like Sanjoy's
16 chemical plant where you open a vent and the level
17 swell hit the vent.

18 MR. KROTIUK: Right.

19 MR. RANSOM: And a significant amount of
20 water does go out the break during that, and then the
21 later collapses down, and you just get steam flowing
22 out, which this shows steam flowing out beyond 50
23 seconds.

24 MR. KROTIUK: Yes. This test was probably
25 the most, the closest application because it is a

1 steam generator model test. Basically there were two
2 tests that I looked at. Again, this was done by ISL,
3 this particular work. The model was, the RELAP5 model
4 already existed, so it was translated to TRACE, and we
5 looked at these two tests. It's a scaled steam
6 generator.

7 The break is occurring on the top of the
8 steam generator and basically we are looking at the
9 swell effects through the steam generator. The actual
10 geometries are shown a little bit more in detail here.
11 I just wanted to point out a couple of things, is that
12 we do have some support plates in the steam generator
13 at various locations with pressure sensors along the
14 central area.

15 These, among other comparisons that were
16 made, I just chose two points across two and three, so
17 this is a delta P measurement across two to three,
18 with the data in green and the predictions in black.
19 Then we have six to seven here, which is basically
20 across the tubes sort of on the top. Again, the
21 comparisons between test data and the predictions.

22 MR. RANSOM: What is happening on the
23 primary side in this test?

24 MR. KROTIUK: The primary side, since it
25 was a test, it was simply a flow rate. I just think

1 the flow rate was -- let me just make sure if I wrote
2 it down, or I didn't write it down. The flow rate was
3 just maintained at the conditions.

4 MR. RANSOM: Yes.

5 MR. KROTIUK: There was a heated flow
6 coming in here.

7 MR. FORD: Again, calibrate me. I heard
8 early on Graham saying that pressure, changes in
9 pressure was a relatively easy thing to predict, and
10 you're seeing here that the system response is
11 reasonably well done, and yet I look at those two
12 curves, and they're fairly far apart in certain parts.
13 Am I misreading Graham's promise to me that it's an
14 easy thing to do?

15 MR. KROTIUK: Well, remember one thing on
16 this, is that we are not -- I didn't plot up absolute
17 pressures here. I'm plotting up pressure
18 differentials now, and that's a little bit different
19 than saying matching pressures.

20 MR. RANSOM: I'm wondering what causes
21 that pressure differential and the change. I mean, in
22 the real situation, I guess flow across a tube bank,
23 and I don't know that much of that is in the codes,
24 though.

25 MR. SIEBER: No.

1 MR. RANSOM: You know, in terms of the
2 obstruction or the drag, and especially to come down
3 and go back up. I'm not sure what --

4 MR. KROTIUK: Well, there's a certain
5 amount, and I'll elaborate on this a little bit more,
6 but I actually did a hand calculation following an
7 acoustic wave, starting at the steam generator and
8 coming back down. The time frame that you're looking
9 at is actually, the time frame for the travel of
10 acoustic wave length, it does match up.

11 MR. RANSOM: What, going down the
12 downcomer?

13 MR. KROTIUK: In other words, like say I
14 would have a just for argument's sake, let's just go
15 through this one here. Say a break at this location,
16 you get a depressurization wave that would occur at
17 the break and then travel down the steam generator.

18 MR. RANSOM: How tall is that?

19 MR. KROTIUK: What were the dimensions on
20 this? I don't remember that.

21 MR. RANSOM: Twenty meters maybe.

22 MR. KRESS: Seven meters.

23 MR. RANSOM: Seven meters.

24 MR. BANERJEE: Presumably initiates at
25 time zero, right?

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1 MR. KROTIUK: Well, that tested an
2 initiate times zero. They sanctioned this --

3 MR. BANERJEE: What is the initiate?

4 MR. KROTIUK: Sixty.

5 MR. BANERJEE: Right, okay.

6 MR. KROTIUK: Sixty.

7 MR. BANERJEE: That's times zero?

8 MR. KROTIUK: That's the time zero, right.

9 MR. RANSOM: When do you break it?

10 MR. KROTIUK: That's when the break
11 occurs.

12 MR. CARUSO: How do you model the acoustic
13 wave propagation through the steam separator and to
14 the dryer?

15 MR. SIEBER: You probably don't.

16 MR. KROTIUK: It's the way that you're
17 using say a controlled volume approach, is that it's
18 basically resistances, and if you notice on the test,
19 for instance, on the semiscale test, the damping, in
20 other words, the damping of the pressure wave is
21 actually over damped, and the test data is -- and the
22 predictions when compared to the test data. So, there
23 is a way that the code is using the shear basically,
24 the friction within the solution of the conservation
25 equations that is coming up with drops in pressure.

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1 MR. BANERJEE: But the acoustic wave is
2 traveling at the speed of sound.

3 MR. KROTIUK: The speed of sound, or
4 either steam, or if it's two-phased, it would, you
5 know --

6 MR. BANERJEE: Let's talk about the steam
7 rate now.

8 MR. SIEBER: Right.

9 MR. BANERJEE: In the steam line, and as
10 it's traveling, the fluid is also accelerating, right?

11 MR. KROTIUK: Yes.

12 MR. BANERJEE: So U minus A , which is the
13 speed of propagation against the flow.

14 MR. KROTIUK: Okay.

15 MR. BANERJEE: The flow reaches the sound
16 speed, it chokes.

17 MR. KROTIUK: And that's when you get the
18 pressure wave traveling back.

19 MR. BANERJEE: Traveling back.

20 MR. KROTIUK: Right.

21 MR. BANERJEE: So, how do you calculate
22 this by hand because in a way, the whole flow is
23 accelerating, right, so there's inertia that you have
24 to take into account against that.

25 MR. KROTIUK: Could I answer that in about

1 four slides?

2 MR. BANERJEE: Oh, okay.

3 MR. KROTIUK: In about four slides, I
4 actually have that.

5 MR. RANSOM: One thing that I think is
6 important here is if you like, let's say this is seven
7 meters long and, you know, even on small speed, would
8 be 100 meters per second.

9 MR. BANERJEE: 300 Meters per second.

10 MR. RANSOM: So, anyway, that's only
11 700ths of a second, the wave reaches the bottom. Most
12 of what you're seeing is a two-phased response, you
13 know, and probably due to things other than just
14 acoustic propagation.

15 MR. KROTIUK: For this problem, yes. For
16 the other problems, for the semiscale, that's
17 different.

18 MR. RANSOM: Yes, that's different, but
19 for this one, you know, you've got 100 second time
20 scale there.

21 MR. KROTIUK: Absolutely.

22 MR. RANSOM: The transient is over, and
23 most of the acoustic part is over in the first second.

24 MR. KROTIUK: Right, but again, like I
25 said, I was looking at two different phenomena. I was

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1 looking at the acoustic part and I was looking at the
2 pool slope part.

3 MR. RANSOM: Right. I think most of your
4 changes in pressure are due flow that's induced within
5 the tube bundle.

6 MR. FORD: So, I'm being a bit thick here.
7 I'm trying to understand what this data is telling me.
8 On the secondary side of this model generator, you've
9 got a pressure of 1,101 psi absolute.

10 MR. KROTIUK: Yes.

11 MR. FORD: And those graphs you're showing
12 there are telling me that the pressure changes by one
13 psi?

14 MR. KROTIUK: Across the tube support
15 plates, yes. Well, let me backtrack on that just a
16 little bit. These are measurements of absolute static
17 pressure. So, in actuality, the force on a tube
18 support plate is not the static pressure difference,
19 but you have to look at the pressures that are due to
20 the flow phenomena through the plate itself.

21 So, this is just comparing, looking at the
22 static delta P, when are you actually calculating the
23 supports on the tube support plates, you have to do --
24 you have to use the information that is calculated by
25 the code with the velocities, the static pressures and

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1 all, and calculate the actual force on the tube
2 support plate.

3 MR. RANSOM: So the void fraction probably
4 enters into it.

5 MR. KROTIUK: The void fraction does enter
6 into it.

7 MR. FORD: The pressure is what you
8 measure.

9 MR. KROTIUK: The pressure is what I'm
10 measuring, yes.

11 MR. WALLIS: Regardless of the cause.

12 MR. KROTIUK: Right, but for instance,
13 I'll show you for this particular --

14 MR. WALLIS: Not much of a pressure.

15 MR. FORD: Why does it go to zero at the
16 end?

17 MR. KROTIUK: It's --

18 MR. SIEBER: The amount of water.

19 MR. WALLIS: The amount of water? So,
20 everything becomes the same pressure?

21 MR. SIEBER: Basically your flow is coming
22 down low enough that you're depleting your mass.

23 MR. CARUSO: What's the maximum delta P
24 across all of those tube sheets?

25 MR. KROTIUK: Okay, well that's -- I'll

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1 show you. Well, no, there isn't.

2 MR. BANERJEE: Well, it seems to be .7 or
3 something like that.

4 MR. FORD: Point 7 or one.

5 MR. KROTIUK: Hold on, let me make sure I
6 put up the right one. Okay, here. For this one right
7 here, which is 2-3, so that's the bottom part here.
8 If I do the calculation to convert the void fraction
9 velocities, densities, everything to an actual force
10 on the tube support plate, okay, just come up here.
11 It actually looks like this.

12 MR. WALLIS: Pretty small pressure
13 differences.

14 MR. KROTIUK: Yes, they're pretty --

15 MR. SIEBER: Well, it's lower in the
16 generator. If you were right on the tube sheet, the
17 velocity would always be zero.

18 MR. KROTIUK: Correct.

19 MR. SIEBER: The higher you go in the
20 steam generator, the higher the velocities get, and
21 the higher the DP's get.

22 MR. KROTIUK: So, that plate is actually
23 outlined there, when you back calculate that.

24 MR. FORD: So is the conclusion that we
25 are coming to right now, is that there's not much of

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1 a pressure across, a bending pressure across that
2 plate?

3 MR. KROTIUK: That's for this particular
4 plate, right. Now I will try to look at an actual
5 steam generator design with conditions.

6 MR. SIEBER: That bottom plate --

7 MR. WALLIS: Well, this pressure drop
8 looks as though it's the pressure drop between PO-2
9 and PO-3, which are pressure taps, which are actually
10 -- what are these units, in centimeters and inches?
11 They're actually two feet apart or something, which is
12 one size. Is this hydrostatic head?

13 MR. KROTIUK: The hydrostatic head does
14 enter into it, yes.

15 MR. WALLIS: That's what it looks like.
16 It just looks like hydrostatic head. It's all that's
17 happening. So, it's a very mild --

18 MR. KROTIUK: But this is not hydrostatic
19 head here. This is the actual force across the plate,
20 because this is a calculation, and I'm sorry. I could
21 give you a copy of this. I just didn't include it in
22 the presentation, but this is the actual calculation
23 of that force on that plate itself.

24 MR. SIEBER: One would expect the bottom
25 tube support plate for the shock wave to be a higher

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1 force than the flow.

2 MR. WALLIS: This is nothing to do with
3 shock waves. This is way, way down.

4 MR. KROTIUK: This is long because this is
5 out from the 30-second time frame.

6 MR. SIEBER: The flow is from the break.
7 The shock wave there probably would dominate, whereas
8 at the top, it would be reversed.

9 MR. KROTIUK: No, there's a shock wave
10 effect on the -- if you wanted to talk about the
11 pressurization rate.

12 MR. SIEBER: I'm talking about relative
13 forces.

14 MR. KROTIUK: And actually, I kind of
15 disagree with that. I think you're going to have,
16 from what I've seen, you actually have a bigger force
17 on the top than you do on the bottom, and you might
18 actually get a force reverse on the bottom, possibly.

19 MR. SIEBER: Okay. I think that's what I
20 said.

21 MR. KROTIUK: Oh, okay. Is that what you
22 were saying?

23 MR. FORD: Now, I assume that these
24 differential pressures across the tubing will depend
25 on the design of the holes, et cetera?

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1 MR. KROTIUK: It depends upon the design
2 of the tube support plates. That's a criteria, yes.
3 That is a --

4 MR. FORD: Is it by much? I mean, it's
5 not much of an argument to change, but does it change
6 it much? If you had a quatrefoil type hole.

7 MR. SIEBER: It makes a big difference.

8 MR. FORD: A big difference, I would
9 imagine.

10 MR. KROTIUK: I didn't look at other
11 drawings.

12 MR. SIEBER: The drilled support plates
13 don't have much of a flow area. There are some extra
14 holes in there where they aren't there.

15 MR. KROTIUK: Specifically for -- yes.

16 MR. SIEBER: But the flow area is pretty
17 small. The quatrefoil, you open it up by you probably
18 increase the flow area, available flow area by a
19 factor of ten.

20 MR. WALLIS: There must be some flow
21 through these plates.

22 MR. KROTIUK: Yes, there are flow through
23 the plates, yes. There are actually holes that are
24 drilled through the plates.

25 MR. SIEBER: Yes, they're there to avoid

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1 the normal differential pressure you would get during
2 the operation.

3 MR. KROTIUK: That's correct.

4 MR. SIEBER: But the flow through the
5 holes where the tubes are is generally either non-
6 existent or very low. It's not high enough to
7 typically clean the product.

8 MR. WALLIS: It flows through somewhere
9 else then. There must be other holes.

10 MR. SIEBER: Well, you can go around the
11 outside. They can go through the drill holes.

12 MR. KROTIUK: Through the flow holes.
13 There are flow holes in the plates.

14 MR. WALLIS: Isn't this pressure
15 differential simply the pressure drop through the flow
16 holes?

17 MR. KROTIUK: Correct.

18 MR. WALLIS: That's all it is.

19 MR. KROTIUK: That's correct. That's it.

20 MR. SIEBER: That's right.

21 MR. KROTIUK: But it's not the static
22 pressure. That's what I was just trying to -- it's a
23 pressure drop through the flow holes, which includes
24 any gravitational effect, any frictional effect, and
25 the acceleration effects.

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1 MR. WALLIS: Right, but it seems such a
2 small value. Is it a problem?

3 MR. FORD: That's why I'm asking the
4 question. And you're going to get to the real answer
5 any minute.

6 MR. KROTIUK: Okay.

7 MR. SIEBER: Part of the design is so that
8 you can accommodate this boiler, you know, because
9 that's what it does during normal operation, and the
10 outsides of them are not closed in.

11 MR. FORD: I think the original concern
12 was if you have a means to, you might break the whole
13 tube sheet. It's going to buckle from -- just because
14 there's always that chance.

15 MR. SIEBER: That's different. The
16 differential pressure on the tube sheet is 10,000
17 pounds, and when you remove the secondary pressure,
18 you have --

19 MR. FORD: Across the tube itself.

20 MR. SIEBER: No, the tube sheet. If you
21 look at the channel head in this sketch here, it's
22 2000 pounds in the channel head, and once you have a
23 steam line rupture, the secondary side goes to zero.

24 MR. KROTIUK: Yes.

25 MR. SIEBER: So that will push the tube

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1 sheet up.

2 MR. WALLIS: You're talking about a
3 different tube sheet, aren't you? Talking about the
4 bottom of the whole thing?

5 MR. SIEBER: Yes.

6 MR. KROTIUK: Yes.

7 MR. WALLIS: But he's talking about the
8 separators.

9 MR. SIEBER: No, he said the word tube
10 sheet.

11 MR. RANSOM: He means tube support plates.

12 MR. KROTIUK: What I'm looking at is the
13 tube support plates, but you're right regarding the
14 tube sheets.

15 MR. SIEBER: Peter said tube sheets.

16 MR. KROTIUK: Tube sheets is different.

17 MR. SIEBER: Tube support plates are
18 different.

19 MR. FORD: Tube sheet is a massive thing.

20 MR. SIEBER: But it bends.

21 MR. FORD: Yes.

22 MR. SIEBER: It's not designed to take the
23 full RCS pressure.

24 MR. WALLIS: Okay, but in the steam line
25 break, it does, doesn't it?

1 MR. SIEBER: It does, and it will distort
2 but not fail.

3 MR. BANERJEE: And the tubes will not
4 rupture, either.

5 MR. SIEBER: That's correct, because
6 there's, you know, it's a factor of three margin on
7 the tube.

8 MR. BANERJEE: Even if they are slightly
9 deteriorated.

10 MR. SIEBER: When they had the steam line
11 break at Turkey Point, the tube sheet was bent. I
12 mean, it was bowed up, and bowed up enough to break
13 the weld on the divider.

14 MR. WALLIS: I don't know what GSI 188 is,
15 so I don't know what question is being asked. That's
16 probably one of my problems.

17 MR. KROTIUK: Well, I think, as I said,
18 the important aspect that I'm looking at is simply the
19 development of the time dependent loadings on the tube
20 support plates within the steam generator.

21 MR. WALLIS: Okay.

22 MR. KROTIUK: Okay, to take this
23 comparison a little bit further, I took an analysis
24 that was done on a Westinghouse Model 51 steam
25 generated that Westinghouse had done using TRANFLO and

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1 RELAP5. I'm basically going to repeat that analysis
2 with TRACE, and looking at conditions of hot standby,
3 100 percent power, and then two steam line break sizes
4 and one feedwater line break size.

5 This represents a full guillotine break
6 and a full guillotine, and this is deep flow
7 restricted break.

8 I have looked at some generated forces,
9 not only against the tube support plates, but of
10 course primary tube where they bend and also of
11 course, the cylinder around the -- in the steam
12 generator itself. I'll only present tube support
13 plate values.

14 MR. SIEBER: Right.

15 MR. KROTIUK: This is the actual steam
16 generator, and we have tube support plates. Let's
17 see, one, two, three, four, five, six, and then seven.

18 MR. SIEBER: There are supposed to be
19 seven. That's a Model 51.

20 MR. KROTIUK: That's a Model 51.

21 MR. SIEBER: Okay.

22 MR. KROTIUK: And this shows the
23 nodalization of the secondary site itself, and this is
24 showing the nodalization on the primary side with the
25 heat transfer nodes, representing the tubing itself.

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1 MR. SIEBER: Right.

2 MR. RANSOM: Jack, are those baffle
3 plates? Do they extend all the way across the two
4 banks, or do they cause cross-flow?

5 MR. SIEBER: No, they go all the way
6 across, but not to the wrapper. In the outside of the
7 wrapper is the downcomer. So, there is flow space
8 between the inside of the wrapper and the outside of
9 the tube support plates. Plus, there's also holes
10 drilled in there, their slots.

11 MR. SIEBER: In fact, from what I
12 understand, they just really fit. In terms of support
13 plates themselves, they only fit on little ledges, and
14 maybe tack welded or something of that nature.

15 MR. SIEBER: Okay, it's not a strong --

16 MR. RANSOM: They're not baffles. They
17 cause cross flow.

18 MR. WALLIS: They're to vent flow induced
19 oscillations? Is that what that --

20 MR. SIEBER: Pardon?

21 MR. WALLIS: Did they have to prevent flow
22 induced oscillations at the tubes?

23 MR. SIEBER: Yes.

24 MR. KROTIUK: Okay, let me show you a
25 comparison. What Westinghouse had found in their

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1 analysis is that the full double ended -- I'm sorry,
2 the guillotine steam line break produced the largest
3 forces, and this day, the conclusion was based on also
4 the TRANFLO or the RELAP5 analysis.

5 What I'm presenting here is a comparison
6 of what Westinghouse presented using TRANFLO
7 calculated using RELAP5 and then the TRACE
8 calculations. This is for the guillotine steam line
9 break, and then on the bottom here, I also presented
10 it for the limited flow steam line break. These are
11 comparative. This one is a slightly different
12 scenario.

13 MR. WALLIS: Are these loadings at some
14 particular time in the transient?

15 MR. KROTIUK: These are the peak loadings
16 on the tube support plates. Now, what you could see
17 here is that that top plate can get a fairly
18 significant loading on it.

19 MR. SIEBER: Yes.

20 MR. KROTIUK: And this is, again, the
21 worst case, and you're talking about 9 psi across that
22 plate.

23 MR. RANSOM: What does Westinghouse
24 believe? I mean, TRANFLO is quite a bit lower.

25 MR. KROTIUK: Yes, I can't trust what

1 TRANFLO is doing.

2 MR. RANSOM: That's the Westinghouse code?

3 MR. KROTIUK: That is a Westinghouse code.

4 MR. FORD: Now, when you say you don't
5 trust it, what was your basis --

6 MR. KROTIUK: I don't know much about it.
7 The results are so different from either RELAP5 or
8 TRACE.

9 MR. RANSOM: Westinghouse believes.

10 MR. KROTIUK: Well, in the report that I
11 have from Westinghouse, they had originally reported
12 the TRANFLO results, and then subsequently did the
13 RELAP5 analysis because it is implied -- it didn't say
14 directly, but it was implied that they themselves were
15 questioning what was coming out of the code, out of
16 TRANFLO.

17 Subsequently, they instructed their, you
18 know, their plants to anyone who was doing an
19 analysis, and I have a copy of all of the reports.
20 All of the subsequent reports were done using RELAP5,
21 subsequent analyses.

22 MR. RANSOM: Well, the agreement between
23 TRACE and RELAP5 would kind of indicate that something
24 may be wrong with the other one.

25 MR. BANERJEE: Well, you don't know,

1 because TRACE and RELAP5 are similar.

2 MR. SIEBER: They're actually the same,
3 are they not?

4 MR. STAUDENMEIER: The thing about
5 TRANFLO, this is Joe Staudenmeier. I was in NRR when
6 they first submitted a calculation like this with
7 TRANFLO, and it had no code assessment at all, and
8 they refused to assess it, so we refused to approve it
9 for the application.

10 MR. SIEBER: There you go. Is that what
11 gave rise to the flow restrictors in the outlets, this
12 calculation, or was that before that?

13 MR. STAUDENMEIER: I don't know what gave
14 rise to the flow restrictors, but it wasn't this
15 calculation that gave rise to them, I don't think.

16 MR. SIEBER: All right.

17 MR. FORD: But the reason, quite apart
18 from pride, we're saying that TRACE and RELAP, which
19 are the same, is the correct answer rather than
20 TRANFLO, is because of the agreement you see in this
21 model test, this one here?

22 MR. KROTIUK: Yes.

23 MR. FORD: But you haven't seen or done
24 equivalent analyses of this test for TRANFLO, because
25 you don't have access?

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1 MR. KROTIUK: Don't have access to the
2 code, no.

3 MR. WALLIS: TRACE and RELAP are supposed
4 to be equivalent, and some of these numbers are quite
5 different. 3.2 psi isn't 1.16 psi, and 2 psi isn't
6 1.15 psi. I'm not quite sure what to conclude from
7 this.

8 MR. STAUDENMEIER: The one thing that
9 hasn't been discussed is these are real sensitive.
10 When the steam generator starts flashing, it has to
11 decide where the stagnation point is, and then from
12 that point, flow will go up and then flow will go
13 down. So, part of the bundle flow will be going up.
14 The other part flow will be going down, and up the
15 downcomer.

16 MR. WALLIS: That's negative pressure.

17 MR. STAUDENMEIER: That's right.

18 MR. KROTIUK: That's right.

19 MR. STAUDENMEIER: In that the answers,
20 the peak load is real sensitive to where that point is
21 where the flow splits. If you want to do a true
22 boundary calculation, you could block off the
23 downcomer, make all the flow go up through the tube
24 sheet, and that would give you a peak load.

25 MR. KROTIUK: I'll address that. I have

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1 a slide that actually talks about that.

2 MR. SIEBER: That's why you get negative
3 numbers in these lower nodes.

4 MR. KROTIUK: And I'll address that in a
5 little bit more.

6 Just to sort of complete the picture here
7 in terms of the TRACE calculations, this table simply
8 just presents the range of breaks that were looked at,
9 the steam line breaks and the feedwater line breaks at
10 the hot standby and in 100 percent power conditions.
11 So, the conclusion that was originally given, that
12 this was the most severe case, was borne out by what
13 TRACE said.

14 MR. SIEBER: That's a double ended break
15 there.

16 MR. KROTIUK: Double ended steam line
17 break, right, at hot steam line.

18 MR. WALLIS: Which is what you might
19 expect, that the biggest hole gives the biggest load?

20 MR. KROTIUK: Yes.

21 MR. SIEBER: No, well, you would expect
22 these results from that kind of a break, but you would
23 not expect that kind of a break as the primary
24 initiating event. More likely have a break in a
25 bolted joint like a water safety valve was bolted on

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1 or something like that, as opposed to the pipe itself.

2 MR. KROTIUK: For that most severe break,
3 and what I previously listed on the tables were these
4 maximum values. To show you what the actual
5 transients looked like, and this is the time frame of
6 two seconds. You can see the highest loading was on
7 the top tube support plate, and you can see the slight
8 negative loading on the lowest tube support plate.

9 MR. WALLIS: Are these support plates just
10 rest on some sort of a --

11 MR. KROTIUK: Just a ledge.

12 MR. WALLIS: They may bounce on the ledge?

13 MR. SIEBER: No, there is threaded stay
14 rods that separate them. So, they're, you know, they
15 don't all fall through the bottom.

16 MR. WALLIS: They might pop the stay rods?

17 MR. SIEBER: Pardon?

18 MR. WALLIS: If this load is big enough,
19 you might break the stay rods? Is that it?

20 MR. KROTIUK: Well, that's --

21 MR. SIEBER: I would doubt it. I think
22 it's designed to be sturdy enough so that that doesn't
23 happen under steam line break. The more likely thing
24 would be that the tube support plate would act as a
25 membrane and get into some oscillatory node where it

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1 pinches the tube and pulls the tube.

2 MR. KROTIUK: That's a primary concern,
3 but again, that's what the stress analysts would be
4 looking at because they would be looking at the
5 movement of the plate.

6 MR. SIEBER: Right.

7 MR. KROTIUK: Now, as a further check on
8 this, what I did, there was a conservative bounding
9 calculation, and this is now we're going to be talking
10 about the transmission and reflection of acoustic
11 waves.

12 To show that this phenomena really was an
13 acoustic wave phenomena, what I did is that I used
14 Moody's approach for just calculating blowdown from a
15 basically a tank of liquid, and from that approach,
16 you could calculate a value for the depressurization
17 wave upstream of a break, and then doing -- this is a
18 tedious, hand calculation where I'm actually looking
19 at relative flow areas between the pipe into the steam
20 generator into flow restrictions in the steam
21 generator and so on, to follow how the
22 depressurization wave would be transmitted or
23 reflected on these various objects.

24 Then coming finally to the tube support
25 plate, knowing the value of that pressure at the top

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1 of the tube support plate, and assuming at an instant
2 of time that the pressure underneath has not changed,
3 and then coming up with a result in delta P across
4 that tube support plate, and then following it down to
5 the seven-tube support plates.

6 The one caveat of this is that I didn't
7 follow what you were talking about, the transmission
8 of a wave back down the annular area. Now, I did that
9 for only one point because that started getting really
10 very tedious to follow by hand.

11 MR. SIEBER: Yes. That's probably a
12 secondary effect anyway, is it not?

13 MR. KROTIUK: Well, I'll show you. For
14 that one value, I'll show you the comparison.

15 MR. SIEBER: All right.

16 MR. KROTIUK: Now, this is the comparison
17 of the Moody calculations, initial conditions, and
18 then for the guillotine steam line break and for the
19 restricted area steam line break, and I just put here
20 the TRACE calculated results at standby 100 percent
21 power conditions, and just the various comparisons.
22 For instance, the maximum break flow rates, and the
23 discharge pressure, which is really the initial
24 depressurization pressure.

25 Then for the limited break, which has a

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1 now FL over D factor in it in terms of the Moody
2 methodology, and then comparison of the flow rates and
3 the pressures at discharge.

4 Now then using this data, I did a hand
5 calculation for the forces on the tube support plates,
6 and for the two cases that I looked at, the guillotine
7 steam line break and the limited area steam line
8 break, these were the comparisons, and you could see,
9 I just again listed for the hot standby and 100
10 percent power condition, the comparison of the
11 calculated pressures across the tube support plates.

12 Basically at least they are somewhat in
13 agreement. Now, one of the things that I was
14 concerned about is again this bottom plate and the
15 fact that I didn't calculate for the depressurization
16 coming down the annulus area. So, I did that
17 calculation to adjust for that, for the annular
18 feedwater area, and came up with this reduction in
19 pressure using the Moody approach. So, it comes out
20 from 3 psi to 1.6 psi across that bottom plate, just -
21 -

22 MR. SIEBER: This is pushing.

23 MR. KROTIUK: No, this is pushing up
24 because it comes -- this is a --

25 MR. SIEBER: The other one is a vacuum.

1 so, it's pulling.

2 MR. KROTIUK: This is actually pushing up
3 right here. This one is actually pushing down.

4 MR. SIEBER: Right.

5 MR. WALLIS: This is acoustic wave in pure
6 water?

7 MR. KROTIUK: This is --

8 MR. WALLIS: It goes through in the
9 attenuators. It goes through the holes and --

10 MR. KROTIUK: It's through steam and
11 water.

12 MR. WALLIS: Steam and water?

13 MR. KROTIUK: Right, because the top of
14 the steam generator will have steam in it.

15 MR. WALLIS: Okay, so this is basically
16 propagation through with the two-phase mixture which
17 is there when the break occurs?

18 MR. KROTIUK: Correct, and again, I came
19 up with an appropriate sound speed to use for that.

20 MR. WALLIS: Okay.

21 MR. KROTIUK: That application. Just to
22 indicate again, this is the again, just showing the
23 comparison for that hot standby condition with the
24 full break, the comparisons between TRANFLO, RELAP,
25 TRACE, and the Moody acoustic calculations.

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1 MR. SIEBER: Now, the Moody and whatever
2 other one you pick are additive, right?

3 MR. KROTIUK: What do you mean?

4 MR. SIEBER: You would add the two
5 together? You have one due to flow and one due to
6 shock.

7 MR. KROTIUK: No, this is the --

8 MR. SIEBER: That's the differential, or
9 is it --

10 MR. KROTIUK: This is the differential
11 pressure across tube support plates.

12 MR. SIEBER: It's the absolute value
13 including both effects?

14 MR. WALLIS: This is shock. This one's
15 due to shock.

16 MR. KROTIUK: This is the absolute value.
17 This is due to the --

18 MR. WALLIS: This is the shock one.

19 MR. KROTIUK: This is the one due to the
20 travel of the acoustic wave.

21 MR. WALLIS: The shock, right.

22 MR. KROTIUK: Right.

23 MR. SIEBER: Right.

24 MR. WALLIS: And the flow is the different
25 problem altogether.

1 MR. KROTIUK: Yes, but you know --

2 MR. SIEBER: It occurs at a different
3 time, too.

4 MR. KROTIUK: Yes, but there is a
5 relationship, you know, because as the wave is
6 traveling --

7 MR. WALLIS: This is the flow.

8 MR. KROTIUK: Yes, this is the flow,
9 right. So, you could calculate a force across the
10 tube support plate by, you know, two different
11 methods. One is looking at the pressures at the exact
12 top and bottom of the tube support plate or by
13 calculating the pressure drop.

14 MR. WALLIS: The CV and the delta P and
15 that sort of stuff.

16 MR. KROTIUK: Right.

17 MR. SIEBER: Okay.

18 MR. KROTIUK: And this was for that
19 smaller break size, the steam line break size again,
20 comparing again, calculations with TRACE, RELAP and
21 TRANFLO.

22 MR. SIEBER: Now that's about the size of
23 a safety valve flange, right, that 1.4? The big one,
24 an agents valve?

25 MR. KROTIUK: Yes, I don't remember

1 specifically.

2 MR. WALLIS: Now, all these wave
3 propagation methods assume that the metal surfaces are
4 not compliant? Then you load the support plate with
5 these loads and see what they do. In reality, the
6 support may be compliant, and that helps to attenuate
7 the weight.

8 MR. KROTIUK: There will be --

9 MR. WALLIS: This is in the model.

10 MR. KROTIUK: There will be some effects
11 of that, and I have read reports about codes that do
12 the fluids, acoustic and the structure. In other
13 words, it does it simultaneously.

14 MR. WALLIS: It doesn't gain you much,
15 does it?

16 MR. KROTIUK: It depends upon the problem.
17 I've seen --

18 MR. WALLIS: In this case, do you think?

19 MR. KROTIUK: No, in this case, no, but
20 there are problems that have seen that effect being
21 important.

22 So, this is the last viewgraph that I
23 have, and basically I'm just trying to, again, show
24 what I was trying to do, is generate the forces on the
25 internal forces in the steam generator due to steam

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1 line break or feedwater line break. Use TRACE to do
2 the calculations. Seem to predict results that were
3 consistent with both the RELAP5 calculations and with
4 the conservative hand calculations.

5 It does appear that the largest forces on
6 the steam generator were due to the acoustic effects,
7 not to the long term full swell effects.

8 MR. FORD: But even so, they're very low
9 for the tube support rates.

10 MR. KROTIUK: Yes, well, you're talking
11 about 9 psi. Do you consider that low?

12 MR. WALLIS: It depends how well it's
13 secured.

14 MR. KROTIUK: Yes.

15 MR. SIEBER: It depends on how big the
16 tube support plate is. Nine pounds over a big area is
17 a lot.

18 MR. STAUDENMEIER: Actually, the original
19 problem, too, was that there were these cracks hidden
20 underneath where the tube went through the tube
21 support plate, and it was a calculation of if the tube
22 support plate moved far enough to expose the crack,
23 and then it would open up.

24 MR. SIEBER: This sounds like the work
25 that was done when the DPO and steam generators was --

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1 MR. WALLIS: But if the support plate is
2 going to move enough to do that, then you've got to
3 put it into the analysis, because its compliance is
4 going to affect everything.

5 MR. KROTIUK: Well, it depends how much
6 you calculate.

7 MR. STAUDENMEIER: It's going to move
8 about a quarter inch or something like that.

9 MR. KROTIUK: Yes. You calculate it's
10 going to move. I mean, I happen to know, you know,
11 the stress analysis has been done, and I happen to
12 know that movement was not --

13 MR. WALLIS: Not very much?

14 MR. KROTIUK: Not very much, no.

15 MR. WALLIS: Okay.

16 MR. KROTIUK: In fact, they sort of came
17 up with the conclusion that it wasn't really a
18 problem.

19 MR. WALLIS: So there's nothing in the new
20 calculation that would make us think it is a problem.
21 Was that sufficiently different from the old one?

22 MR. STAUDENMEIER: I guess the other
23 assumption in it is that the tube would stick at its
24 maximum deflection by some crud build-up because the
25 maximum DP isn't right at the steam line break. It's

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1 actually -- that's not too big there, and they would
2 evaluate this break-up in criteria at the maximum DP,
3 which as 2500, which was after the steam generator had
4 totally blown down and they had refilled the system
5 water solid because of some other failure, and it
6 would go up to the primary safety valve limit,
7 essentially, and that was the DP they used, and they
8 used the peak port plate deflection that happened in
9 the first second or so, and assumed that it locked
10 there.

11 MR. FORD: And I assume that some tests
12 would have been done at Argonne or wherever, to see
13 whether the deflection in the plate at the hole,
14 assuming that you had a circumferential vector site
15 crack in that crevice where that didn't just shear off
16 the tube.

17 MR. STAUDENMEIER: I don't know anything
18 about that.

19 MR. KROTIUK: That's not in our area.

20 MR. SIEBER: Not for the DPO. I remember
21 the calculation because they had graphics of the
22 motion of the tube to port plate.

23 MR. CARUSO: I believe that's what we're
24 going to hear about in February.

25 MR. WALLIS: So this GSI has not been

1 resolved?

2 MR. KROTIUK: That's correct. February is
3 planned for a person to present.

4 MR. SIEBER: It was very interesting.
5 Thank you.

6 MR. KROTIUK: But as I said,, the main
7 purpose of this was to show an actual application.

8 MR. SIEBER: Yes, well, I think we had
9 seen it before from the other end where we were
10 looking at the gross effects as opposed to how it was
11 calculated. This fills in a lot of the blanks.

12 MR. KROTIUK: Okay, good.

13 MR. WALLIS: Okay, are we through for
14 today? Thank you very much. This is just for your
15 interest.

16 I don't think we're writing a letter.
17 This is part of our investigation of this code. Our
18 intent was to have a meeting today, and have another
19 meeting and another meeting, and three or four or
20 whatever, and really to make sure that this code is
21 coming along, to see if we could add value in any way
22 to what you're doing.

23 If it were appropriate, to say at this
24 time that things are good or bad, or you need to
25 change direction or anything. We might want to think

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1 of writing on that. I think the intent was so we
2 would not have a full committee and write a letter
3 unless the subcommittee thought it was really
4 necessary.

5 We will make a report to the full
6 committee on what we have seen here.

7 MR. BANERJEE: When is the letter due?

8 MR. WALLIS: I think the immediate concern
9 we have is we have to write a research report where we
10 evaluate the research that's been going on, and this
11 would be input to the research report, which is being
12 written now. That's where there would be an
13 influence.

14 MR. SIEBER: Our comments are due
15 tomorrow. I'm not sure I have the draft.

16 MR. WALLIS: Would my colleagues like to
17 make comments now that would be fed back to the staff,
18 and it would help me, too. I have to make the report
19 to the full committee. Would you like to make some
20 comments now?

21 MR. RANSOM: Well, I'm encouraged. You
22 know, I think that the effort certainly is better off
23 than I thought it would be, I guess. At the same
24 time, it's still a little disturbing that we've spent
25 six years and still, you know, and probably two to

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1 three years more before you can really utilize this
2 thing in a regulatory framework, but that's I think
3 the state it's in, and at this point, there's really
4 no going back. I mean, you have to finish the job.

5 I think there are a few issues that we can
6 certainly take up in future meetings and maybe add
7 value, as you say, in terms of some of the energy
8 partitioning, some of the momentum treatment. I guess
9 those are the major areas that I see right now.

10 I think one thing that the NRC ought to
11 think about is independent assessment of the code.
12 It's unusual to have the developers actually doing the
13 assessment, and I guess there is some independent
14 assessment being done by the ISL contractor, which
15 provides a measure of independence, but you'd like to
16 be able to look at the warts as well as the successes.

17 I know that from a development point of
18 view, just from my own perspective, you always try to
19 show your best, and put your best foot forward.

20 MR. WALLIS: I thought we saw some warts
21 today, didn't we?

22 MR. RANSOM: Pardon?

23 MR. WALLIS: Didn't we see some warts
24 today?

25 MR. RANSOM: Well, I think we saw a few,

1 but it kind of makes you wonder if there really are
2 more serious warts somewhere.

3 MR. SIEBER: We were shown a few.

4 MR. RANSOM: That's all I had.

5 MR. FORD: My concern yesterday was that
6 I didn't have any clear idea of what the definition of
7 success was, the quantity to the expectation of
8 whether the TRAC or the TRACE was any better than the
9 existing codes. Steve put that concern to bed
10 largely.

11 My recommendations on that issue, in terms
12 of the quantification of success, it returns to
13 accuracy, comes from my much aligned colleagues who
14 see materials as scattered all over the earth. I
15 guess they are.

16 The first thing is that I hope sufficient
17 attention is given to the quantity of data against
18 which the code is being assessed. I still find it
19 curious that we allow licensees to get away with just
20 one set of data.

21 The other question is the quality of the
22 data, its relevance to the reactor, and the quality of
23 the system definition. That comes directly out of my
24 materials background because I'm sure it applies here.

25 I think the metric of accuracy should be

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1 the mean and the variance of the ratio of the
2 calculated to observe parameter for the PCT or whether
3 the reflood temperature or whatever. You have to
4 assess if that mean is closer to one and the variance
5 is smaller than those calculated for RELAP or TRAC, P
6 or B, and I think the acceptability of criterion
7 should be somewhat like the sigma methodology, that
8 the variance should be small enough where you don't
9 have any risk for the outlines.

10 MR. KRESS: Well, I thought I saw a lot of
11 progress since the last time we reviewed, and I too am
12 encouraged that they're on the right track. When they
13 get to the point where they've got the architecture
14 right and the SNAP working correctly and the glitches
15 out of the code and the models corrected to where they
16 think we have some good models, then I think you need
17 to start thinking about having a built-in uncertainty
18 capability.

19 I think I would give that high priority to
20 the code. I don't think that's part of the program
21 right now. I'm not sure.

22 Then there needs to be some thought given
23 in my mind to how to use the experimental data to
24 develop this uncertainty. Now, I don't think it's as
25 straightforward as you seem to think it would because

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1 --

2 MR. FORD: Probably not.

3 MR. KRESS: Yes. I think the uncertainty
4 is the measure of the quality, how good it is, but you
5 don't just -- what you've got is a set of separate
6 effects data. You've got a set of some integral data,
7 and these are transients and different figures of
8 merit, and they go through different time frames, and
9 how to convert that into an uncertainty is not clear
10 to me, but I heard some things from Steve on how we
11 might do that with looking at different phenomena and
12 different time frames, and I was encouraged that he's
13 on the right track with how to develop some sort of a
14 measure of uncertainty.

15 With respect to that uncertainty and what
16 it means, is I think we need to give some real serious
17 thought on how we choose node sizes. You know, I have
18 never been enamored with this choosing node sizes for
19 the experiments, and making the full scale node size
20 look like that. I've never been happy with that, and
21 that needs to be given more thought on how we do that.

22 I still think I'll fall back on the old
23 canard that you bury the node size until it doesn't
24 make anymore difference in the answer, but then you
25 can't have a node size that's tuned to the experiment

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1 if you do that. So, I think some more thought needs
2 to be given along those lines.

3 With respect to some of the models, we
4 still are basically in 1D space, and there are places
5 where I'm sure multi-dimensions are important. For
6 example, in the momentum uses at T's and expansions
7 and places, and where I think a CFD calculation has a
8 compliment to the TRACE would be useful, but I'm not
9 sure how it's to be done. I think there's a need to
10 have a CFD code as one of the plug-in modules. I
11 don't know if it's possible or not, but that's
12 something that can be thought about.

13 I don't give much value in having the
14 difference between the TRACE and say the TRAC-P and
15 the TRAC-B, just as long as they're qualitatively
16 similar. I think this qualitative assessment is good
17 enough. What I want to see eventually is to have an
18 acceptable uncertainty with respect to real data, and
19 with respect to that. I don't know what the
20 definition of acceptable uncertainty is.

21 I guess I also don't put much value in
22 comparing the run time to the previous codes. So long
23 as you get a run time that's good enough to use with
24 the computers as we now have, I don't think it has to
25 be faster or better than the run time in the alcoves.

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1 It just has to be run time that's fast enough that you
2 can efficiently use it without wasting all your time.

3 I guess a frivolous comment is, I don't
4 think TRACE is a very good name for this code. I wish
5 you would have come up with a different one, but
6 that's just a personal thing. Somebody is going to
7 think it's for looking at TRACE contaminants or
8 something.

9 Anyway, that's my feelings right now.

10 MR. WALLIS: Thank you.

11 MR. KRESS: I'm encouraged. I think
12 they're on the right track. I like the way they're
13 going, and I think they're doing good work.

14 As far as peer review and the developers
15 maybe not having as good and skeptical, I didn't see
16 that. I thought Joe Kelly was real skeptical, and had
17 the right viewpoint, and I'm not so sure peer review
18 is needed except for appearance sakes.

19 Okay, that's all I have.

20 MR. SIEBER: Okay. I was taken in the
21 beginning by Dr. Wallis's remark that said something
22 like we have reg guides and regulations that describe
23 what you have to do to these codes to assure their
24 quality. What popped in my mind was Reg Guide 1.168,
25 which really applies to process and protection

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1 computers and not analytical tools.

2 On the other hand, the description of what
3 you're doing as far as what I consider to be
4 independent review follows along the lines of what
5 we've been doing for years under Appendix B for
6 calculations and codes of records, and I think that's
7 a good idea. I would encourage re-reading Appendix B
8 and following it because it to me presents the minimum
9 safeguards for code integrity and accuracy.

10 I was also sort of struck by how one
11 determines that the code is functional, and it's
12 typically by comparing test data, but the test data
13 comes from prototypes or facilities that are sort of
14 look-alikes of parts of power plants, and you can
15 perhaps model what goes on in the prototype, but you
16 have two sources of errors that come in. One of them
17 is how good did you build the prototype and how well
18 does it mimic the actual plant.

19 The other one is how well did you
20 analytically model the prototype with the presumption
21 that if you do that, that you adequately model the
22 plant. So, I was looking for opportunities to pick on
23 folks for a failure to do that, but I didn't find
24 that. In fact, Joe Kelly's explanation and zeal for
25 improving the various modules within the code, I felt,

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1 was very encouraging.

2 What was discouraging is that that came
3 from RELAP and TRAC-P or TRAC-B, which has been around
4 since the 1970's. So, these errors -- I wouldn't call
5 them errors, but they're modeling looseness has been
6 in existence and used as codes of record to establish
7 compliance with the regulations for about that length
8 of time, and they still exist that way. It would
9 appear that TRACE will end up being the best code out
10 there if the staff continues to pursue its efforts in
11 this area. To me, I think that's a great thing, and
12 so I would encourage that.

13 As far as criticizing for anything other
14 than the amount of time and resources that are
15 directed to this, it doesn't seem to be a crash
16 project. On the other hand, people are working on it
17 all the time. I would just like to see it move a
18 little bit faster.

19 So, I think overall, I'm very encouraged
20 by what I've heard over the last two days, and plus I
21 also understand a little bit more about how the
22 individual modeling works and what goes into it and
23 what databases lie behind it. So, to me, that was
24 very helpful.

25 That's it.

1 MR. BANERJEE: Well, I look at this from
2 two different viewpoints. One is that the staff are
3 doing work within a certain set of constraints, and
4 those constraints were set about six or seven years
5 ago when this part was embarked on.

6 Now, the wisdom of that choice at that
7 time is not one that I can debate right now because I
8 don't think that's worth talking about. It's done.
9 Having said that, though, what struck me is that I sat
10 in some of these advanced code review group meetings
11 back in the 70's when Novak Zuber and Stan Favik used
12 to organize them. If I look at the field equations
13 and the structure and things today, and many of the
14 correlations, before Joe Kelly got his hands on them,
15 nothing much has changed, actually.

16 So, we are now looking 30 years or 25
17 years down the road, and frankly, I feel pretty
18 disappointed that the state of the art is the same
19 today as it was then. We are making some advances,
20 and notably I like the interface. It's nice. It
21 allows people to use the code more easily I think in
22 the future. We nodalize more easily.

23 I like the fact that now the code will be
24 usable on different computers, including the Linux
25 clusters, which no longer will allow people to make

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1 the excuse that they can't finally nodalize because
2 now they will be able to finally nodalize and make
3 runs in reasonable length of time.

4 So, from that point of view, the excuse
5 that we have to only use 100 nodes or 200 or 300 or
6 whatever the number is, no longer will exist because
7 you'll have enormous computing power readily, and you
8 can nodalize as finely as needed.

9 So, I think that that is an advance, and
10 I like the fact that the architecture of the code is
11 being made in such a way that it will be transparent,
12 that it will be running on borrowed machines on
13 clusters in the future, and therefore, and also
14 written in Fortran 95 now, which will allow some
15 degree of modularity so things can be changed
16 relatively easily.

17 I also like the fact that there is a big
18 effort being made on the side of improving the
19 physical models, removing let's say, as Vic would say,
20 ad hoc character, and Joe Kelly certainly seems to be
21 treating this with a skeptical eye, which is
22 commendable and is to be encouraged at all costs, I
23 think. However long it takes to put these models on
24 a physically sound basis is very important.

25 Now, having said that, though, the rest of

1 the world in other fields are moving on to take
2 advantage of the enormous increases in computing power
3 and simulation capability in many fields, and this is
4 really a field where we are still back in the 1D days,
5 which we were 30 years ago. We are not even thinking
6 in a clear way as to how to put 3D components in into
7 locations where they are absolutely needed.

8 There's no way you can defend a peculiar
9 set of nodes which gives you a right answer which
10 don't sort of follow the equations in any way when you
11 sort of refine the nodes down to what Graham wants,
12 which is mathematical conversions. So, from that
13 point of view, I must say, I'm very disappointed that
14 a greater effort isn't being made in that direction.

15 So, overall, I think it's a commendable
16 effort given the constraints that they have started
17 with, and given the new relatively new capability to
18 parallelize and to improve the physical models. On
19 the other hand, from the basic structure of those
20 constraints, you know, I think we need to start to see
21 how to break out of them and put this in a sounder
22 physical basis where possible.

23 MR. WALLIS: Well, I have said things
24 throughout the presentations, which you can read from
25 the transcript, to respond to some of the points made

1 by my colleagues. I think one of the independent
2 assessments which is very useful is for you to publish
3 this stuff. If Joe publishes his work in the
4 technical literature, then it gets, as it were,
5 endorsed by the technical community, and too much of
6 this stuff is hidden in proprietary methods of vendors
7 and so on, and is not exposed to this sort of review.

8 When the ACRS gets to see it, that's about
9 the only outside group that ever gets to see it. So,
10 if you can publish this stuff, so much the better.

11 In the matter of measures of success, yes,
12 meaning variance and uncertainties, two of my
13 colleagues point that out. You really need to find a
14 way to use the code and the data to evaluate these
15 measures of quality and uncertainty, and that's the
16 way you're going to have to do it in order to use risk
17 informed methods.

18 This ties up I think with -- I think I
19 disagree with Dr. Kress about the need for these codes
20 to run faster. Unless you can get a lot of runs done
21 quickly, you cannot sort of explore the space of, and
22 I meant to say in a Monte Carlo sense, that you like
23 to perhaps do for risk informed regulation.

24 MR. KRESS: Well, I got the impression
25 they were running fast.

1 MR. WALLIS: Oh, I'm not sure that they
2 are.

3 MR. KRESS: But I may be wrong.

4 MR. WALLIS: I'm not sure that they are.
5 Yes, something has to be done, I think, about these
6 sort of basic building blocks which are not really
7 appropriately modeled by 1D approximation or
8 guesswork, which is very often not well explained or
9 justified in the documentation. So, I think you need
10 to do something about these uncertainties in building
11 blocks like the equation for funny looking parts of
12 the system, which are certainly not like straight
13 pipes, and all these equations, as I see here, are
14 straight pipe equations. They can't apply, not just
15 to plan, but even to bend some things like that.
16 There are all sorts of places where the basic building
17 block, particularly momentum equation, has
18 uncertainties in it.

19 There's got to be a way to put fudge
20 factor or something in there and assess their effect
21 on the answer.

22 I like Sanjoy's point that this is useable
23 on different computers, particularly the most modern
24 sets of computers, because we had that problem before.
25 The codes seemed to be restricted to running on old

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1 fashioned platforms.

2 It's too bad the state of the art hasn't
3 advanced over 30 years, and I'm very glad to see Joe
4 Kelly trying to make his advance. He needs to stick
5 with it. I just wonder how much he can do because it
6 isn't trivial. I mean, a lot of people worked on
7 building up the state of the art. To improve it is
8 going to take some doing. So, you have to put your
9 effort where it can really pay off, and stick with it.
10 I just hope that the ACRS can do something to keep the
11 support of management consistent so you can complete
12 this work.

13 So, I'm impressed by the amount of work
14 you still need to do, and I'm also frustrated by the
15 fact that we don't have this code so we can say this
16 is it, and this is a great success story. Now let's
17 go out and use it.

18 I think you need to show some successes in
19 solving topical problems as well as this long term
20 effort. If you could show that TRACE has really been
21 able to do something with this problem that is a
22 concern now or next year or two to the agency,
23 hopefully in a better way than could be done before.
24 Then you win points and then you can keep your effort
25 going and justify it better.

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1 I'm impressed by what I see as a good
2 morale of this group, and what seems to be good
3 support from the management. There have been ups and
4 downs I think over the years in that respect.

5 So, I still hope that the finished product
6 comes out before I leave this committee.

7 MR. SIEBER: Forget it.

8 MR. KRESS: I'm really skeptical about
9 your fudge factor use to evaluate the 3D effects, or
10 the uncertainties to the 1D models. I think that
11 would end up being a real mish-mash of --

12 MR. WALLIS: Well, it might be a mish-
13 mash, but if we did, could say have CFD models or
14 something better for these things, we could see that
15 there is an error of maybe 50 percent in evaluating
16 momentum flux or something. That would give us a
17 fudge factor we could put in there.

18 MR. KRESS: Yes, I would just as soon see
19 that you have a good model being plugged in.

20 MR. WALLIS: Well, that may be too much to
21 do.

22 MR. KRESS: It may be. It may be.

23 MR. WALLIS: Maybe a bridge between the
24 CFD, but you cannot really ignore the fact that these
25 --

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1 MR. KRESS: Then it wouldn't be such a
2 flexion of geometry and flow rate.

3 MR. WALLIS: But you ignore it now. You
4 make some assumption and that's it.

5 MR. KRESS: Yes, I know it would be
6 better.

7 MR. WALLIS: There's no reality check at
8 all at the moment.

9 MR. BANERJEE: Well, the fudge factor is
10 the nodalization right now.

11 MR. WALLIS: Well, the other thing to do
12 is simply to put, as I've suggested, put a factor of
13 two on the momentum flux on all nodes and see if it
14 makes a difference. If it makes no difference, then
15 we don't need to worry about it.

16 Okay, now we're going to see you some
17 more, so I think that when we dig into the details,
18 you may get some more value added at that level. At
19 the moment, I'm pleased with what I see.

20 MR. CARUSO: Could I ask you all to think
21 about what you want to hear next time?

22 MR. WALLIS: We could share it with you.
23 We'll send you an e-mail.

24 MR. CARUSO: That's why I'm just -- there
25 is attached to the status report that I gave to you

1 before this meeting a long term plan. It's got three
2 meetings scheduled. This is the first one, and then
3 it's got suggested topics for the next meeting and the
4 third meeting. I'd like you to look at that and tell
5 me if those are what you want to hear or if you want
6 to add something or move things around.

7 Give me some ideas, and Joe was very good
8 to work with on this, and thank God he put together
9 quite a good presentation today that gave us both an
10 overview of the code and specifics about some of the
11 new things they're doing. If you want to get into the
12 details and spend two days with Joe Kelly standing up
13 there talking about heat transfer, we can arrange
14 that.

15 MR. SIEBER: Put him on video and send it
16 to us.

17 MR. WALLIS: Well, I have noticed that he
18 tends to produce results when he has a deadline.

19 MR. CARUSO: What I'm saying is look at
20 that list, okay, and give me ideas, and we can work it
21 out. We would look, we have a meeting in January to
22 talk about ESBWR. There is a subcommittee meeting
23 scheduled for the 2nd, 3rd, and 4th of February to
24 talk about this GSI-188. I'm going to ask you to come
25 back probably the next week to talk about AP1000.

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1 MR. WALLIS: That's a lot of meetings.

2 MR. CARUSO: I understand that, but the
3 AP1000 effort --

4 MR. BANERJEE: The next week.

5 MR. SIEBER: I think I might get an
6 apartment here.

7 MR. CARUSO: The next week, the second
8 week in February, the 10th and 11th. Put these days
9 down on your calendar and let me know what you think
10 about the 10th and 11th.

11 MR. BANERJEE: And when is the second
12 meeting of this, the 2nd and 3rd?

13 MR. CARUSO: There's a meeting the 2nd,
14 3rd, and 4th. I'm not sure I'm going to ask you to
15 that because that's going to be GSI-188, and that's
16 going to be mostly -- yes, that's mostly going to be
17 Peter on that one. I think it's going to be mostly
18 materials issues.

19 MR. BANERJEE: But when is the second
20 meeting of this TRACE? Will it be together with the
21 AP1000?

22 MR. CARUSO: That's what I'm not sure
23 about. It depends on whether we can do AP1000 in
24 maybe a day or if AP1000 is not settled at that point
25 and we have to go two days.

1 MR. WALLIS: We don't yet know what the
2 staff position is.

3 MR. CARUSO: We don't know yet what that
4 position is, so I can't plan for a second meeting to
5 talk about the code.

6 MR. KRESS: You're talking about AP1000.
7 You're talking about TRACE applications in AP1000?

8 MR. CARUSO: No, no, no. The AP1000
9 issue.

10 MR. KRESS: You're talking about the
11 certification issues?

12 MR. CARUSO: Yes.

13 MR. KRESS: Thermal hydraulic
14 certification issues?

15 MR. CARUSO: Yes, that's correct.

16 MR. WALLIS: I would like to see when we
17 discuss this ESBWR and AP1000, that we have actually
18 TRACE calculations we can look at to help guide us in
19 deciding about the issues.

20 MR. CARUSO: I will mention that to the
21 staff for the ESBWR meeting, and I'll see what they
22 can provide.

23 MR. WALLIS: All right.

24 MR. RANSOM: That's in January?

25 MR. CARUSO: January 14 and 15.

1 MR. WALLIS: That's not something that
2 we'd ask these folks to do. We'd ask NRR to do it.

3 MR. CARUSO: NRR has got the
4 responsibility.

5 MR. WALLIS: So if TRACE is to be
6 valuable, it has to be used by the customer.

7 MR. CARUSO: Yes.

8 MR. WALLIS: To answer current questions.

9 MR. CARUSO: Yes.

10 MR. WALLIS: So let's see if we can make
11 that happen. I'll encourage it.

12 MR. RANSOM: Is NRR presenting on the
13 AP1000 also?

14 MR. CARUSO: In February, yes. They have
15 to come in with Westinghouse and tell us where they
16 have finally ended up, because the last time we met,
17 it wasn't clear.

18 MR. BANERJEE: So those dates are not set
19 and therefore we cannot set the TRACE meeting dates?

20 MR. KRESS: January 14 and 15 was some
21 application to ESBWR.

22 MR. CARUSO: Yes, ESBWR, SCR, that's
23 right.

24 MR. KRESS: SCR. So, that's what's you're
25 talking about.

1 MR. CARUSO: That's in January. Then in
2 February, you have this meeting on this GSI-188.
3 That's a joint meeting with the materials
4 subcommittee. Then I want to hold another meeting the
5 next week, and I've got the 10th and the 11th of
6 February blocked out to talk about the AP1000.

7 That meeting can be very short if
8 Westinghouse and the staff are in alignment. If
9 they're not in alignment, I might not even hold the
10 meeting because I don't want to hear them, that they
11 don't agree.

12 MR. WALLIS: So if they don't agree, we
13 can hear about TRACE then?

14 MR. CARUSO: Maybe we can hear about
15 TRACE, but if not, then we may try to hear about TRACE
16 at that time. We may wait until March.

17 MR. WALLIS: I hope it doesn't take too
18 long for you to prepare for meetings because you know,
19 this is work you are doing. You're right on top of
20 it. So we say we'd like to hear these other things in
21 February. It's not going to be a great struggle for
22 you to get ready for it.

23 MR. KELLY: It depends on like my reflood
24 presentation. That's work I've been doing, so say a
25 couple of days. If you wanted someone to say expound

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1 the equation and that would be all new stuff, that can
2 take a long time.

3 MR. WALLIS: I think just somebody may get
4 up and say it's the same derivation that you find in
5 all the other codes and has the same --

6 MR. KELLY: I mean, if I were to take this
7 question seriously and really try to explore to get
8 you a good answer.

9 MR. WALLIS: I think that would -- might
10 require some research.

11 MR. KELLY: Right.

12 MR. BANERJEE: Well, in one of the topics,
13 it's detailed discussions of the two fluid model for
14 1D and 3D. So, I assume we'll look into the
15 equations, the model, the requirements for closure
16 relationships within the 1D and the 3D context to
17 revisit this. I don't know what is meant there, but
18 I assume that's one of the topics.

19 MR. WALLIS: Okay, so we will work on this
20 calendar, all right?

21 I'm ready to close the meeting. Okay,
22 we'll close the meeting then. Thank you very much,
23 everybody, including our transcriber.

24 (Whereupon, the above-referenced meeting
25 was adjourned at 5:15 p.m.)

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CERTIFICATE

This is to certify that the attached proceedings before the United States Nuclear Regulatory Commission in the matter of:

Name of Proceeding: Advisory Committee on
Reactor Safeguards
Thermal-Hydraulic Phenomena
Subcommittee

Docket Number: n/a

Location: Rockville, MD

were held as herein appears, and that this is the original transcript thereof for the file of the United States Nuclear Regulatory Commission taken by me and, thereafter reduced to typewriting by me or under the direction of the court reporting company, and that the transcript is a true and accurate record of the foregoing proceedings.



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TRACE Assessment Plan and Status



Stephen M. Bajorek
Office of Nuclear Regulatory Research
United States Nuclear Regulatory Commission
Ph.: (301) 415-7574 / smb4@nrc.gov

**Advisory Committee on Reactor Safeguards
Meeting of the Subcommittee on Thermal-Hydraulic Phenomena
November 19-20, 2003**

INTRODUCTION

- Legacy code assessment for TRAC and RELAP is extensive. A large number of simulations have been conducted to validate thermal-hydraulic models in the codes and to demonstrate code capabilities.
- Most recent assessment activities have been designed to show:

TRACE equivalent to TRAC-P / TRAC-B

or

TRACE equivalent to RELAP

Outline

- Summary of Assessment Performed in 2003
 - Code Consolidation
 - Model Development & Assessment
- Results
- Planned Assessment & Approach for 2004+

Experiments Simulated for Code Consolidation (2003)

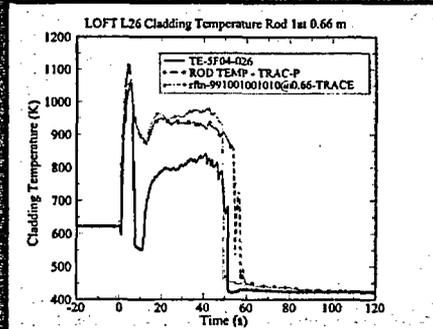
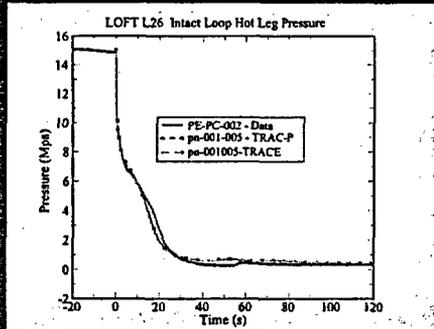
14 Transients simulated – 9 Integral type, 5 Separate Effects type

Category	Type	Experiment	TRACE Input Origin	Comparison
PWR - Large Break	Integral	LOFT L2-5	TRAC-P	TRACE, TRAC-P, Data
PWR - Large Break	Integral	LOFT L2-6	TRAC-P	TRACE, TRAC-P, Data
PWR - Large Break	Integral	LOFT LB-1	TRAC-P	TRACE, TRAC-P, Data
PWR - Small Break	Integral	LOFT L3-1	TRAC-P	TRACE, RELAP5, Data
PWR - Small Break	Integral	LOFT L3-7	TRAC-P	TRACE, RELAP5, Data
BWR - Large Break	Integral	TLTA_6425	TRAC-B	TRACE, TRAC-B, Data
BWR - Small Break	Integral	FIST 6SB2c	TRAC-B	TRACE, TRAC-B, Data
BWR - Small Break	Integral	ROSA III Run 912	TRAC-B	TRACE, TRAC-B, Data
BWR - Intermediate Break	Integral	Browns Ferry	TRAC-B	TRACE, TRAC-B
PWR	Separate Effects	MIT Pressurizer Test ST4	TRACE	TRACE, RELAP5, Data
PWR	Separate Effects	MIT Pwr. Insurge-Outsurge	TRACE	TRACE, RELAP5, Data
BWR	Separate Effects	GOTA Radiation 27	TRAC-B	TRACE, TRAC-B, Data
BWR	Separate Effects	GOTA Reflood 42	TRAC-B	TRACE, TRAC-B, Data
BWR	Separate Effects	SSTF-111 Run EA3.1	TRAC-B	TRACE, TRAC-B, Data

PWR Integral Test Results

LOFT Test L2-6 - 200% Cold Leg Break Test

TRACE, TRAC-P and Experimental Data Comparison



- Hydraulic parameters generally compare very well with data.
- Both Codes yield similar output.

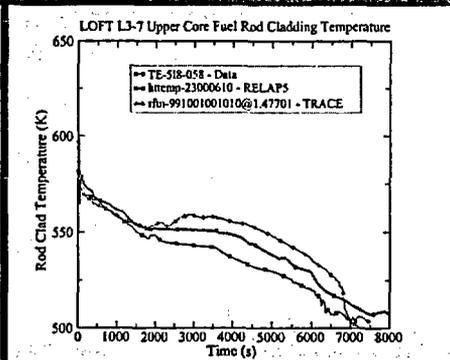
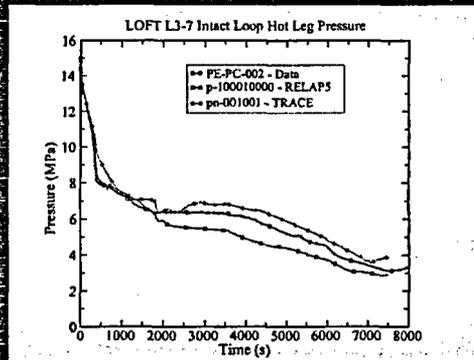
- Test Data exhibits an early core rewet not predicted by either code.
- Both Codes over-predict the sustained rod heat-up.

Code assessment for LOFT Test L2-5 and LB-1 show similar results

PWR Integral Test Results

LOFT Test L3-7 - PWR Scaled 0.0254 m (1 in.) dia. Cold Leg Break Test

TRACE, RELAP5 and Experimental Data Comparison



- Both codes generally showed favorable comparisons between measured and calculated event sequence times.
- The quantitative behavior of thermal-hydraulic parameters calculated by both codes well represented the test data.

- The predictions of all parameters evaluated were considered acceptable with both codes.
- Generally, the TRACE prediction was judged as good as or better than the RELAP5 prediction.

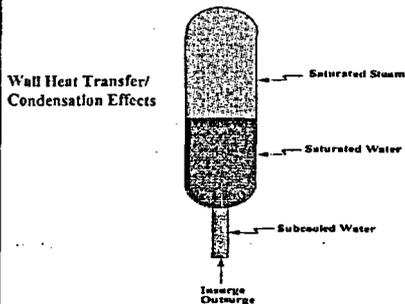
Code assessment for LOFT Test L3-1 show similar results

PWR Separate Effects Test Results

MIT Pressurizer Inflow/Outflow

TRACE, RELAP5, and Data Comparison

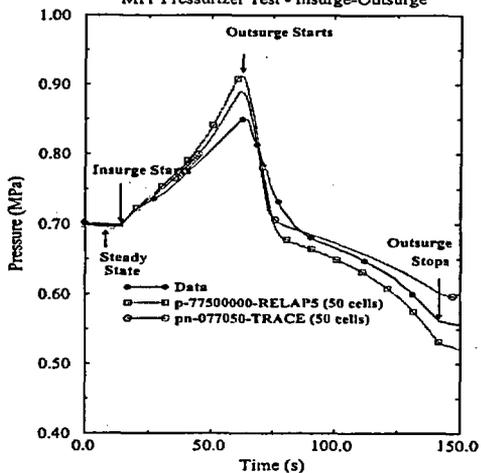
MIT Pressurizer Setup



Both RELAP5 and TRACE predict the MIT Pressurizer data reasonably well.

TRACE did a better job during the falling pressure part of both transients.

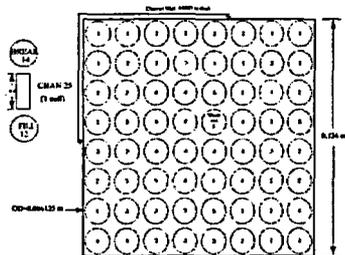
MIT Pressurizer Test - Insurge-Outsurge



BWR Separate Effects Test Results

GOTA Radiation Test 27

TRACE, TRAC-B, and Data Comparison

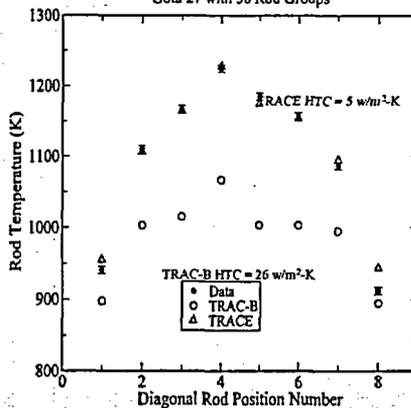


Steady-State Test in steam environment. High rod temperature, low pressure, and high radial temperature gradient across the bundle. Canister wall maintained at 375 K by running water on the outside. No internal spray water.

TRACE predicts GOTA Radiation Test 27 data with excellent accuracy.

Reason for the better prediction with TRACE is a more accurate HTC in natural convection steam cooling.

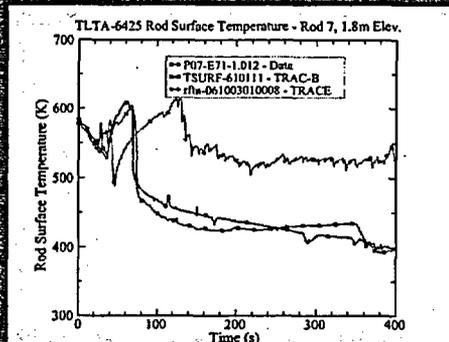
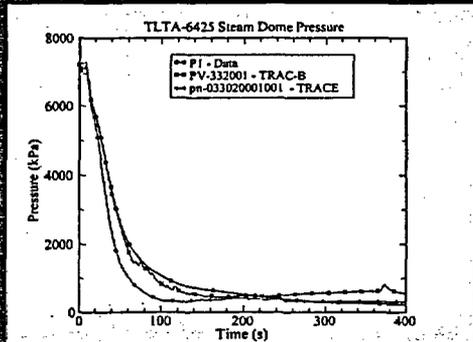
Gota 27 with 36 Rod Groups



BWR Integral Test Results

TLTA 6425 – Recirculation Suction Line Large Break Test

TRACE, TRAC-B, and Data Comparison



- Generally, TRAC-B predictions were judged to be better than TRACE.
- 3-D level tracking was a problem with TRACE and was turned off to run the transient.
- TRACE predicted too much liquid hold-up in the upper plenum affecting bundle reflood. It appears interfacial drag is higher in TRACE.
- There is an error in the TRACE transition boiling model that results in low IITCs. This is expected to go away when the new reflood package is implemented.

TRACE Code Consolidation Summary

Experiment	TRACE compared to	Good or better than	Worse	Comment
LOFT L2-5	TRAC-P		X	TRACE failed at 41 seconds
LOFT L2-6	TRAC-P	X		
LOFT LB-1	TRAC-P	X		
LOFT L3-1	RELAP5	X		
LOFT L3-7	RELAP5	X		
TLTA-6425	TRAC-B		X	Running with 3-D level tracking was a problem.
FIST 6SB2c	TRAC-B	X		TRACE showed robustness weaknesses.
ROSA-III Run 012	TRAC-B	X		TRACE exhibited problems with the downcomer flows at the separator level.
Browns Ferry	TRAC-B		X	There are robustness issues with the 3-D level tracking model turned on.
MIT Pressurizer Test ST-4	RELAP5	X		
MIT Pressurizer Insurge-Outsurge	RELAP5	X		During outsurge TRACE showed a better pressure prediction than RELAP5
GOTA Radiation 27	TRAC-B	X		
GOTA Reflood 42	TRAC-B		X	Energy removal from the rods was too large.
SSTF-111 Run EA3.1	TRAC-B	X		

These assessments were made on TRACE code versions prior to version 4.0. Some improvements to the code have since been made such as an improved level tracking model. The code weaknesses identified are being addressed.

TRACE Code Consolidation Conclusions

- ▣ The 2003 assessment, together with assessments performed in 2002 demonstrate TRACE performance is approximately equivalent to TRAC-P, TRAC-B, and RELAP.
- ▣ Issues identified:
 - Robustness
 - 3D Level Tracking
 - Reflow Model
- ▣ Future assessments to focus on model development & improvement.

TRACE Assessment Plans

Shortcomings of Previous Assessment

1. Assessment has not always made efficient use of available input decks.
2. Simulation results have generally not been used to determine code or model package bias & uncertainty. That is, code accuracy has not been quantified.

TRACE Assessment Plans

1. Expand assessment matrix to include a greater number of tests in a particular facility. Focus will be on model improvement, as opposed to code consolidation.
2. Characterize model and code performance with a bias & uncertainty using T/H parameters of major interest – not simply PCT.

Experiments Simulated for Model Improvement

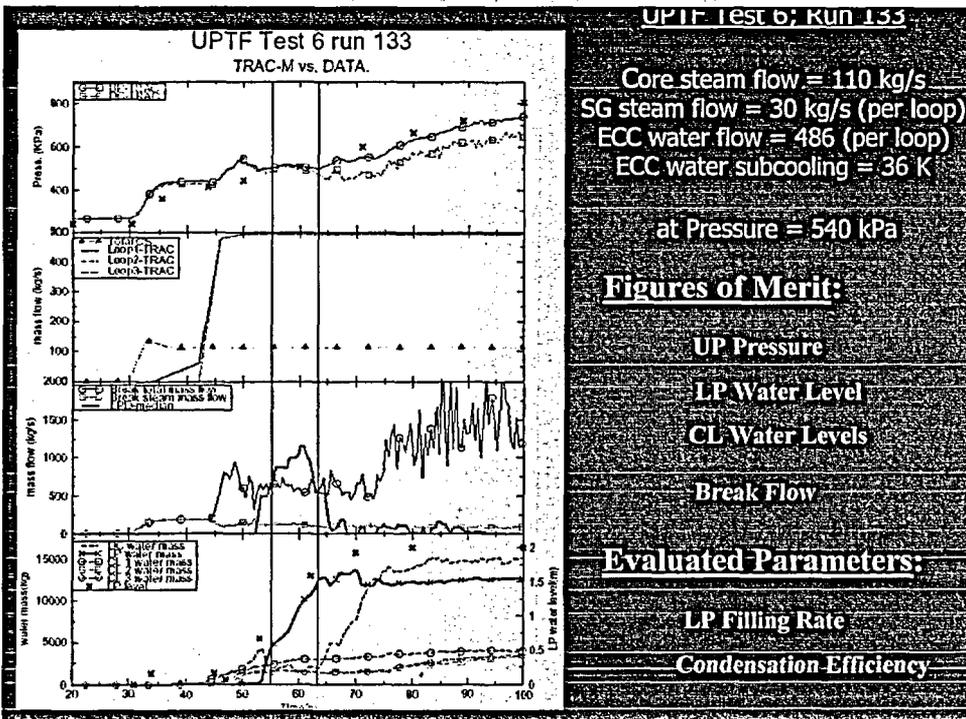
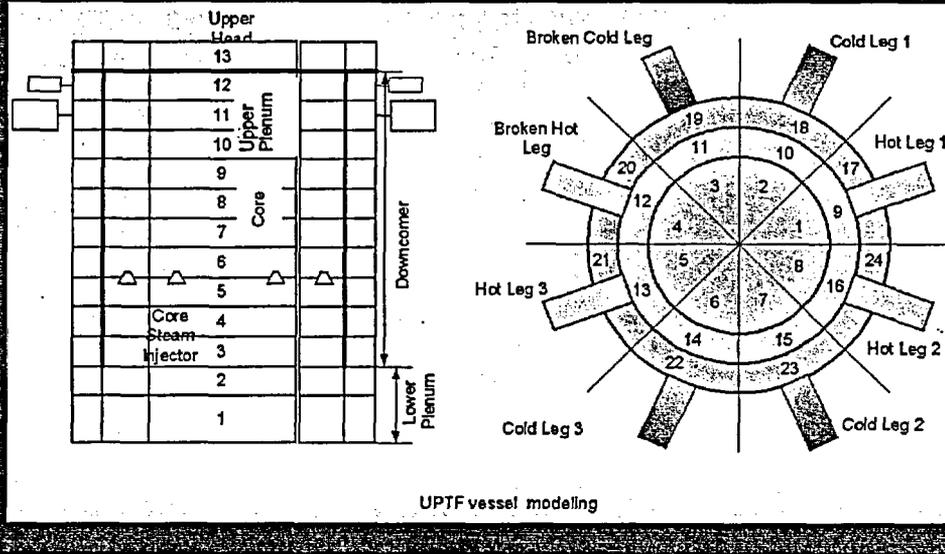
25 Transients simulated – 22 Integral type, 3 Separate Effects type

Category	Type	Experiment	TRACE Input Origin	Model Package
PWR - Large Break	Integral	UPTF Tests 5, 6	TRAC-P	ECC Bypass (uniform injection)
PWR - Large Break	Integral	UPTF Test 7	TRACE	ECC Bypass (asymmetric injection)
PWR - Large Break	Integral	UPTF Test 21	TRACE	ECC Bypass (DVI)
PWR - Large Break	Separate	FLECHT-SEASET 31504	TRAC-P	Reflood (Low VIN)
PWR - Large Break	Separate	FLECHT-SEASET 31701	TRAC-P	Reflood (High VIN)
PWR - Small Break	Separate	RBHT Test 1690	TRAC-P	Level Swell / Reflood
PWR - Small Break	Integral	SemiScale LH-2	TRAC-P	Various
PWR - Small Break	Integral	SemiScale LH-1	TRAC-P	Various

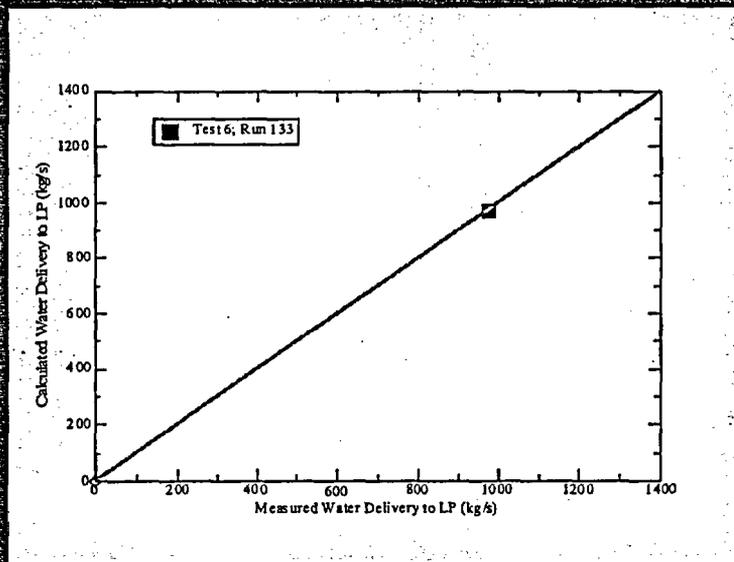
Example – ECC Bypass

- Previous assessment: Test 6; Run 133
- Current assessment:
 - Test 6; Runs 131, 132, 133, 135, 136
 - Test 7; Runs 201, 202, 203
 - Test 5
 - Test 21
 - Test 25

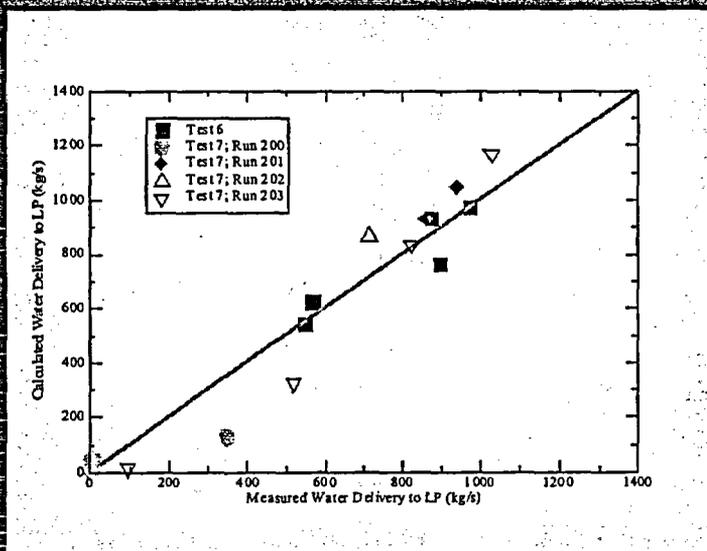
TRACE Nodalization for UPTF



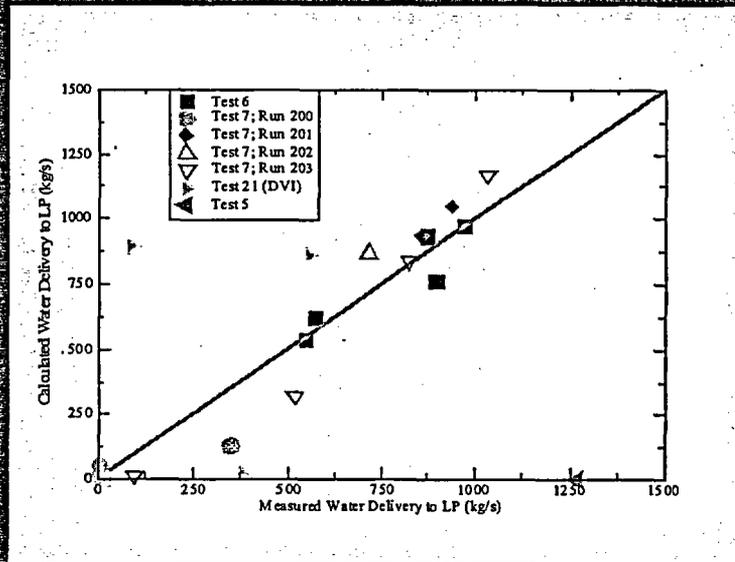
Previous Assessment: UPTF Test 6; Run 133



Current Assessment: UPTF Tests 6 & 7



Current Assessment: UPTF Tests 5, 6, 7, 21



Current Status: ECC Bypass Assessment

- ▣ Bypass model is deficient for ECC injection with high subcooling: Condensation efficiency is too high compared to UPTF data.
- ▣ Cause: Ad-hoc model for interfacial area at downcomer/ECC injection junction.

Example – Reflood SETs

- Previous: FLECHT-SEASET 31504, 33436 or 31701
- Current:
 - FLECHT-SEASET 31701, 31203, 31504, 31805, 31302, 31108, 32013, 30619, 30518, 31922, 30223, 32333, 32235, 33436
 - FLECHT Top-Skewed: 9 tests
 - FLECHT 98-rod: 7 tests
 - RBHT: TBD

2003-2004 Assessment

- Reflood Model Assessment:
 - FLECHT-SEASET
 - FLECHT 98-rod
 - FLECHT Top-Skewed
 - Penn State Univ. RBHT
 - CCTF (Runs 55, 58, 62, 63, 64, 67, 71)
 - SCTF (Runs 604, 605, 606)
- Results to be characterized by bias & uncertainty in parameters such as HTC, T_{min}, carryover fraction, void distribution, etc. as opposed to simply PCT.

2003-2004 Assessment

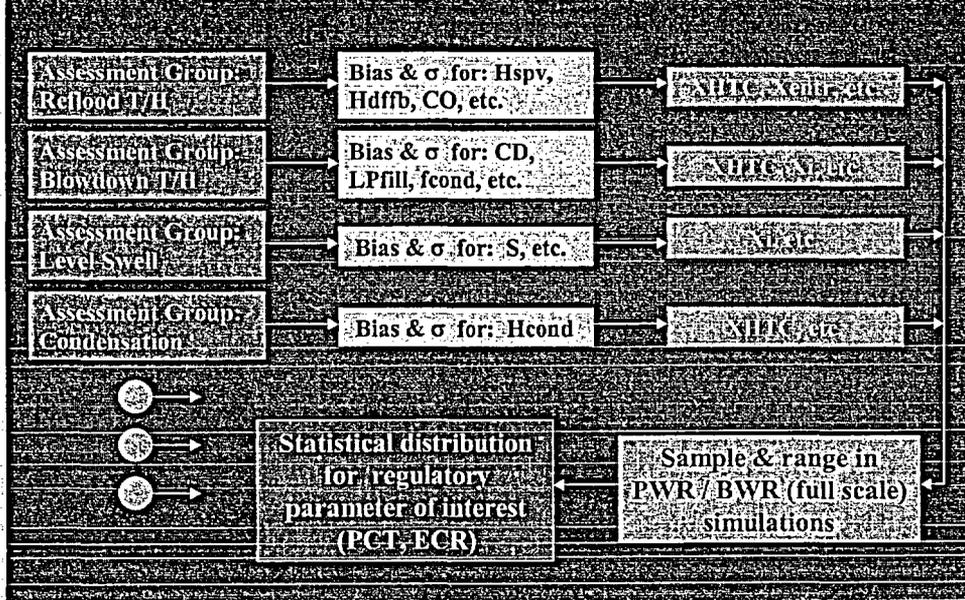
▣ Small Break LOCA Integral Tests:

- ROSA-IV (SB-CL-05, -18, -14, -15, -16)
- BETHSY Test 9.1.b (ISP-27)
- Semiscale (LH-01, LH-02, NH-1, NH-2)
- APEX-AP1000 (DEDVI)

▣ Small Break Separate Effects Tests:

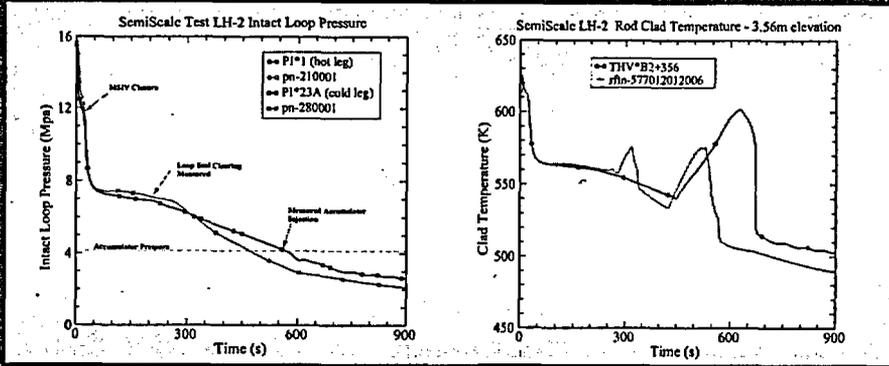
- THETIS
- Penn State Univ. RBHT (Int. Drag Tests)

Relation of Model Bias & Uncertainty to TRACE Uncertainty for Applications



PWR Integral Test Results

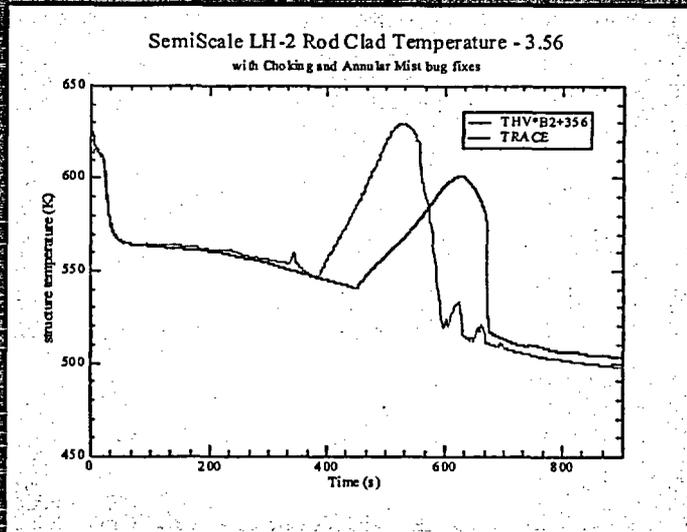
Semiscale Test LH-2; 5% Cold Leg Break LOCA



Integral Test Metrics: Several parameters needed, along with use of ACAP to compare transients.

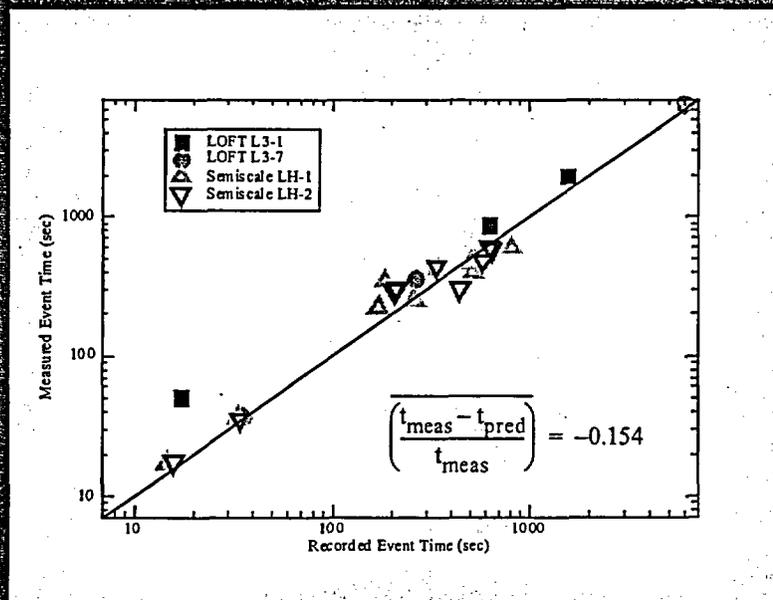
PWR Integral Test Results

Semiscale Test LH-2; 5% Cold Leg Break LOCA



(includes annular mist error correction)

Integral Test Assessment: Comparison of Predicted and Recorded Event Times



Summary & Conclusions

- Code consolidation phase is complete.
- Assessment will focus on quantification of code accuracy, and on providing information necessary to improve and develop models as deficiencies are identified.
- Assessments develop "AVSCRIPT" for each case, so that assessments can be easily repeated in future.



United States Nuclear Regulatory Commission

TRACE: Interim Reflood Model Development

Presented to the ACRS Thermal-Hydraulic and Severe
Accident Subcommittee

by

Joseph M. Kelly

Weidong Wang

Nov. 20, 2003

TRACE:

Interim Reflood Model Development

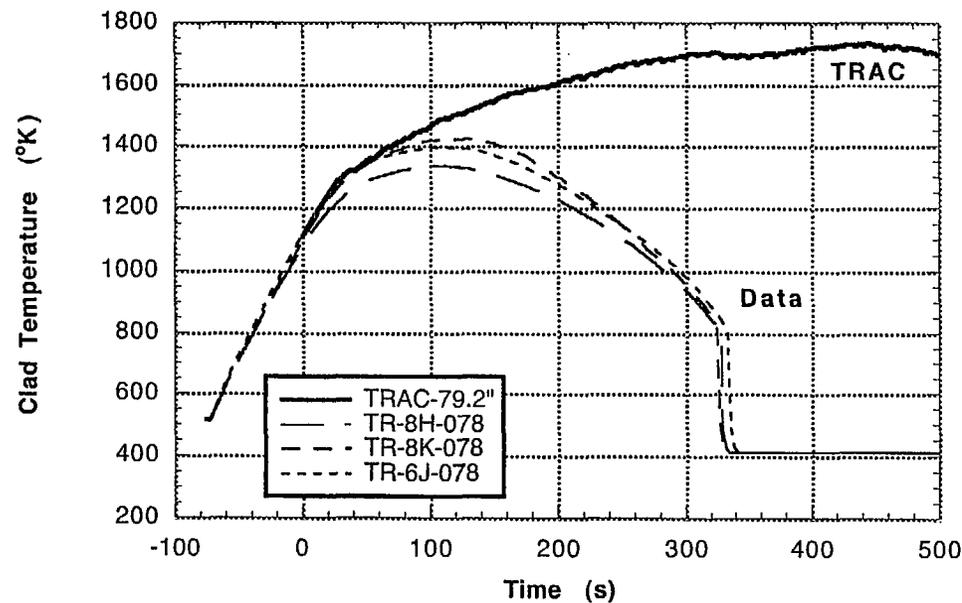
■ CONTENTS:

- Introduction
 - ➔ Why is a new reflood model needed?
 - ➔ Why is it called an “interim” model?
- Example of Preliminary Results
 - ➔ FLECHT-SEASET Forced Reflood Tests:
 - Low Flooding Rate Case: #31504
 - High Flooding Rate Case: #31701
- Example of Model Development
 - ➔ Inverted Annular Film Boiling
- Summary

TRACE: Interim Reflood Model Development

■ Introduction

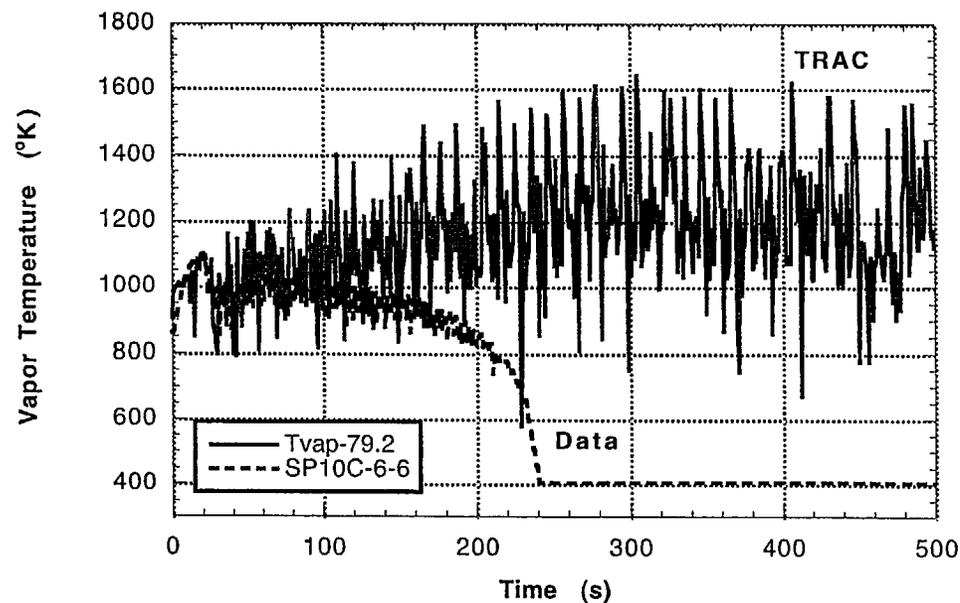
- Why is a new reflood model needed?
 - ➔ Current model (TRAC-PF1/Mod2) has unacceptably large oscillations and is highly conservative for separate effects tests.
 - FSS Test 31504: Clad Temperature at 78 in.



TRACE: Interim Reflood Model Development

■ Introduction

- Why is a new reflood model needed?
 - ➔ Current model (TRAC-PF1/Mod2) has unacceptably large oscillations and is highly conservative for separate effects tests.
 - ⊗ FSS Test 31504: Vapor Temperature at 78 in.



TRACE:

Interim Reflood Model Development

■ Introduction

- Why is the new reflood model referred to as an “interim” model?
 - ➔ A reasonably accurate reflood modeling capability was needed quickly so that:
 - ⊗ LBLOCA separate effects developmental assessment could proceed.
 - ⊗ Perform realistic auditing calculations for the proposed AP-1000 design.
 - ➔ Model development could not wait for:
 - ⊗ Implementation of droplet field,
 - ⊗ Analysis of data from the NRC reflood experiment at PSU (RBHT).
 - ➔ Subsequent reflood model development is planned for 2005-2006:
 - ⊗ Take advantage of droplet field & RBHT data,
 - ⊗ Implement a grid spacer model.,
 - ⊗ Develop a subgrid resolution scheme for fluid solution.

Example of Preliminary Assessment Results

■ FLECHT-SEASET Forced Flooding Rate Tests

➔ Geometry:

- ⊗ 17 x 17 bundle geometry
- ⊗ 161 heated rods & 16 thimbles
- ⊗ 8 egg-crate grid spacers
- ⊗ full heated length (3.66 m)
- ⊗ chopped cosine axial power profile (peak/avg. = 1.66)
- ⊗ uniform radial power profile

➔ Test Conditions

	31504	31701
Pressure (bar)	2.8	2.8
Flooding Rate (mm/s)	24	155
Inlet Subcooling (deg C)	80	80
Nominal Heat Flux (W/cm ²)	4.64	4.64

Example of Preliminary Assessment Results

■ FLECHT-SEASET Input Model

● TRACE

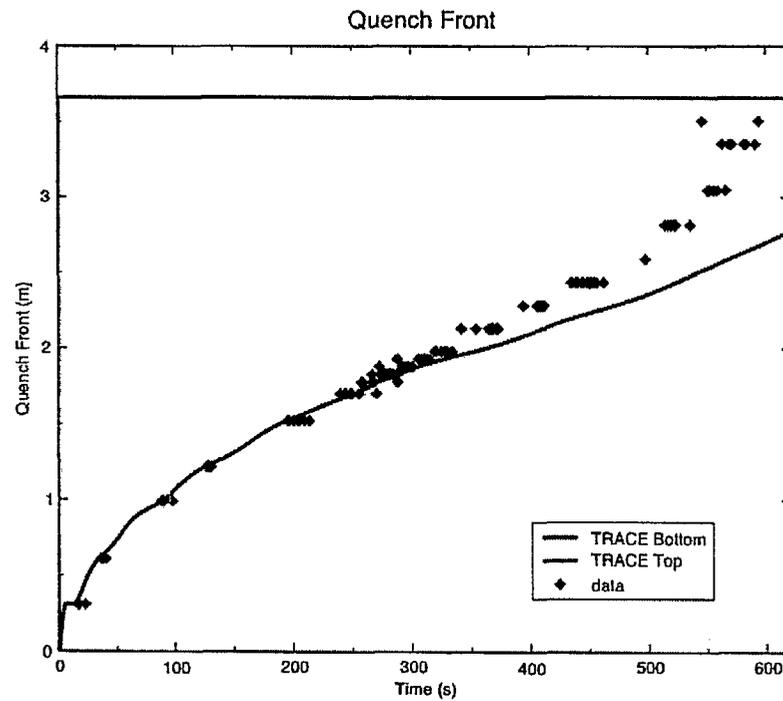
- ➔ 1-D Vessel Model
- ➔ 12 axial nodes in heated length
 - ⊙ Chosen to match delta-P cells
 - ⊙ $\Delta Z = 30.48$ cm.
- ➔ 2 Heat Structures:
 - ⊙ Heater Rods
 - ⊙ Bundle Housing
- ➔ Graphics edit interval matches that of test data (2 Hz).

● RELAP5

- ➔ Identical to TRACE Input Model, Except
 - ⊙ Uses Pipe instead of 1-D Vessel

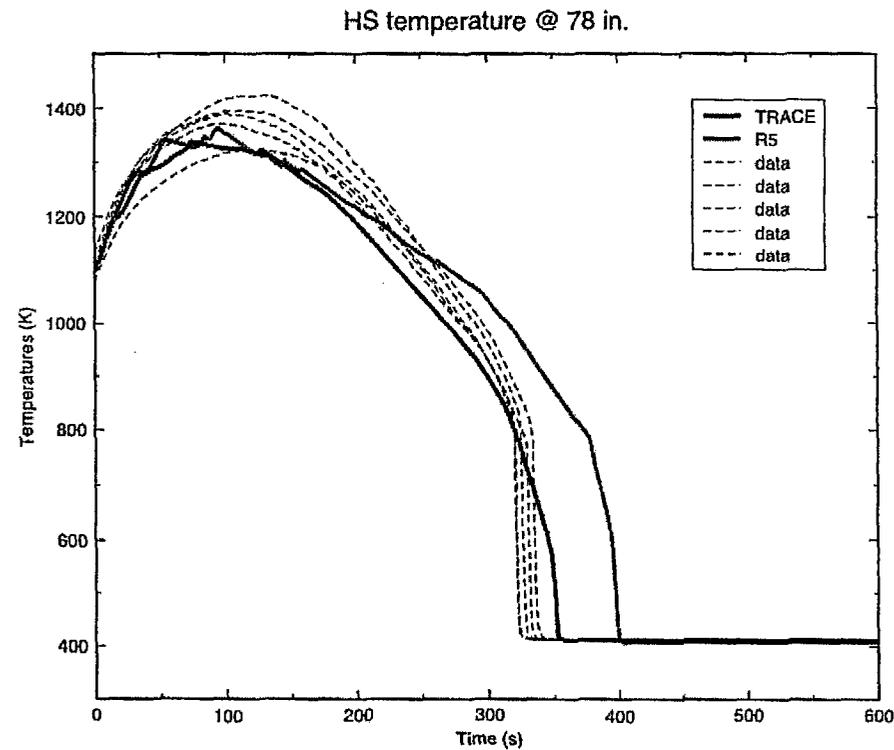
Example of Preliminary Assessment Results

■ FLECHT-SEASET Test 31504



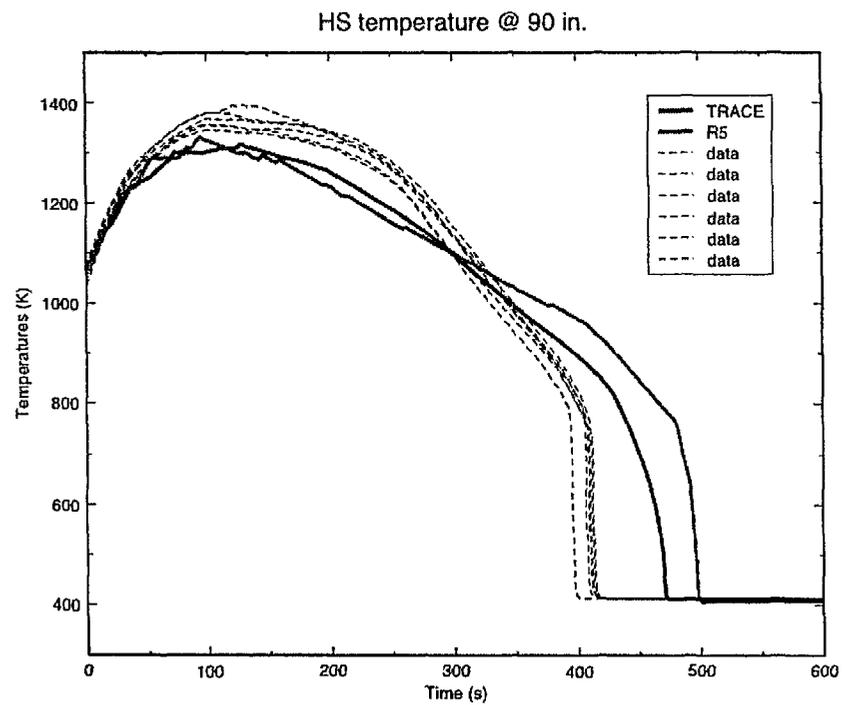
Example of Preliminary Assessment Results

■ FLECHT-SEASET Test 31504



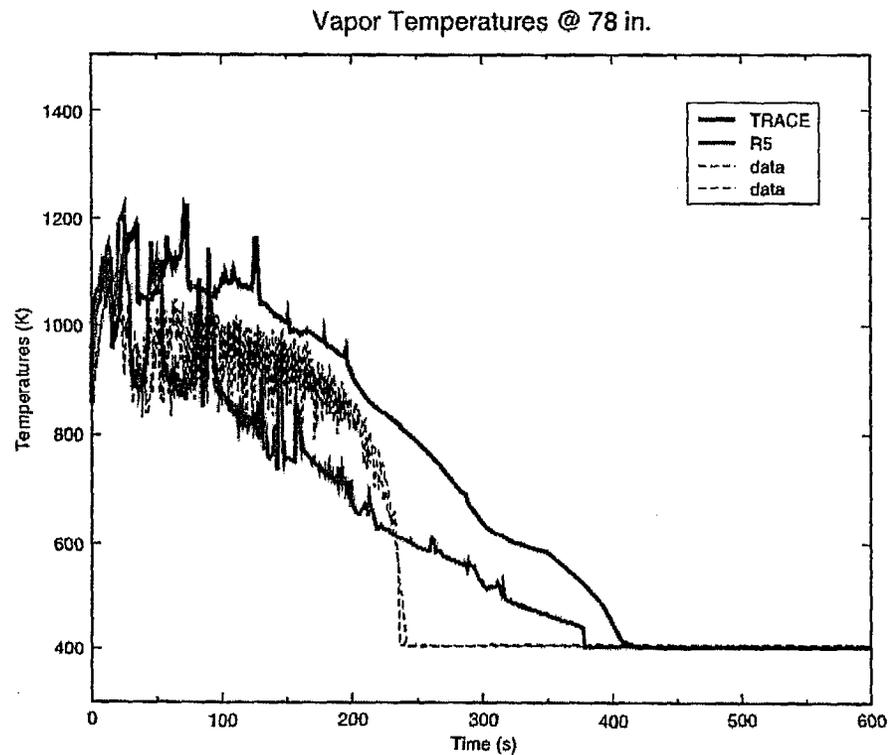
Example of Preliminary Assessment Results

■ FLECHT-SEASET Test 31504



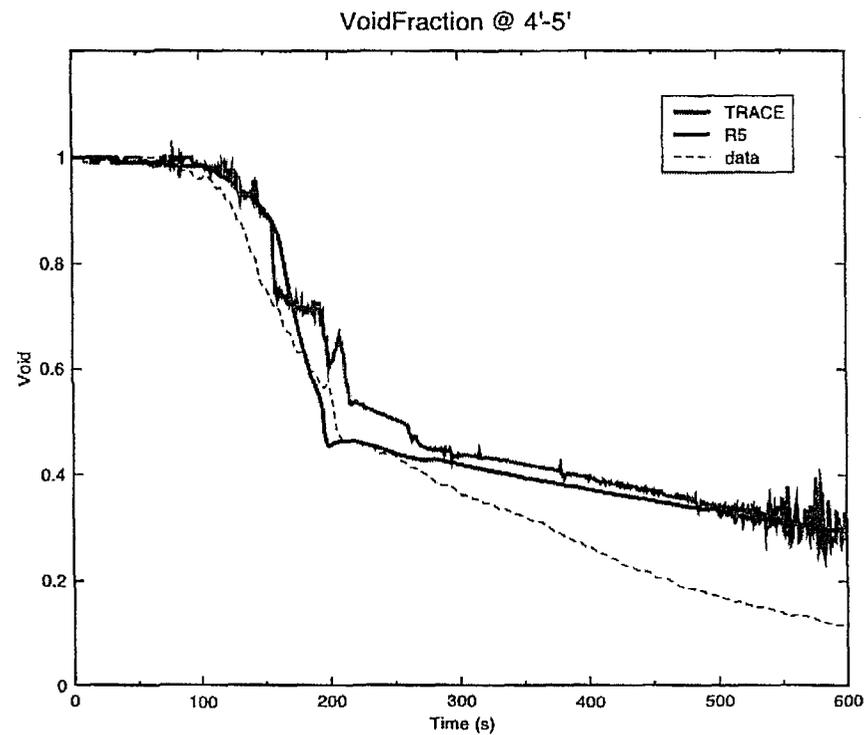
Example of Preliminary Assessment Results

■ FLECHT-SEASET Test 31504



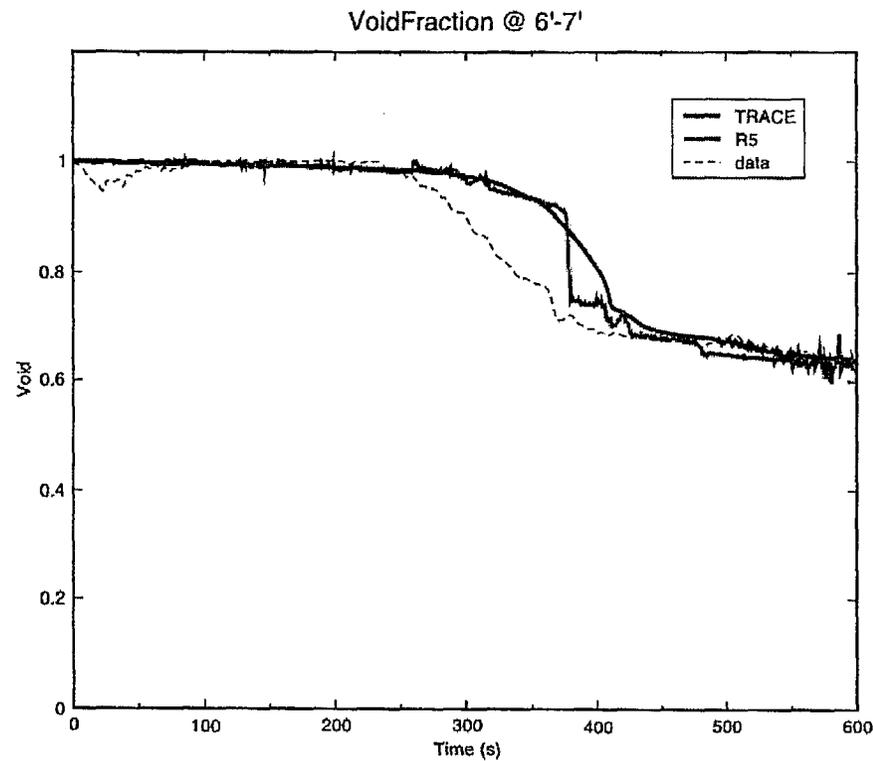
Example of Preliminary Assessment Results

■ FLECHT-SEASET Test 31504



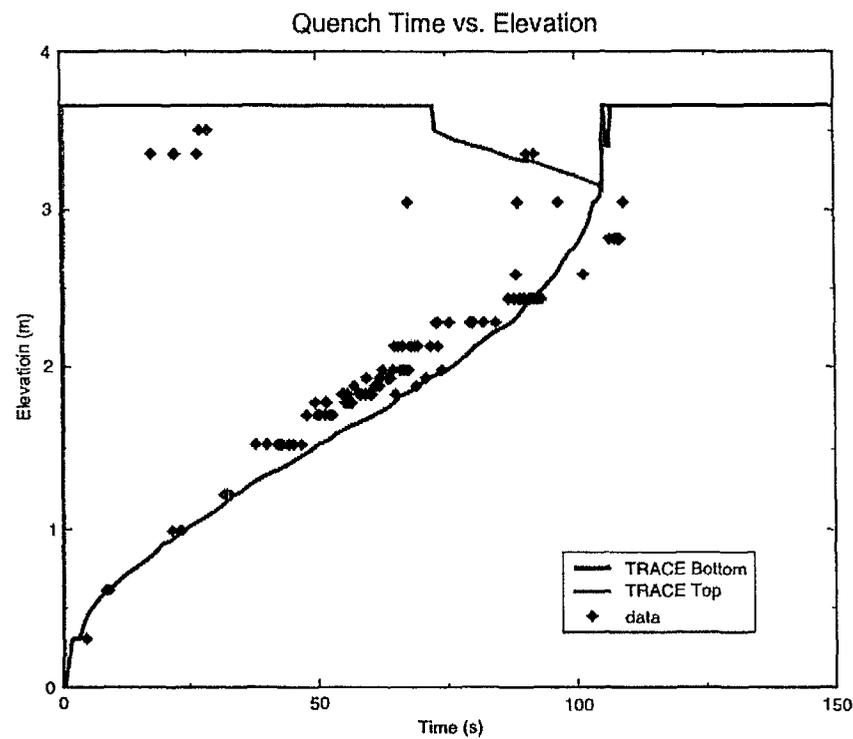
Example of Preliminary Assessment Results

■ FLECHT-SEASET Test 31504



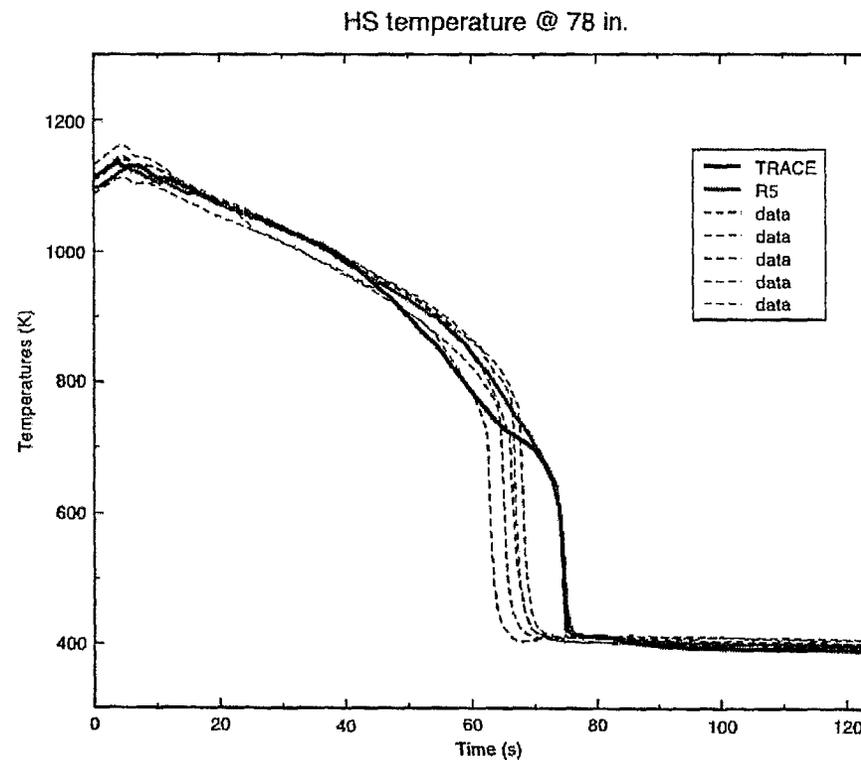
Example of Preliminary Assessment Results

■ FLECHT-SEASET Test 31701



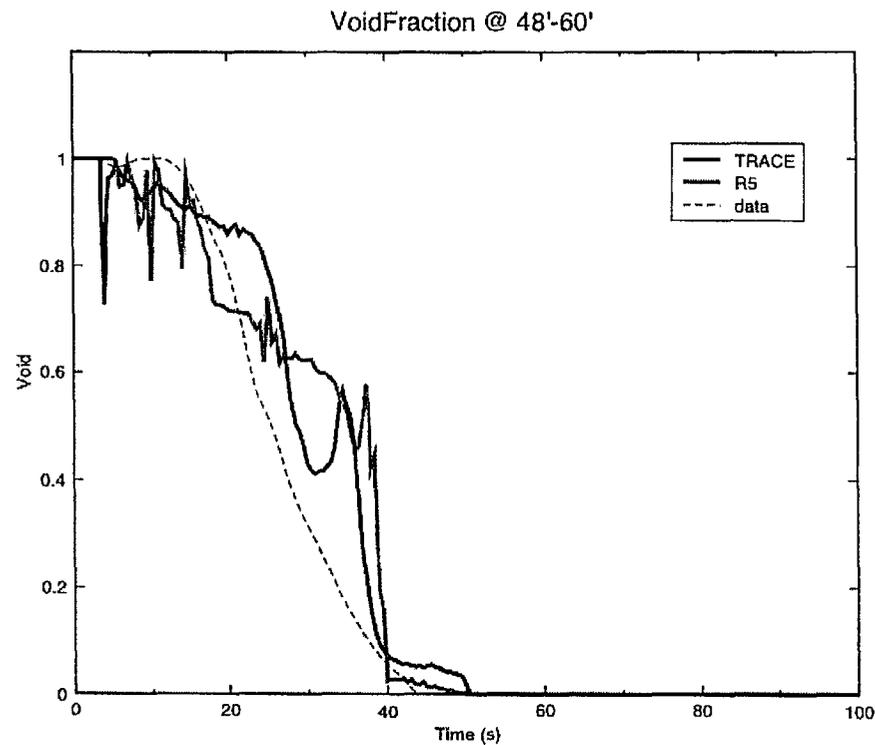
Example of Preliminary Assessment Results

■ FLECHT-SEASET Test 31701



Example of Preliminary Assessment Results

- FLECHT-SEASET Test 31701



Example of Preliminary Assessment Results Computational Statistics

- Calculations performed on a PC Laptop with
 - Pentium 3 processor @ 500 MHz
 - 264 MB of memory

	31504		31701	
	TRACE	RELAP5	TRACE	RELAP5
Transient Time (s)	700	700	200	200
Maximum Time Step (s)	0.05	0.05	0.01	0.01
No. of Time Steps	14,193	42,147	20,127	34,550
Total CPU Time (s)	276	174	321	119
Grind Time (ms) (CPU/time step/cell)	1.22	0.26	1.00	0.22

Example of Preliminary Assessment Results Computational Statistics

■ Level Swell Tests

- FLECHT-SEASET #31504 at end-of-reflood conditions.
 - Transient to a steady-state two-phase condition.

	TRACE			RELAP5
	1-D Vessel	1-D Pipe (SETS)	1-D Pipe (Semi)	1-D Pipe
Transient Time (s)	200	200	200	200
Maximum Time Step (s)	0.05	0.05	0.05	0.05
No. of Time Steps	4183	4723	6415	6291
Total CPU Time (s)	54.4	23.2	28.1	15.1
Grind Time (ms) (CPU/time step/cell)	0.81	0.31	0.27	0.15

Example of Preliminary Assessment Results

■ Summary

● Code Accuracy

- ➔ Overall accuracy of TRACE interim reflood model is somewhat superior to that of RELAP5.
- ➔ TRACE calculated results (especially vapor temperature and void fraction) are much smoother than those of RELAP5.
- ➔ For low flooding rate test, improvements are needed for peak clad temperature and quenching rate for upper portion of bundle.
- ➔ For high flooding rate test, there is an unphysical increase in the void fraction associated with the entry of the quench front into the cell.

● Computational Efficiency

- ➔ TRACE can use larger (i.e., fewer) time steps than RELAP5, but its grind time is ~4 times higher.
 - ⦿ NOTE: RELAP5 pipe vs. TRACE 1-D vessel.
- ➔ Effort is needed to improve TRACE's run time performance.

Interim Reflood Model

Remaining Effort

■ Code / Model Development

- Apply reflood model to 1-D components (pipe & CHAN)
- Improve models for top-down quench & blowdown rewet.
- Accuracy improvements noted on summary slide.

■ Assessment

- Expand forced reflood test matrix:
 - ➔ FLECHT-SEASET: flooding rate, pressure & subcooling
 - ➔ FLECHT-Skewed, FLECHT Low Flooding Rate & RBHT
 - ➔ ORNL/THTF high pressure reflood
- Large-Scale and Gravity Reflood:
 - ➔ CCTF & SCTF
- Develop metrics for quantitative comparisons.
- Convergence Studies: time-step and node size.

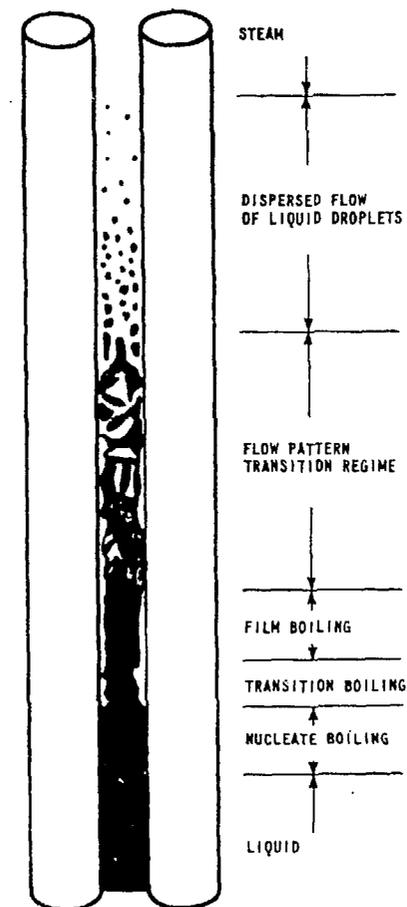
■ Documentation

- Update TRACE Theory & Assessment Manuals.
- Software Quality Assurance.

Model Development: Inverted Annular Film Boiling

■ Reflood Regimes

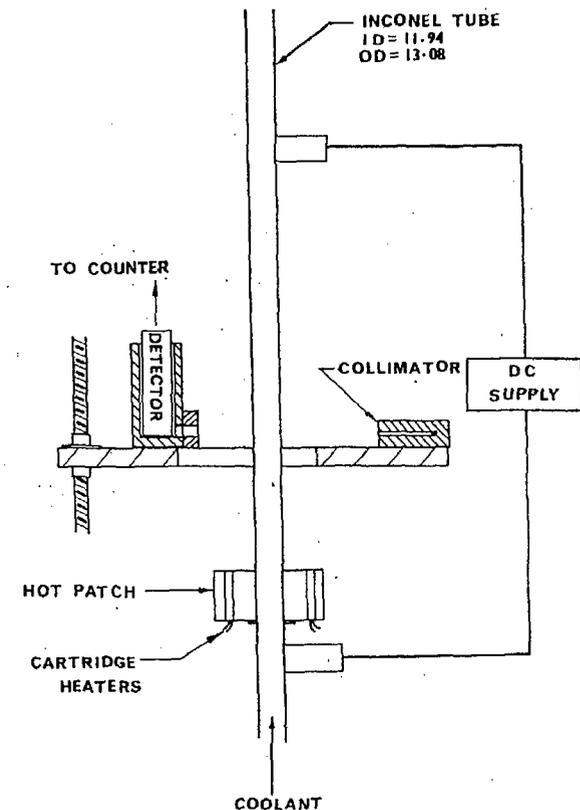
- Transition Boiling:
 - ➔ at quench front, ~ 1-2 cm long.
- Film Boiling:
 - ➔ a.k.a. inverted annular film boiling
 - ➔ occurs for high flow & subcooled conditions.
- Flow Pattern Transition Regime:
 - ➔ a.k.a. inverted slug, agitated inverted annular, or froth.
 - ➔ mixture of liquid fragments & droplets
 - ➔ occurs when inverted core disintegrates or when 2Φ mixture exists below quench front.
- Dispersed Flow:
 - ➔ a.k.a. dispersed flow film boiling.
 - ➔ superheated steam & droplets with Sauter mean diameter ~ 1 mm.



Model Development: Inverted Annular Film Boiling

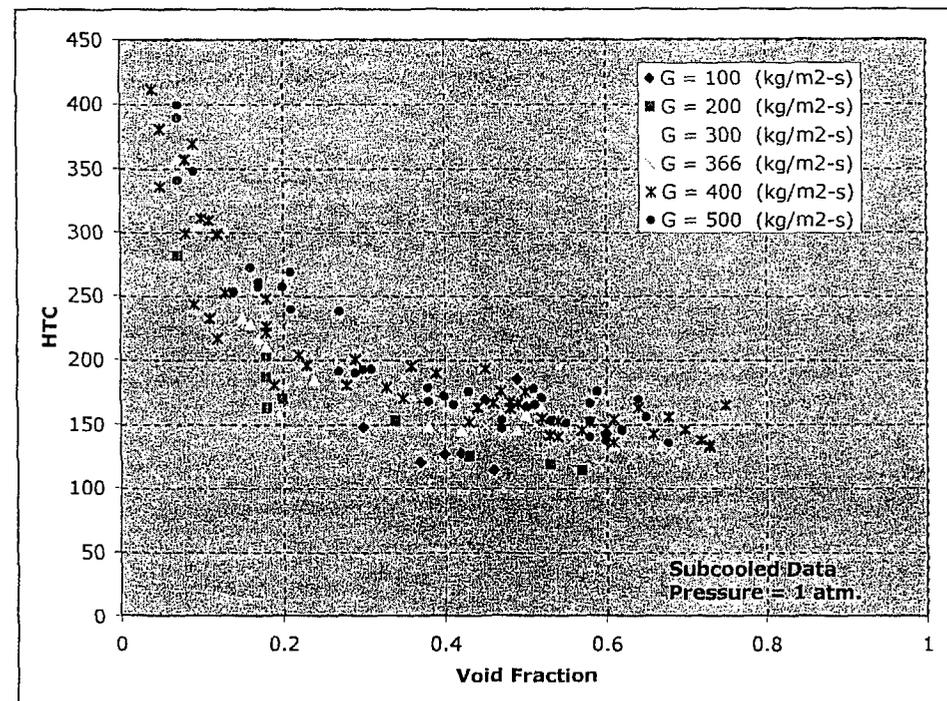
■ Background: Fung Low-Quality Film Boiling Experiment

- “Hot Patch” to freeze quench front.
- Instrumentation:
 - ➔ 10 wall thermocouples
 - ➔ Gamma densitometer => void fraction at 5 elevations
- Test Conditions:
 - ➔ Atmospheric pressure
 - ➔ Mass Flux = 100 - 500 (kg/m²-s)
 - ➔ Inlet Subcooling = 1 - 20 (C)



Model Development: Inverted Annular Film Boiling

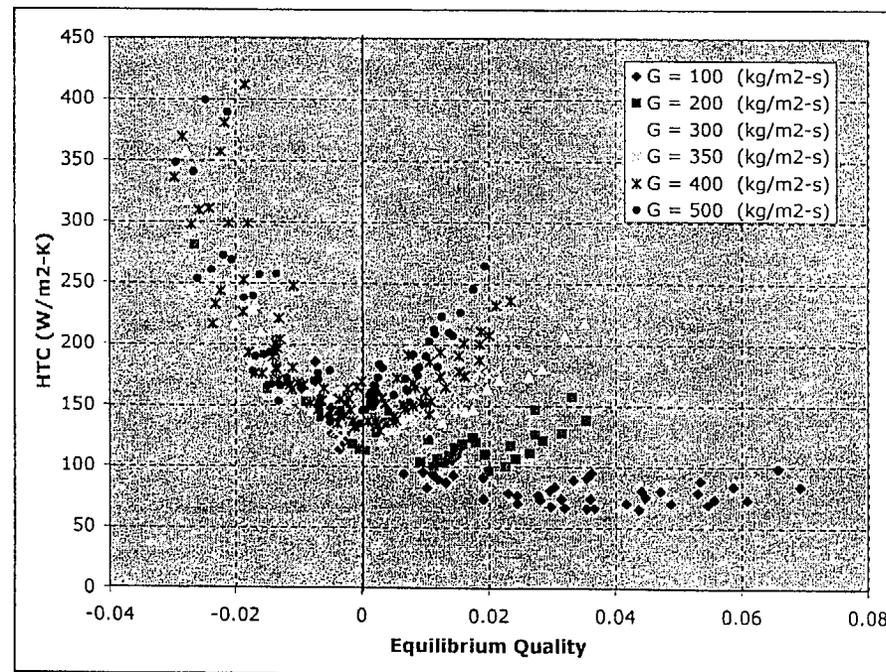
- Fung Low-Quality Film Boiling
 - Strong void fraction dependence.
 - ➔ Mass flux effect may be present but is of secondary importance.
 - Note: void fraction can be $> 70\%$ even though liquid is subcooled!



Model Development: Inverted Annular Film Boiling

■ Fung Low-Quality Film Boiling

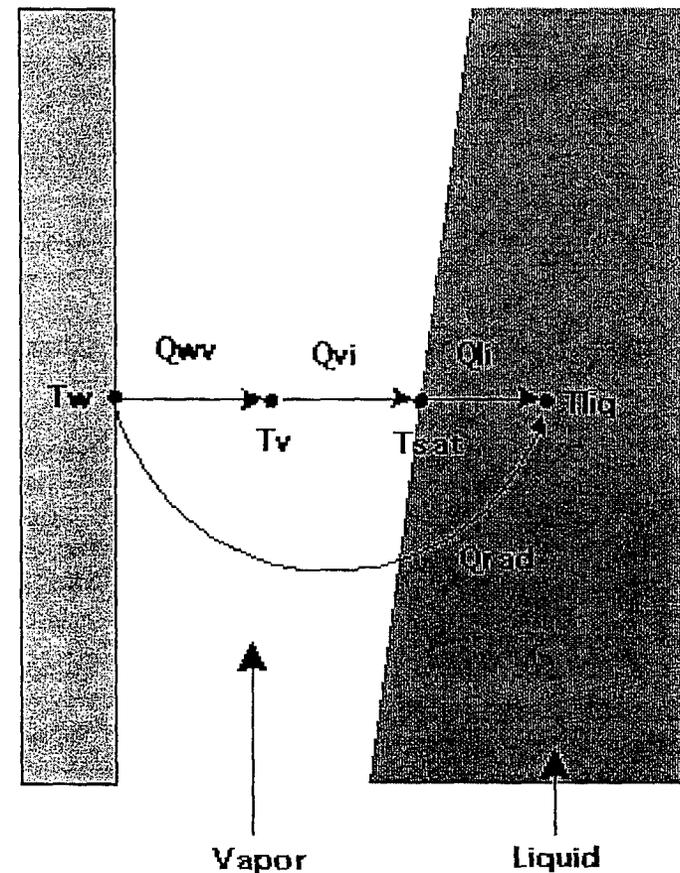
- Film boiling heat transfer coefficient is primarily a function of equilibrium quality, i.e., the liquid subcooling.
 - ➔ Interfacial heat transfer (interface-liquid) must be modeled accurately.



Model Development: Inverted Annular Film Boiling

■ Constitutive Models Needed

- Primary wall heat transfer mode is convection to vapor film, ultimate heat sink is the subcooled liquid.
- Models needed are:
 - ➔ Wall-Vapor heat transfer
 - ➔ Vapor-Interface heat transfer
 - ➔ Liquid-Interface heat transfer
 - ➔ Wall-Liquid radiation heat transfer
 - ➔ Interfacial drag
 - ➔ Criteria for regime transition (liquid core breakup)
- ➔ Note: the wall heat transfer is enhanced above laminar convection due to waviness of liquid core, as is the interfacial drag.



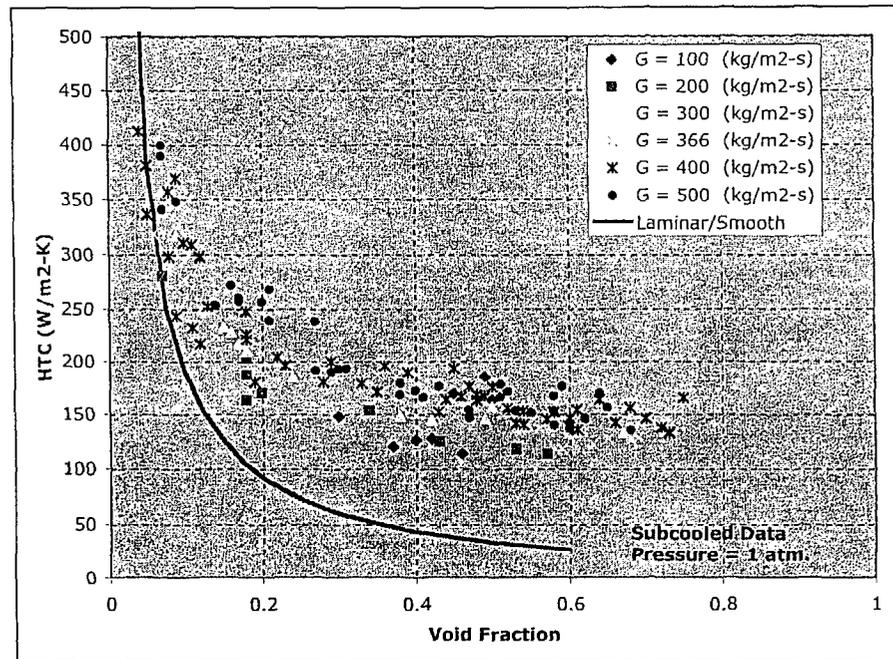
Model Development: Inverted Annular Film Boiling

■ Wall-Interface Heat Transfer

➔ If vapor-liquid interface is smooth and vapor flow is laminar, then

$$q_w'' = h_w \cdot (T_w - T_{sat})$$
$$h_w = \frac{k_v}{\delta}$$

and



Model Development: Inverted Annular Film Boiling

■ Wall-Interface Heat Transfer

- Define Nusselt no.

$$Nu_w = \frac{h_w \cdot 2\delta}{k_v}$$

- Introduce non-dimensional film thickness.

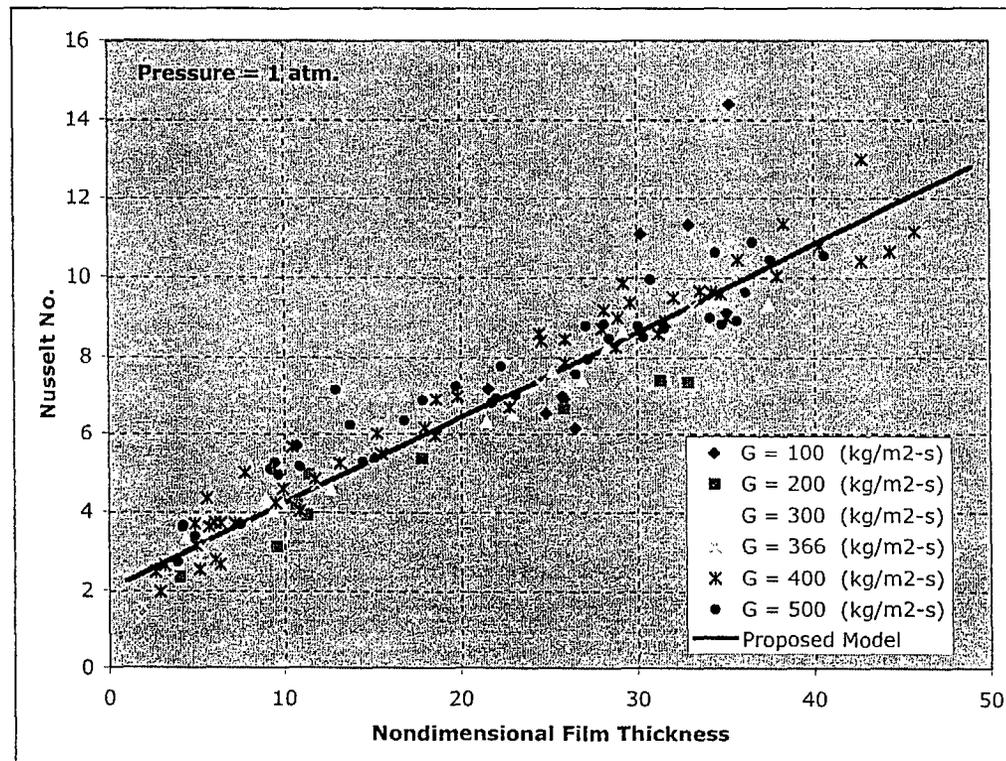
$$\delta^* = \delta \cdot \left(\frac{\rho_v \cdot g \cdot \Delta\rho}{\mu_v^2} \right)^{\frac{1}{3}}$$

- Correlate Nusselt No. from Fung data.
 - ⊙ Introduce enhancement factor to account for interface waves.
 - » Approach is similar to that of Cachard et al. (NUREG/IA-0133)

$$Nu_w = 2 \cdot (1 + 0.1098 \cdot \delta^*)$$

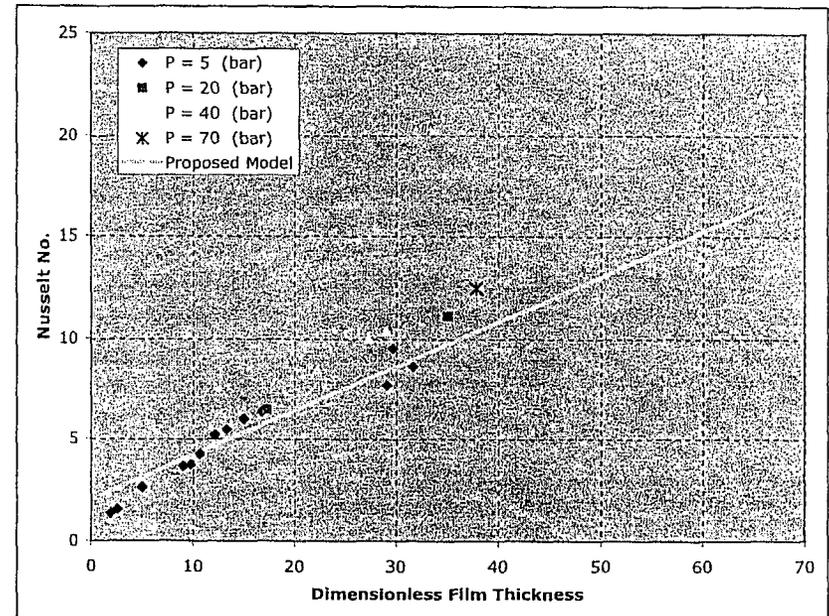
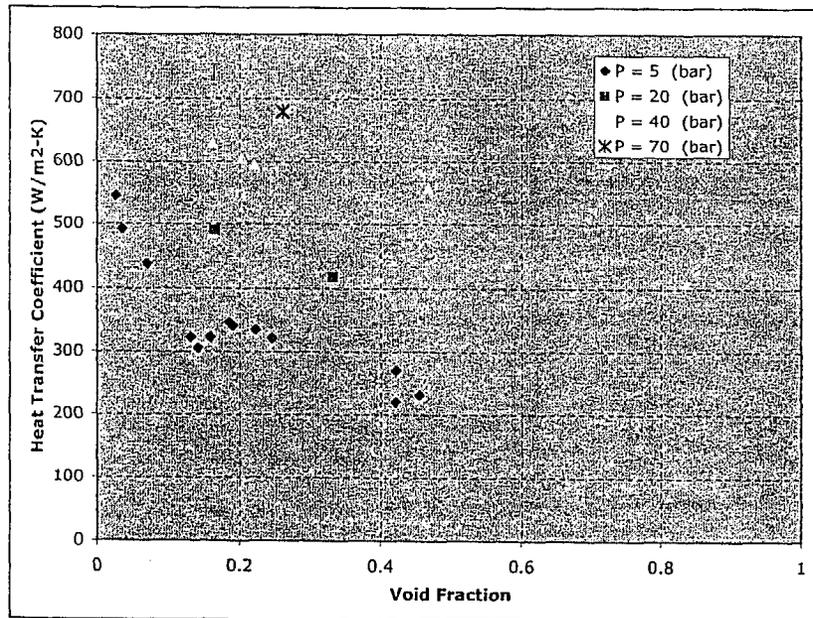
Model Development: Inverted Annular Film Boiling

- Wall-Interface Heat Transfer
 - Comparison with Fung Subcooled data



Model Development: Inverted Annular Film Boiling

- Wall-Interface Heat Transfer
 - Comparison with Winfrith Series-4 Subcooled data.
 - ▶ Pressure effect well captured by non-dimensional film thickness.



Model Development: Inverted Annular Film Boiling

■ Wall Heat Transfer

- We now have a correlation for the wall heat transfer coefficient, where

$$h_w = \frac{k_v}{\delta} \cdot (1 + 0.1098 \cdot \delta^*)$$

$$q_w'' = h_w \cdot (T_w - T_{sat})$$

- But we need:

- ➔ Wall-Vapor heat transfer coefficient, and
- ➔ Vapor-Interface heat transfer coefficient.

$$q_{wv}'' = h_{wv} \cdot (T_w - T_v)$$

$$q_{vi}'' = h_{vi} \cdot (T_v - T_{sat})$$

- Split heat transfer resistance equally between wall-vapor and vapor-interface:

$$h_{wv} = h_{vi} = 2 \cdot h_w$$

Model Development: Inverted Annular Film Boiling

■ Wall Heat Transfer

● Applicability of correlation derived from tube data to rod bundles?

➔ Use “frozen” quench front approach:

- ⊙ Look at wall heat transfer coefficients downstream of quench front
- ⊙ Interpolate void fractions from delta-P measurements

➔ Used data from:

- ⊙ FLECHT-SEASET Tests 31701 and 31302
- ⊙ PERICLES Runs #8, 13 and 14

● Results

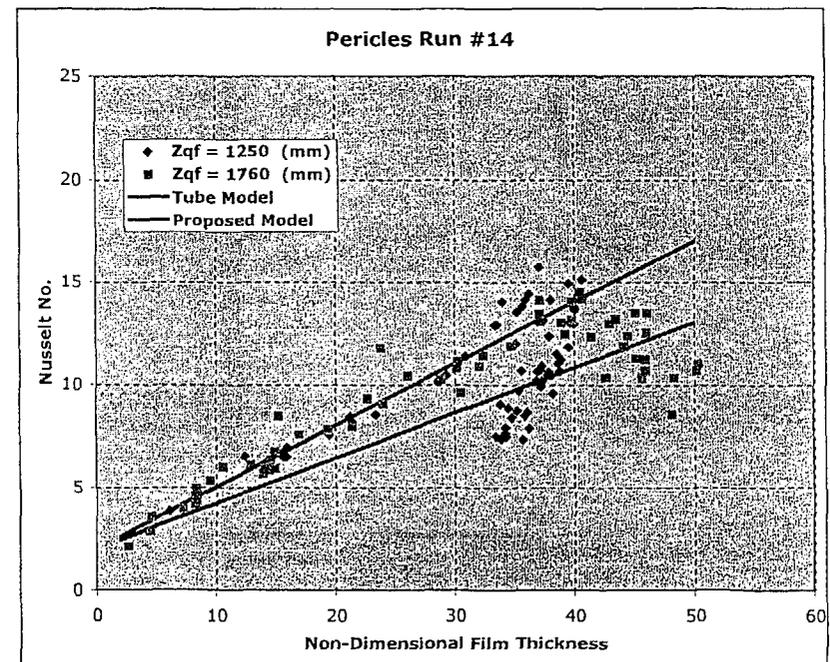
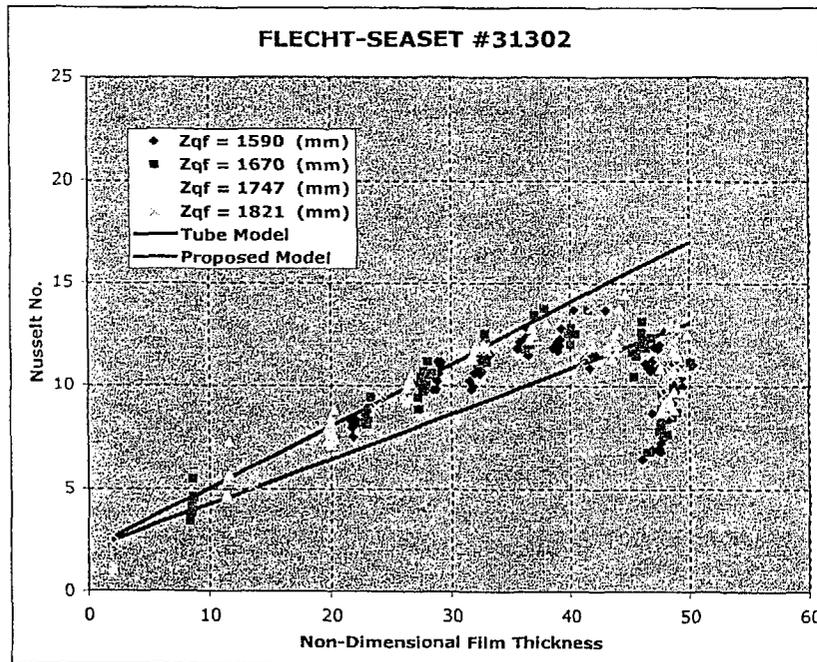
➔ IAFB Heat Transfer Correlation for Rod Bundles

$$h_w = \frac{k_v}{\delta} \cdot (1 + 0.3 \cdot \delta^*)$$

$$q_w'' = h_w \cdot (T_w - T_{sat})$$

Model Development: Inverted Annular Film Boiling

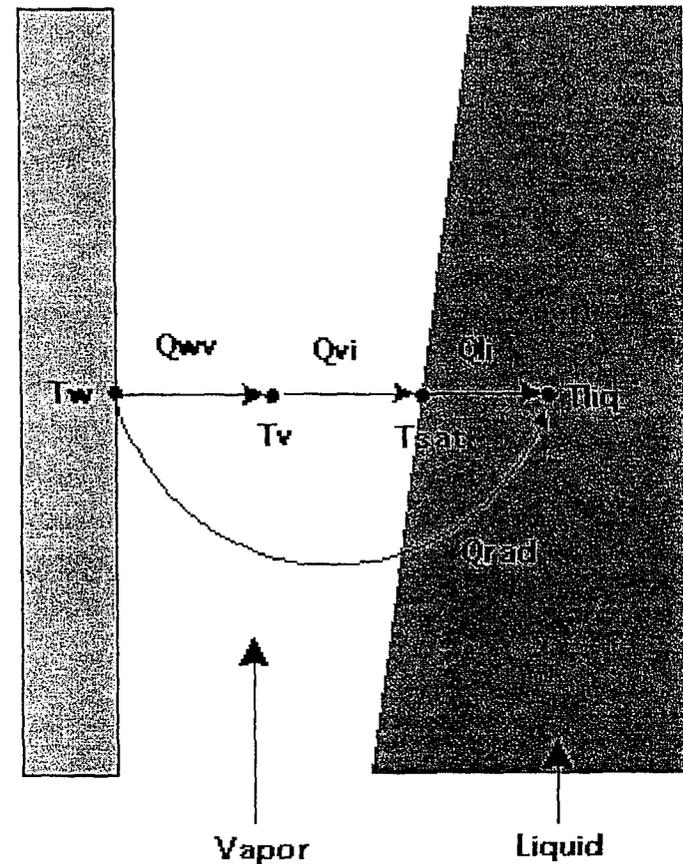
- Wall Heat Transfer
 - IAFB Heat Transfer Correlation for Rod Bundles



Model Development: Inverted Annular Film Boiling

■ Constitutive Models Needed

- Primary wall heat transfer mode is convection to vapor film, ultimate heat sink is the subcooled liquid.
- Models needed are:
 - ⇒ Wall-Vapor heat transfer
 - ⇒ Vapor-Interface heat transfer
 - ⇒ Liquid-Interface heat transfer
 - ⇒ Wall-Liquid radiation heat transfer
 - ⇒ Interfacial drag
 - ⇒ Criteria for regime transition (liquid core breakup)
- ➔ Note: the wall heat transfer is enhanced above laminar convection due to waviness of liquid core, as is the interfacial drag.



Model Development: Inverted Annular Film Boiling

■ Liquid-Interface Heat Transfer

● Observation:

- When liquid is significantly subcooled, most of wall heat transfer goes into the subcooled liquid core increasing its sensible heat.
- The thickness of the vapor film “adjusts” so that the wall heat transfer rate is approximately equal to what the liquid core can absorb by interfacial heat transfer.

$$q_w'' = h_w \cdot (T_w - T_{sat}) \approx h_{li} \cdot (T_{sat} - T_l)$$

● Data Analysis:

- Use above assumption to get an estimate of the liquid-interface htc.
 - ⊙ Will over-estimate value, especially for small liquid subcooling.

$$h_{li} \approx \frac{q_w''}{(T_{sat} - T_l)}$$

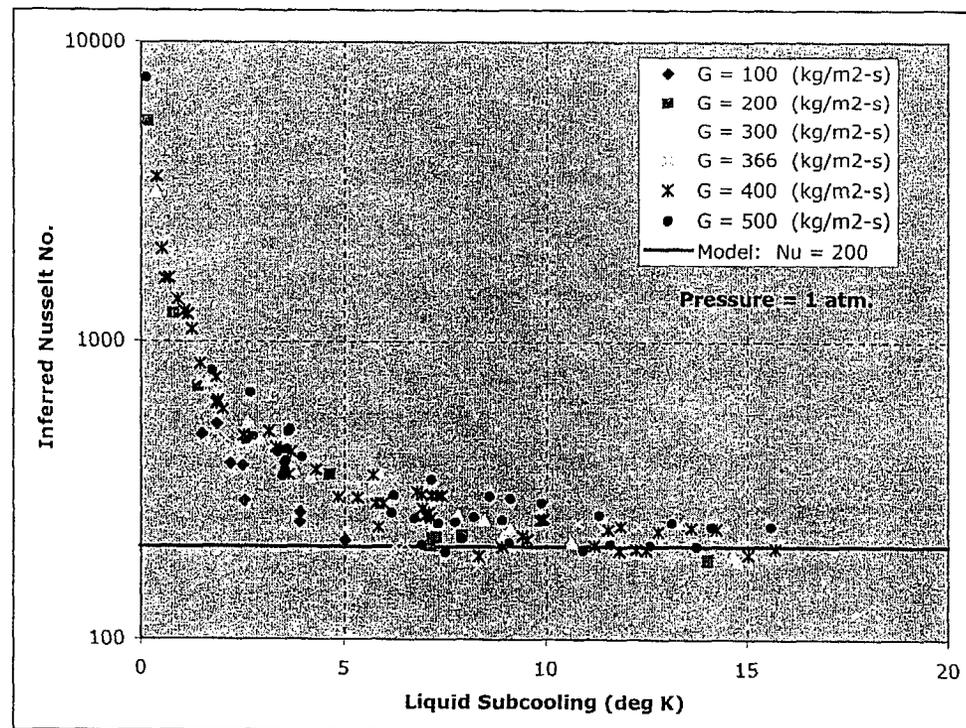
$$Nu_{li} = \frac{h_{li} \cdot d_c}{k_l}$$

Model Development: Inverted Annular Film Boiling

■ Liquid-Interface Heat Transfer

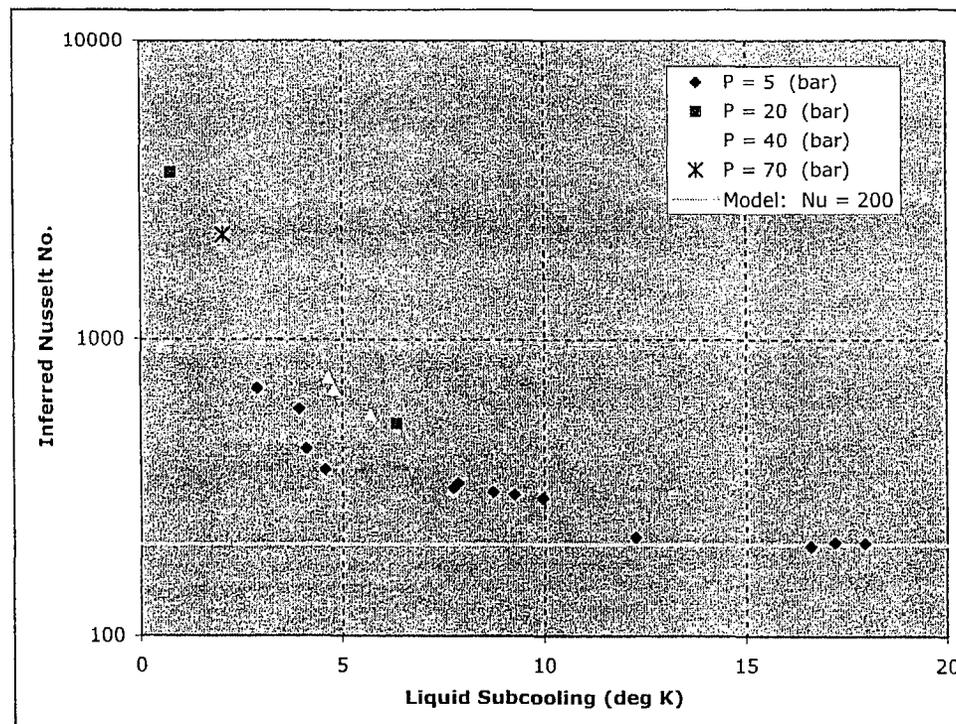
● Fung Low Quality Film Boiling Data:

- No noticeable mass flux effect.
- Data reasonably well represented by constant Nusselt no. = 200.



Model Development: Inverted Annular Film Boiling

- Liquid-Interface Heat Transfer
 - Winfrith Series-4 Film Boiling Data
 - ▶ Same trends as Fung data.



Model Development: Inverted Annular Film Boiling

■ Wall-Liquid Radiation Model

- Almost all wall radiation heat transfer will be absorbed in the liquid core, radiation to vapor is negligible.
- No way to isolate radiation heat transfer from total wall heat transfer, so
 - ➔ Use simple coaxial cylinder model:

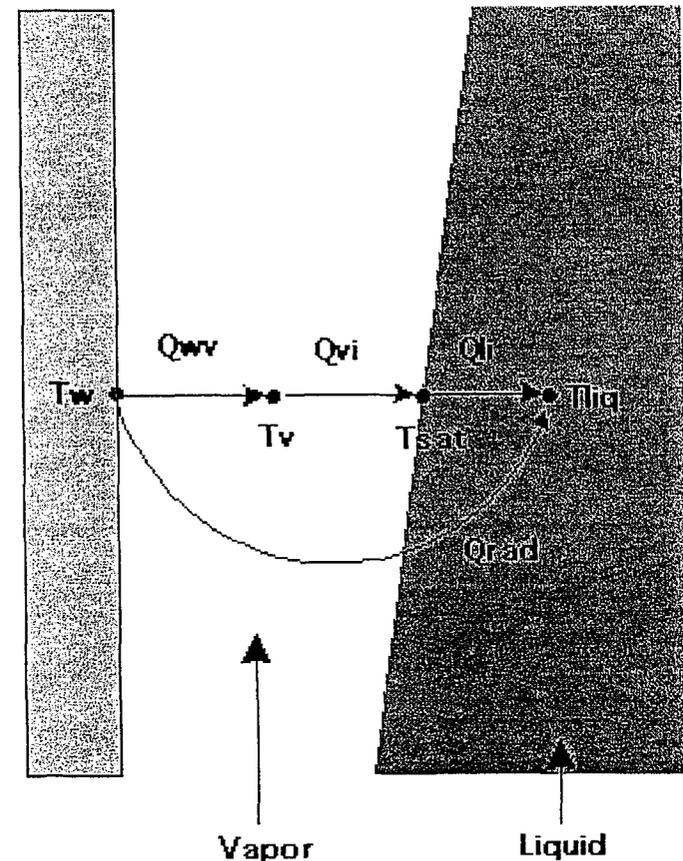
$$q''_{Rad,wl} = \frac{\sigma \cdot (T_w^4 - T_l^4)}{\frac{1}{\varepsilon_l \cdot \sqrt{1-\alpha}} + \left(\frac{1}{\varepsilon_w} - 1\right)}$$

- ➔ NOTE: this formulation was used in reducing the data used to develop the wall-interface heat transfer model presented earlier.

Model Development: Inverted Annular Film Boiling

■ Constitutive Models Needed

- Primary wall heat transfer mode is convection to vapor film, ultimate heat sink is the subcooled liquid.
- Models needed are:
 - ➔ Wall-Vapor heat transfer
 - ➔ Vapor-Interface heat transfer
 - ➔ Liquid-Interface heat transfer
 - ➔ Wall-Liquid radiation heat transfer
 - ➔ Interfacial drag
 - ➔ Criteria for regime transition (liquid core breakup)
- ➔ Note: the wall heat transfer is enhanced above laminar convection due to waviness of liquid core, as is the interfacial drag.



Model Development: Inverted Annular Film Boiling

■ Vapor-Liquid Interfacial Friction

- Film Boiling Database: phase velocities are unknown.
 - ➔ Impossible to determine interfacial friction factors.
- Observations:
 - ➔ Ducts with grooved or wavy walls:
 - ⊙ Friction factor follows that of smooth parallel plates for $Re < 200-400$.
 - ⊙ For higher Re , friction factor approaches constant value (similar to fully rough turbulent flow) that is dependent upon amplitude/wavelength ratio.
 - ➔ Horizontal Stratified Flow: Andritsos & Hanratty
 - ⊙ Interfacial friction factor is dependent upon the wave amplitude, and
 - ⊙ Is linearly proportional to the vapor Reynolds no.

Model Development: Inverted Annular Film Boiling

■ Vapor-Liquid Interfacial Friction

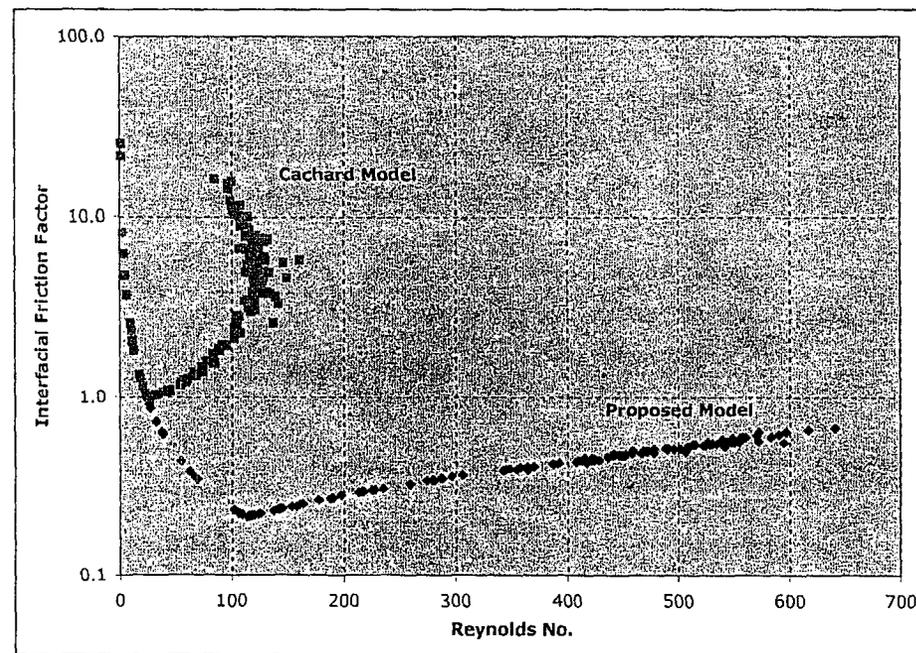
● Proposed Model:

- ▶ Reduces to smooth parallel plate for low Reynolds no.
- ▶ Is linearly proportional to vapor Reynolds no. when surface waves govern its value.
- ▶ That the vapor Reynolds no. increases monotonically with respect to vapor film thickness (as expected).
- ▶ Avoids unrealistically high vapor Reynolds no. values associated with smooth laminar flow assumption as the vapor film thickness grows.

$$f_i = \text{Max} \left[\frac{24}{\text{Re}}, 0.043 \cdot (\delta^*)^{0.72} \right]$$

Model Development: Inverted Annular Film Boiling

- Vapor-Liquid Interfacial Friction: Proposed Model
 - Calculated behavior of interfacial friction factor vs. Reynolds no.
 - ➔ Reduces to smooth parallel plate for low Reynolds no.
 - ➔ Is linearly proportional to vapor Reynolds no. when surface waves govern its value.

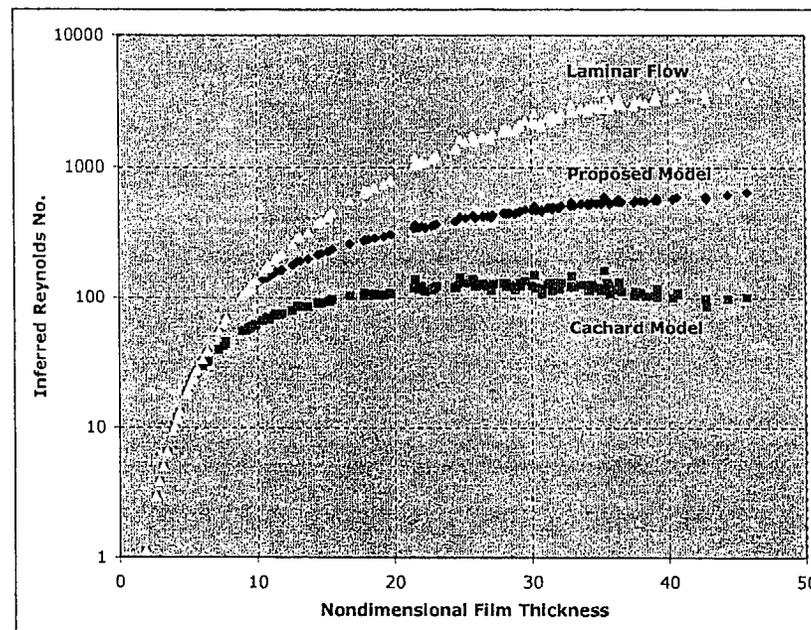


Model Development: Inverted Annular Film Boiling

■ Vapor-Liquid Interfacial Friction: Proposed Model

● Calculated behavior of vapor Reynolds no. vs. film thickness:

- ▶ Vapor Reynolds no. increases monotonically with respect to vapor film thickness (as expected).
- ▶ Avoids unrealistically high vapor Reynolds no. values associated with smooth laminar flow assumption as the vapor film thickness grows.



TRACE:

Interim Reflood Model Development

■ SUMMARY

- Interim reflood model has been developed and is beginning process of developmental assessment.
- Preliminary tests show that overall accuracy is somewhat better than that of RELAP5 for forced flooding rate tests.
 - In particular, calculated results for void fraction and vapor temperature do not exhibit the large oscillations seen in RELAP5 results.
 - Improvement needed for peak rod temperatures, quenching in upper part of bundle, and void fraction for high flooding rate tests.
- Computational efficiency is worse than that of RELAP5.
 - Grind time is about 4 times higher.
 - NOTE: RELAP5 pipe vs. TRACE 1-D vessel.
 - Effort is needed to improve TRACE's run time performance.
- Future reflood model development will be undertaken making usage of PSU/RBHT data and the droplet field.



United States Nuclear Regulatory Commission

TRACE: Tube Condensation Model Development

Presented to the ACRS Thermal-Hydraulic and Severe
Accident Subcommittee

by

Joseph M. Kelly

Birol Aktas (ISL)

Nov. 20, 2003

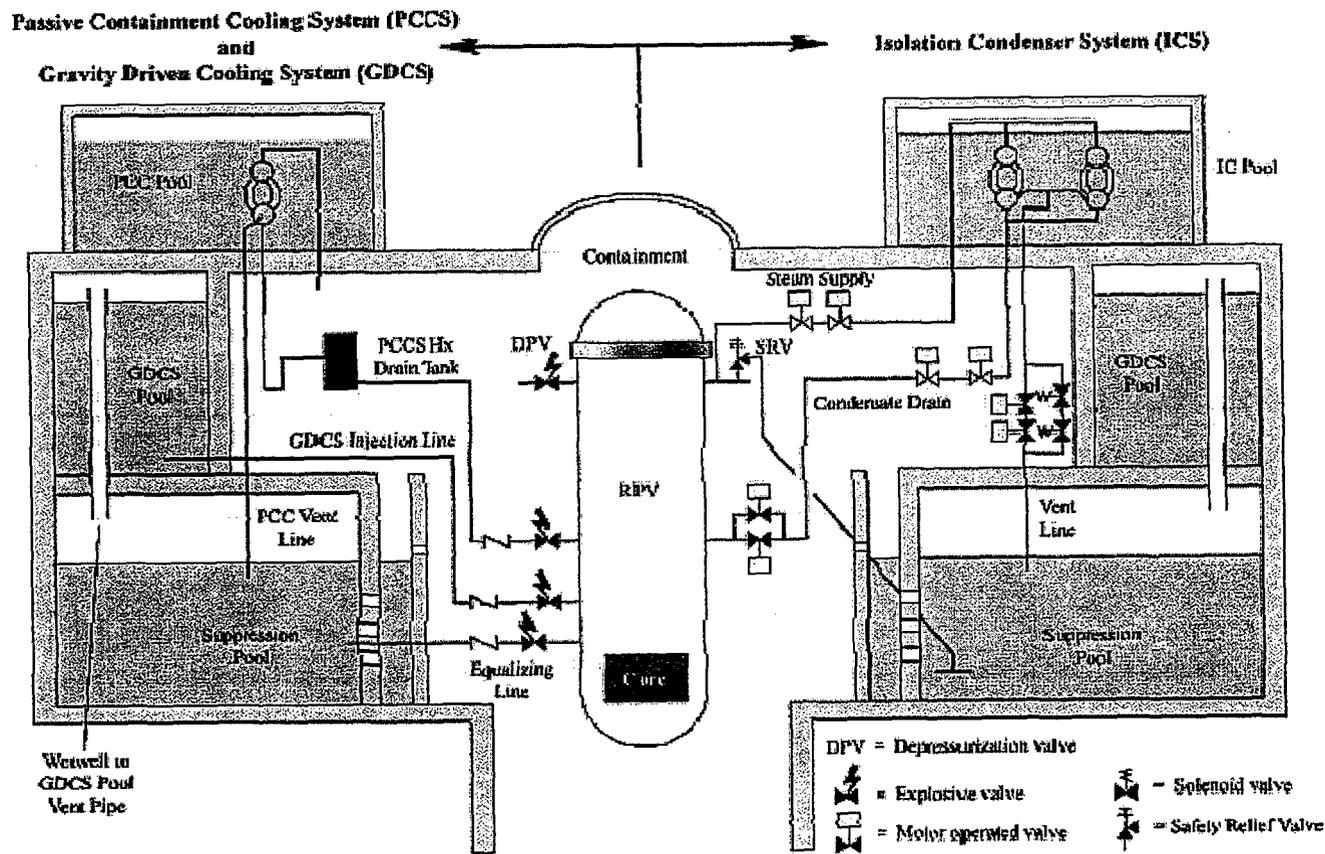
TRACE: Tube Condensation Model Development

■ CONTENTS

- Introduction
 - ➔ ESBWR: ICS & PCCS systems
 - ➔ TRACE condensation model (same as TRAC/PF1-Mod2)
- “Investigatory” Model Assessment
 - ➔ Are current models adequate?
- Model Development Effort
 - ➔ This is a work in progress, only a partial description of the following models will be provided:
 - Wall Friction
 - Interfacial Shear
 - Wall-Fluid Heat Transfer
 - Interfacial Heat Transfer
 - Non-Condensable Gas Effect (will be discussed next time)
- Summary

Introduction

■ ESBWR: ICS & PCCS systems



Introduction: TRACE Condensation Models

■ Wall Heat Transfer

- Total wall heat flux for condensation regime:

$$q_w'' = h_{wv} \cdot (T_w - T_{sat}) + h_{wl} \cdot (T_w - T_l)$$

- ➔ Note that vapor contribution uses the saturation temperature (at the bulk vapor partial pressure) while the liquid contribution uses its phasic temperature.

- Phasic heat transfer contributions ramped by:

$$h_{wv} = f \cdot h_{v,cond} + (1 - f) \cdot h_{v,conv}$$

$$h_{wl} = (1 - f) \cdot h_{l,conv}$$

- ➔ where

$$f = (x - x_{chen}) / (1 - x_{chen})$$

- ➔ static mixture enthalpy is used to compute the quality, and

$$x_{chen} = 0.71$$

Introduction: TRACE Condensation Models

■ Wall-Vapor Condensation HTC:

$$h_{v,cond} = (1-w) \cdot h_{v,cond} + w \cdot \text{Max}(h_{v,cond}, h_2)$$

● Nusselt Formula for Laminar Film Condensation:

$$h_{v,cond} = 0.9428 \cdot \left[\frac{\rho_l^2 \cdot g \cdot k_l^3 \cdot h_{fg}}{\mu_l \cdot L \cdot (T_{sat} - T_w)} \right]^{\frac{1}{4}}$$

● Empirical Formula for Turbulent Film Condensation:

$$h_2 = 0.003 \cdot \left[\frac{\rho_l^2 \cdot g \cdot k_l^3 \cdot L \cdot (T_{sat} - T_w)}{\mu_l^3 \cdot h_{fg}} \right]^{\frac{1}{2}}$$

● Weighting Factor:

$$w = \text{Min} \left[1, \text{Max} \left[0, (L - 0.2) / 1.8 \right] \right]$$

$$L = \Delta Z$$

Introduction: TRACE Condensation Models

■ Wall-Liquid Convective HTC:

$$h_{l,conv} = \text{Max}[h_{NC1}, h_{NC2}, h_{fc}]$$

● Two-Phase Turbulent Convection:

$$h_{fc} = 0.023 \cdot \text{Re}_l^{0.8} \cdot \text{Pr}_l^{0.4} \cdot F$$

➔ where F is the “flow factor” of the Chen correlation.

● Natural Convection:

$$h_{NC1} = 0.59 \cdot \frac{k_l}{D_h} \cdot \text{Gr}_l^{0.25} \cdot \text{Pr}_l^{0.25}$$

$$h_{NC2} = 0.10 \cdot \frac{k_l}{D_h} \cdot \text{Gr}_l^{0.333} \cdot \text{Pr}_l^{0.333}$$

$$\text{Gr}_l = \frac{g \cdot \beta \cdot |T_w - T_l| \cdot \rho_l^2 \cdot L^3}{\mu_l^2}$$

Introduction: TRACE Condensation Models

■ Interfacial Heat Transfer

● Non-Condensable Gas Effect

- ➔ Empirical model of Sklover & Rodivilin developed for cross-flow of gas-vapor mixtures on liquid jets is used.

$$\frac{h_{li,NC}}{h_{li}} = 0.366 \cdot \left(\frac{\rho_v}{\rho_a} \right)^{0.2} \cdot \left(\frac{G_v}{G_l} \right)^{0.2}$$

- ➔ The normal liquid-interface HTC is decremented using the above formula, this has the effect of reducing condensation due to wall-liquid heat transfer, but
- ➔ It has no effect upon condensation due to wall-vapor heat transfer, and
- ➔ Its application to in-tube condensation for downward co-current flow is questionable at best.

Introduction: TRACE Condensation Models

■ Summary:

- TRAC/PF1-Mod2 model is overly complicated:
 - ➔ Superposes wall-liquid and wall-vapor heat fluxes over a wide range of conditions, so that
 - ➔ Difficult to know which model is actually being used.
- Inappropriately uses analytical condensation models
 - ➔ Analytical models integrate the condensation rate over the entire heat transfer surface to get an average film thickness, but
 - ➔ TRAC applies these models as if each individual node is the entire heat transfer surface, introduces an explicit node size effect.
- No effect of interfacial shear on condensation heat transfer.
 - ➔ Except through the flow factor of Chen for wall-liquid heat transfer.
- No effect of non-condensable gases upon wall-vapor condensation:
 - ➔ Except through decrease of driving potential due to effect of bulk gas partial pressure upon the saturation temperature.
 - ➔ Empirical model applied to wall-liquid interfacial heat transfer but its applicability is questionable.

Tube Condensation: Investigatory Assessment

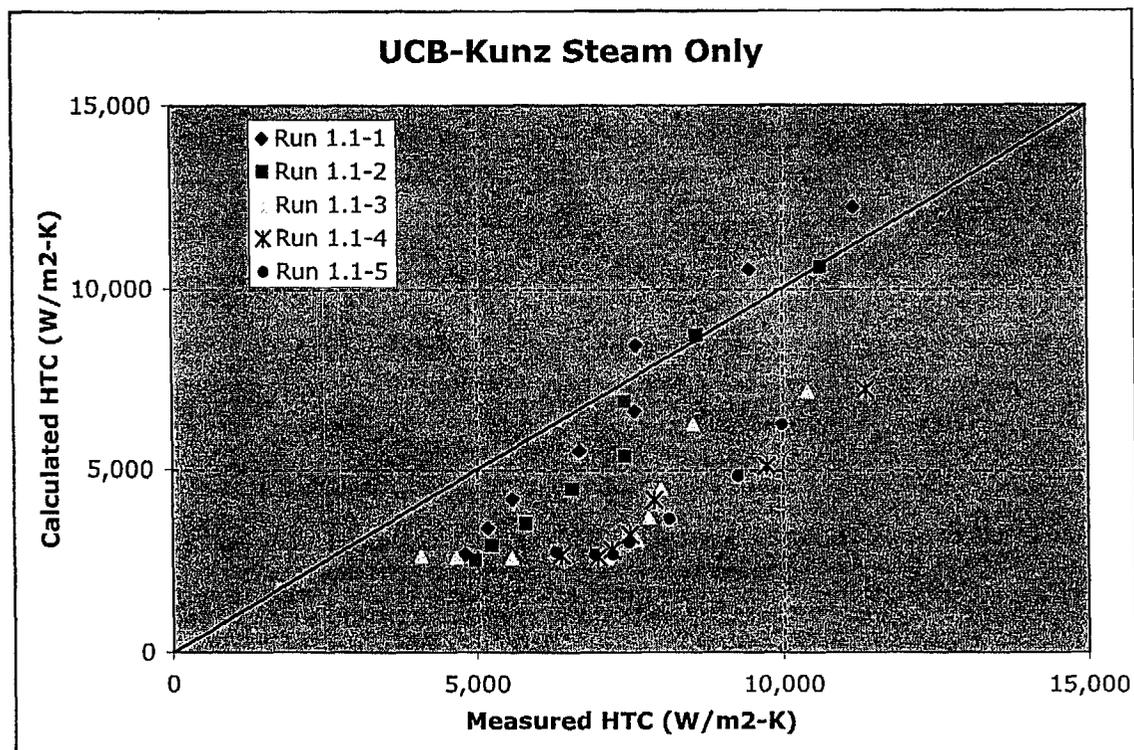
■ Test Matrix

	Run No.	Pressure (bar)	Gas Reynolds No.	Film Reynolds No.	NC Gas Mass Fraction (%)
Laminar Film UCB - Kunz (Steam Only)	1.1-1	1.16	35,400	113	-
	1.1-2	2.02	33,900	180	-
	1.1-3	3.07	30,500	385	-
	1.1-4	4.07	29,000	400	-
	1.1-5	5.04	28,200	495	-
Turbulent Film NASA - Goodykoontz	172	1.77	113,300	6060	-
NC Gas Effect MIT - Siddique	7A	2.08	5800	63	8
	8A	2.17	5900	61	14
	25A	2.14	12,700	134	11
	52A	4.78	22,733	437	35

Tube Condensation: Investigatory Assessment

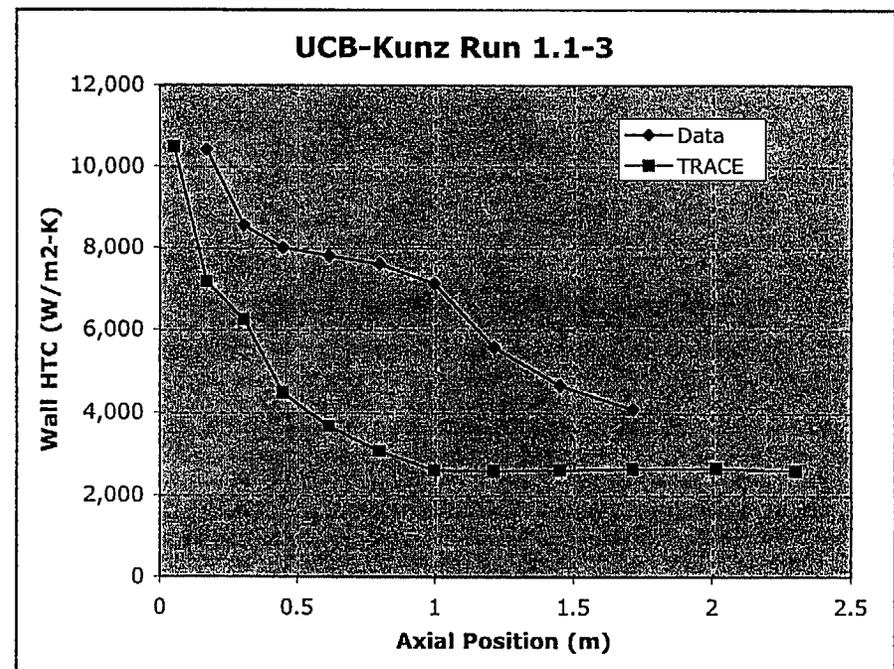
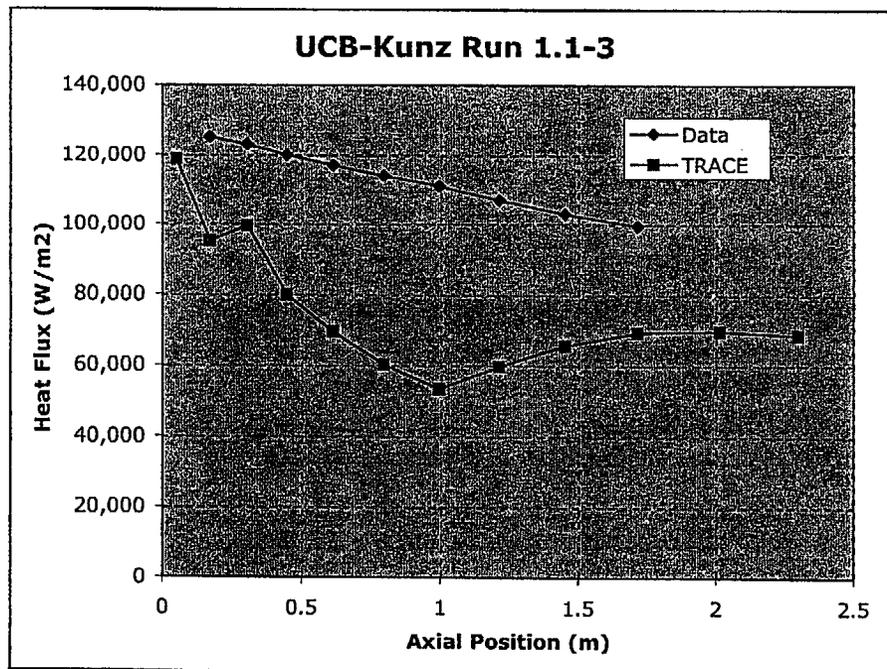
■ Laminar Film Condensation:

- A few low pressure points are well predicted.
- Most have a large under-prediction that worsens as pressure increases.



Tube Condensation: Investigatory Assessment

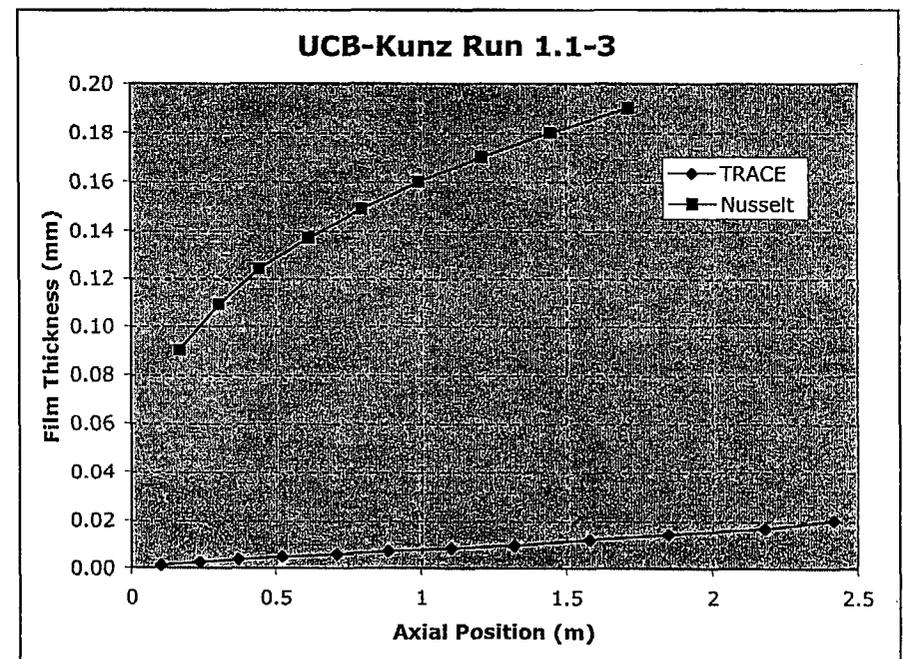
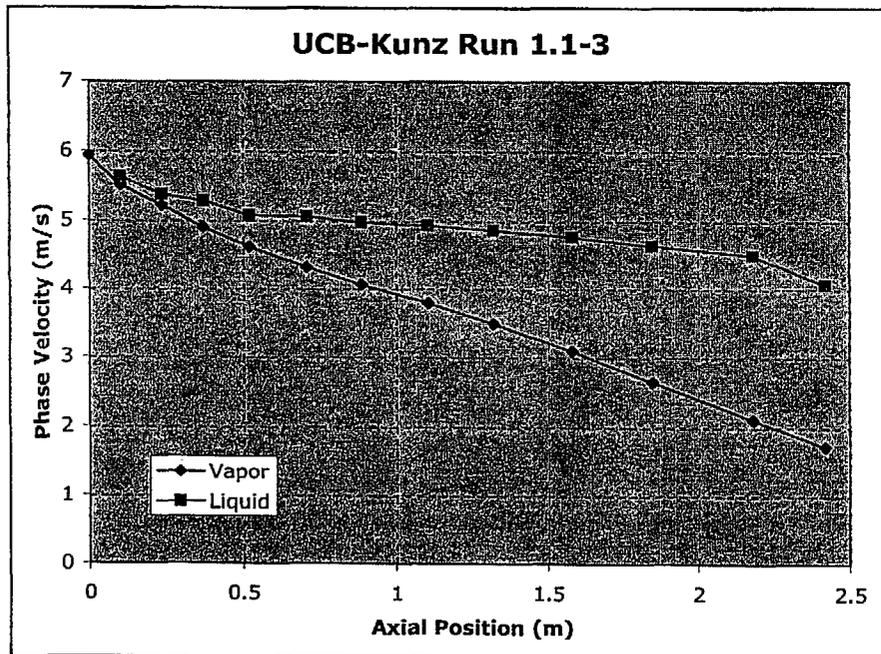
- Laminar Film Condensation:
 - Significant under-prediction of wall heat transfer.
 - Axial trend does not match that of data.



Tube Condensation: Investigatory Assessment

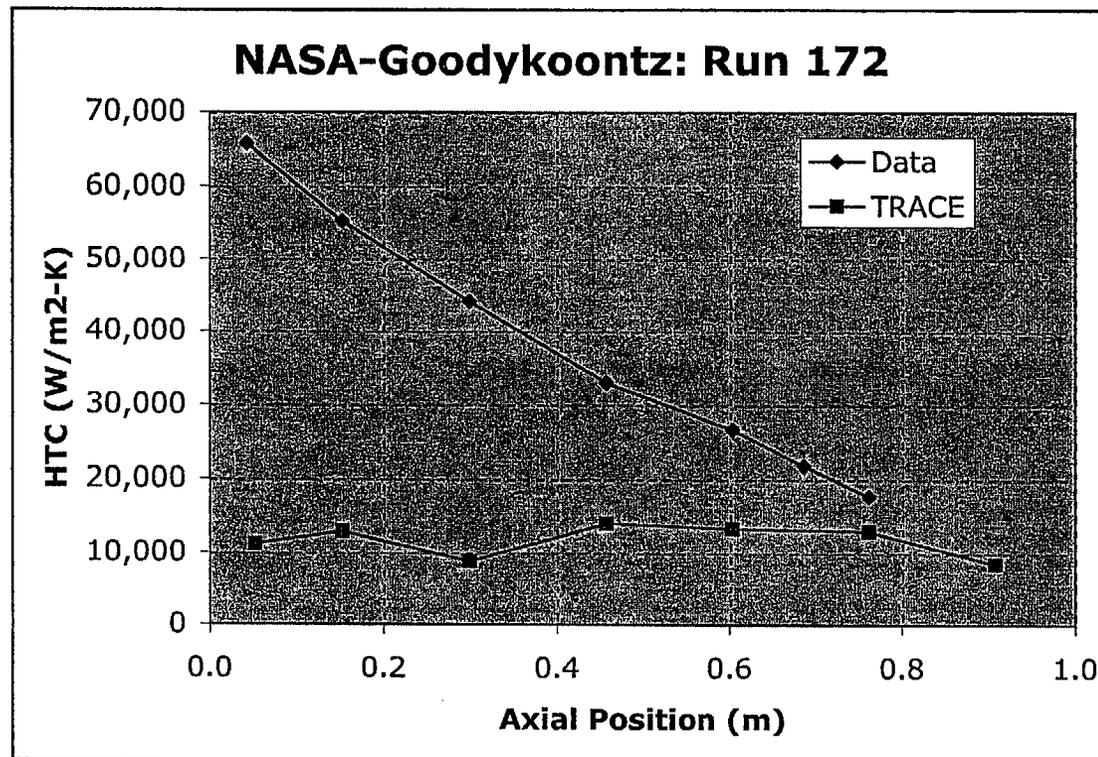
■ Laminar Film Condensation:

- Unphysical behavior for liquid film velocity.
- Film thickness is an order of magnitude too small.



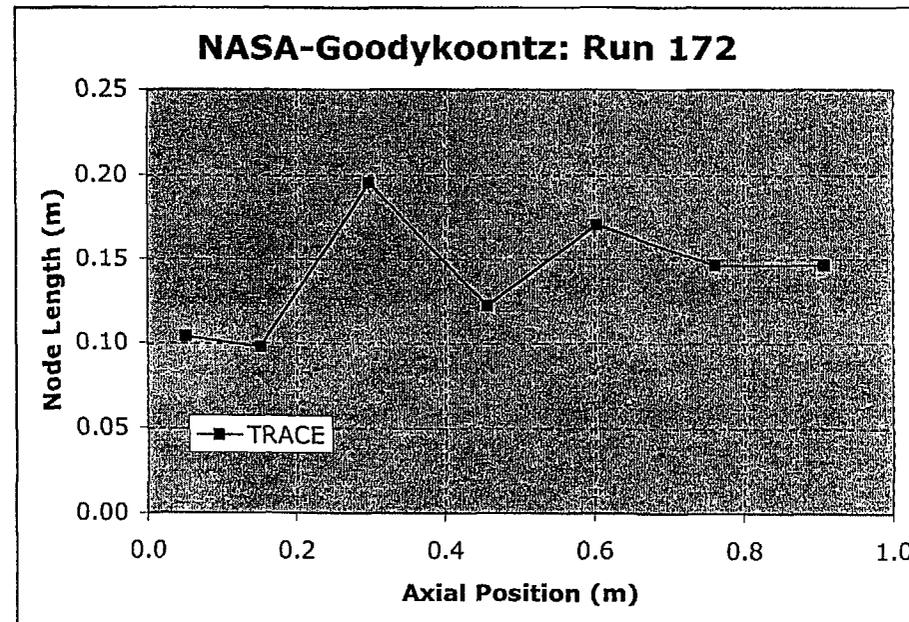
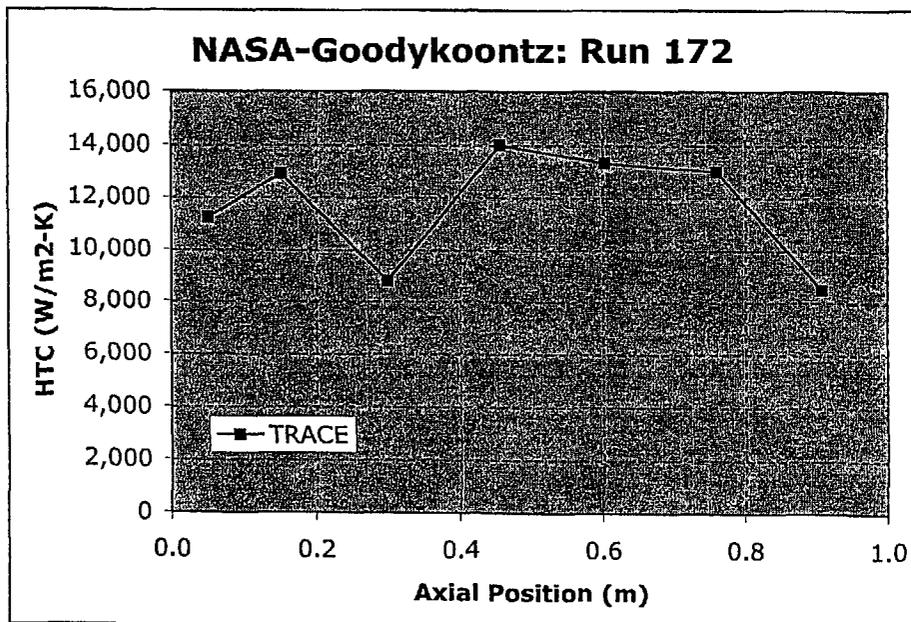
Tube Condensation: Investigatory Assessment

- Turbulent Film Condensation:
 - Large under-prediction of heat transfer.



Tube Condensation: Investigatory Assessment

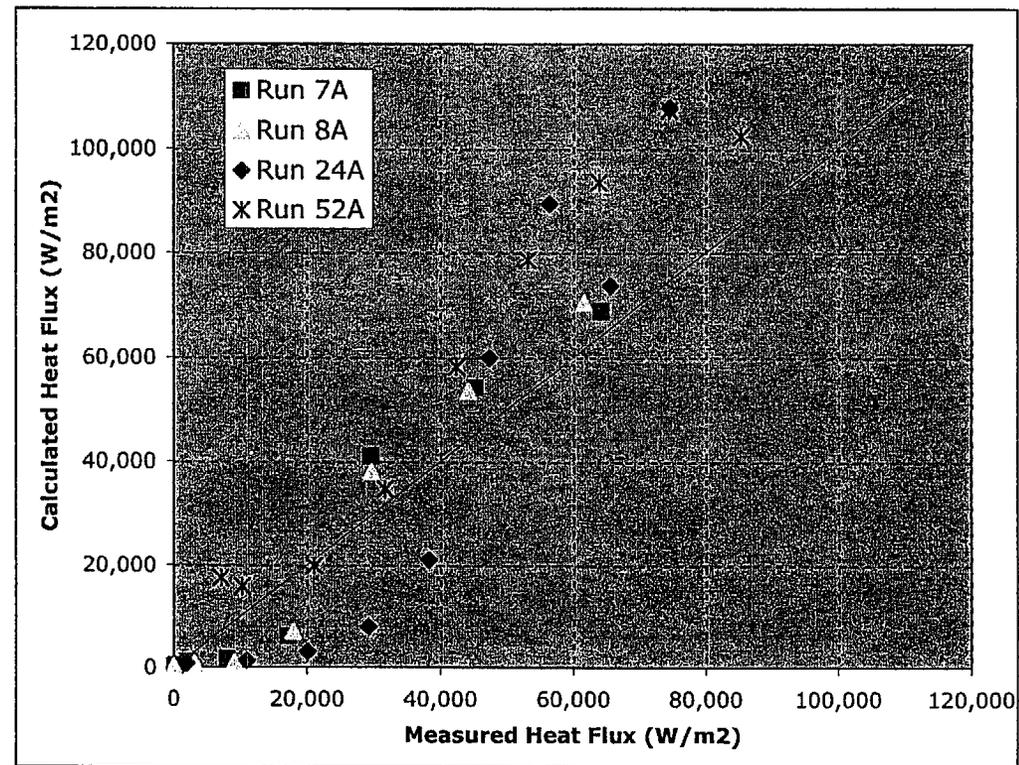
- Turbulent Film Condensation:
 - Wall heat transfer indicates node size effect.



Tube Condensation: Investigatory Assessment

■ Non-Condensable Gas Effect:

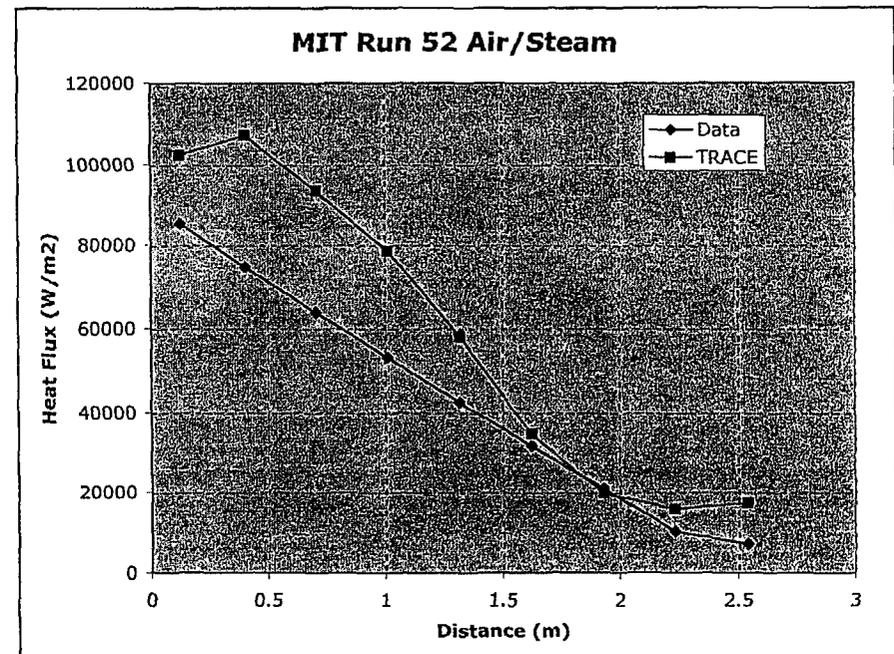
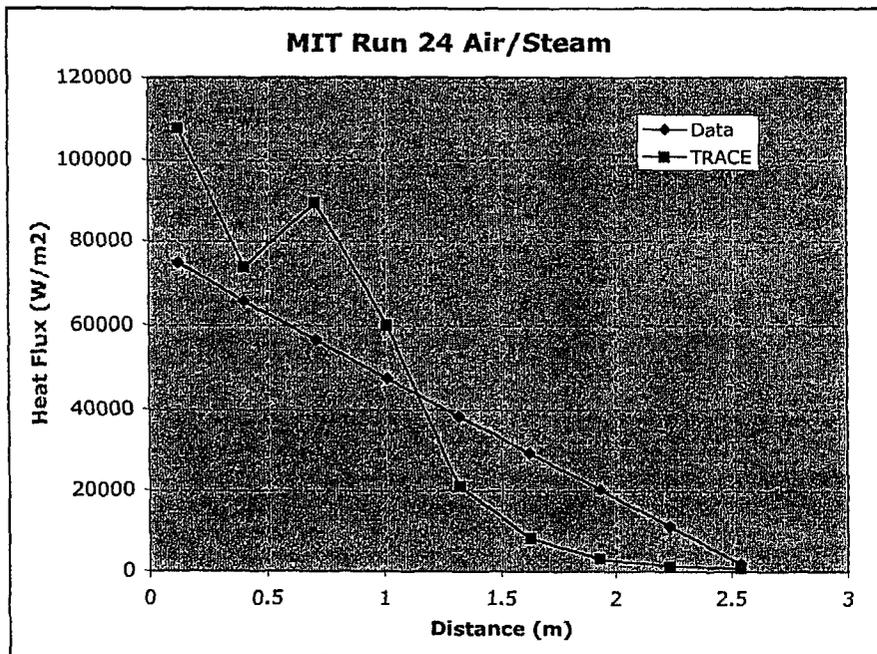
- Consistent over-prediction of wall heat transfer until the driving potential is reduced due to the over-condensation.



Tube Condensation: Investigatory Assessment

■ Non-Condensible Gas Effect:

- Over-prediction of wall heat transfer at inlet until the driving potential is reduced due to the over-condensation.
- Non-monotonic behavior of the HTC with axial position due to regime changes.



Tube Condensation: Investigatory Assessment

■ SUMMARY

- Significant deficiencies exist in the TRAC-PF1/Mod2 condensation models, specifically
 - ➔ Overall poor prediction:
 - Under-predicts pure steam condensation,
 - Over-predicts condensation with non-condensable gases,
 - ➔ Film Thickness and Liquid Velocity:
 - Partitioning of the wall drag leads to unphysical result.
 - ➔ No effect of interfacial friction on condensation HTC's.
 - ➔ Wall HTC's can be directly dependent upon node size.
 - Incorrect usage of node size as characteristic length.
 - ➔ Non-condensable gas effect:
 - No model for wall-vapor condensation.
 - Questionable model used for liquid-interface HTC.

Tube Condensation: Model Development Effort

■ Objective

- Implement a model in TRACE for in-tube condensation that is applicable to the ICS and PCCS systems of the ESBWR design.

■ Approach

- Model should be compatible with two-fluid numerical framework.
- Model should take advantage of quantities computed by TRACE through the solution of the conservation equations:
 - ➔ e.g., axial distribution of the condensate flow rate and film thickness
 - ⊗ then, the Nusselt formula becomes: $h = k_l/\delta$
- Model will first be implemented as a specialized package applied to pipes that are labeled “condenser tubes”:
 - ➔ can be added to TRACE without changing all previous results, and
 - ➔ models proved to be generically applicable can then be migrated over to the normal constitutive package.

Tube Condensation: Model Development Effort

■ Film Condensation

● Normal Representation

$$q_w'' = h_{cond} \cdot (T_w - T_{sat})$$

● Two-Fluid Model

$$q_w'' = h_{wl} \cdot (T_w - T_i)$$

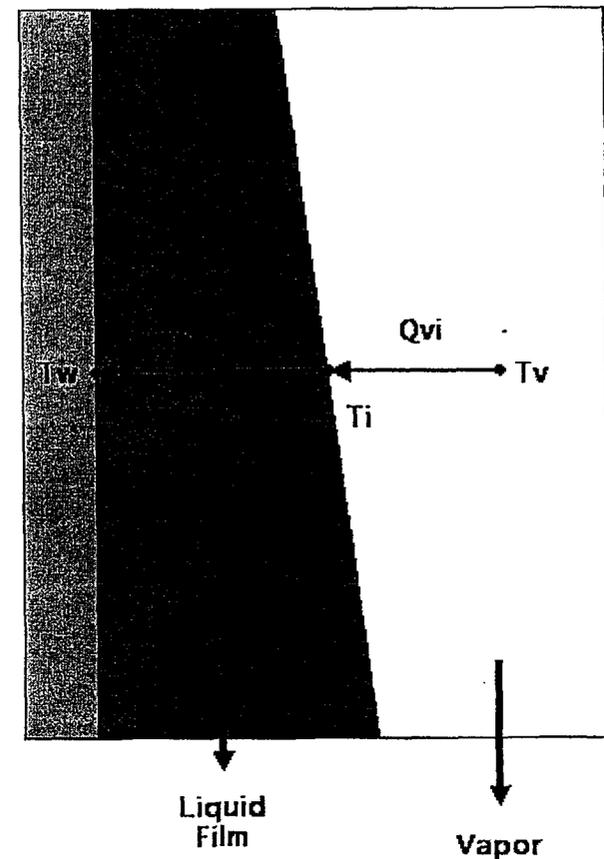
$$\Gamma = \frac{q_{li} + q_{vi}}{h_{fg}}$$

→ where

$$q_{li} = h_{li} \cdot A_i \cdot (T_l - T_i)$$

$$q_{vi} = h_{vi} \cdot A_i \cdot (T_v - T_i)$$

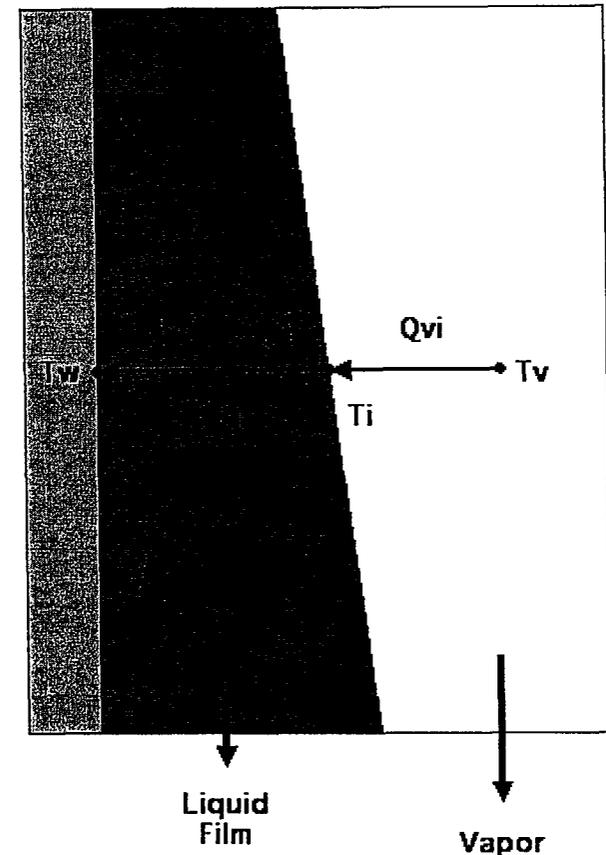
→ and T_i is the saturation temperature at the bulk vapor partial pressure.



Tube Condensation: Model Development Effort

■ Film Condensation

- Model Requirements
 - ➔ Condensation with pure steam and steam-NC gas mixtures
 - ➔ Applicable to both falling and sheared films
- Models Needed
 - ➔ Film Thickness
 - ⊙ Wall Friction
 - ⊙ Interfacial Shear
 - ➔ Wall Heat Transfer
 - ⊙ Wall-Liquid HTC
 - ➔ Interfacial Heat Transfer
 - ⊙ Liquid-Interface HTC
 - ⊙ Vapor-Interface HTC
 - ⊙ Non-Condensable Gas Effect



Tube Condensation: Model Development Effort

■ Film Thickness: Falling Film

- Results from balance of gravitational and wall drag forces on the liquid film.

➔ for steady, fully-developed flow with no mass transfer

$$\alpha \cdot (1 - \alpha) \cdot g \cdot \Delta \rho = f_w \cdot \frac{1}{2} \cdot \rho_l \cdot V_l^2 \cdot \frac{4}{D_h}$$

➔ or, in terms of the liquid Reynolds no.

$$\alpha \cdot (1 - \alpha)^3 \cdot g \cdot \Delta \rho = 2 \cdot f_w \cdot \text{Re}_l^2 \cdot \frac{\mu_l^2}{\rho_l \cdot D_h^3}$$

➔ with the usual thin film assumption , we have

$$\delta = \left[\frac{f_w \cdot \text{Re}_l^2}{32} \cdot \frac{\mu_l^2}{g \cdot \Delta \rho \cdot \rho_l} \right]^{\frac{1}{3}}$$

Tube Condensation: Model Development Effort

■ Film Thickness: Falling Film

➔ Defining a non-dimensional film thickness

$$\delta^* = \delta \cdot \left[\frac{g \cdot \Delta\rho \cdot \rho_l}{\mu_l^2} \right]^{\frac{1}{3}}$$

➔ We have

$$\delta^* = \left[\frac{f_w \cdot \text{Re}_l^2}{32} \right]^{\frac{1}{3}}$$

➔ Introducing the parallel plate friction factor for laminar flow

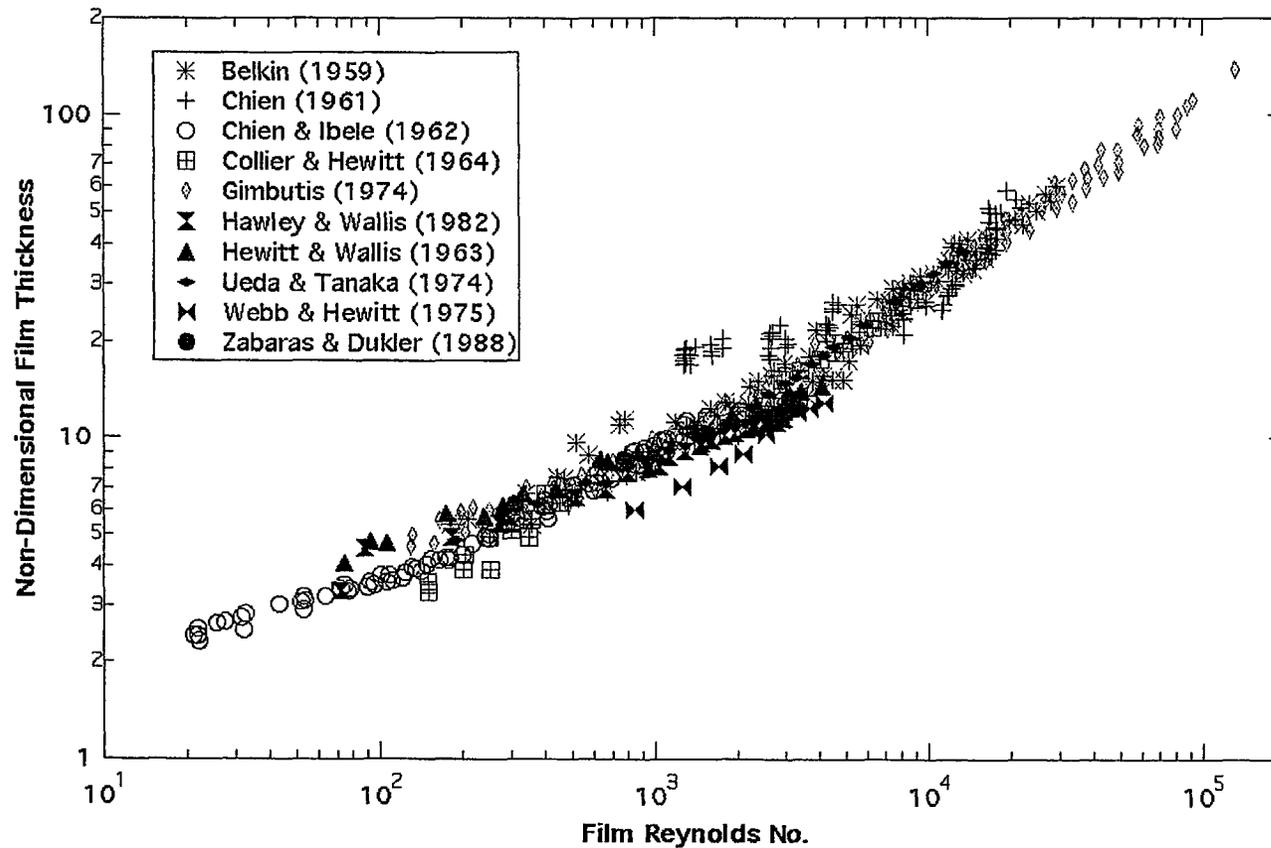
$$f_w = \frac{24}{\text{Re}_l}$$

➔ Yields the classic result of Nusselt

$$\delta^* = \left[\frac{3}{4} \cdot \text{Re}_l \right]^{\frac{1}{3}}$$

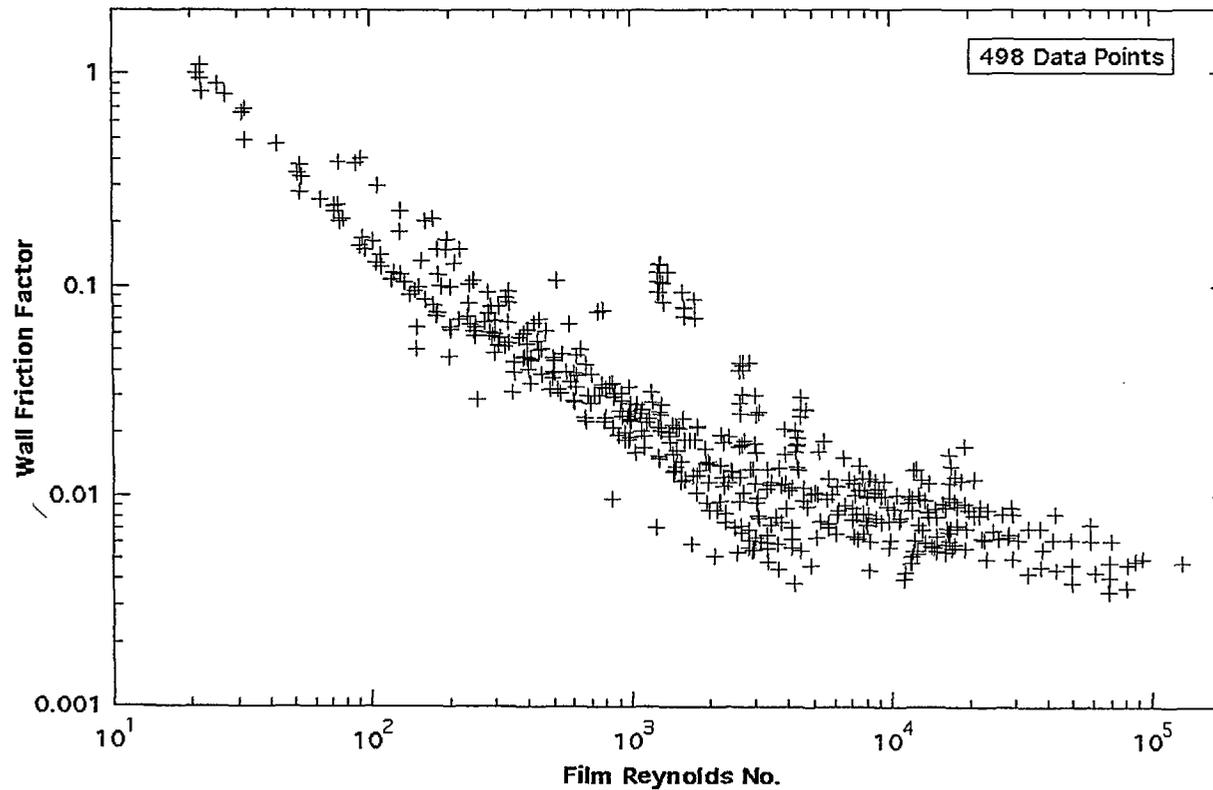
Tube Condensation: Model Development Effort

■ Film Thickness: Falling Film



Tube Condensation: Model Development Effort

- Film Thickness: Falling Film
 - Translate film thickness data to friction factor vs. Re



Tube Condensation: Model Development Effort

■ Film Thickness: Falling Film

● Wall Friction - Proposed Model

➔ Laminar

- ⊗ Parallel plate formula for a smooth laminar film

$$f_l = \frac{24}{Re_l}$$

- » Note: will slightly over-predict film thickness due to neglecting effect of ripples, this effect will be taken into account in the wall heat transfer model.

➔ Turbulent

- ⊗ Haaland explicit approximation of Colebrook-White

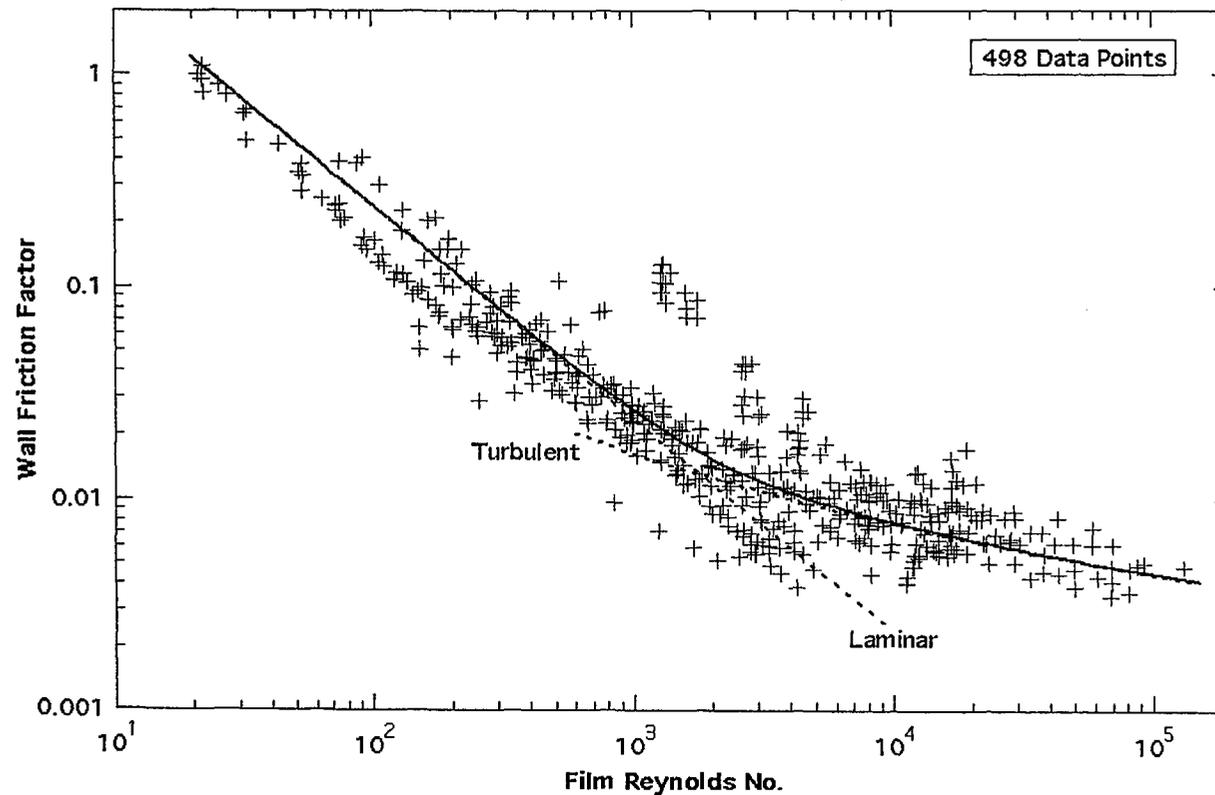
$$f_t = \left[3.6 \cdot \log_{10} \left(\frac{6.9}{Re_l} + \left[\frac{\varepsilon/D}{3.7} \right]^{1.11} \right) \right]^{-2}$$

➔ Power-Law Combination

$$f_w = \left[f_l^3 + f_t^3 \right]^{\frac{1}{3}}$$

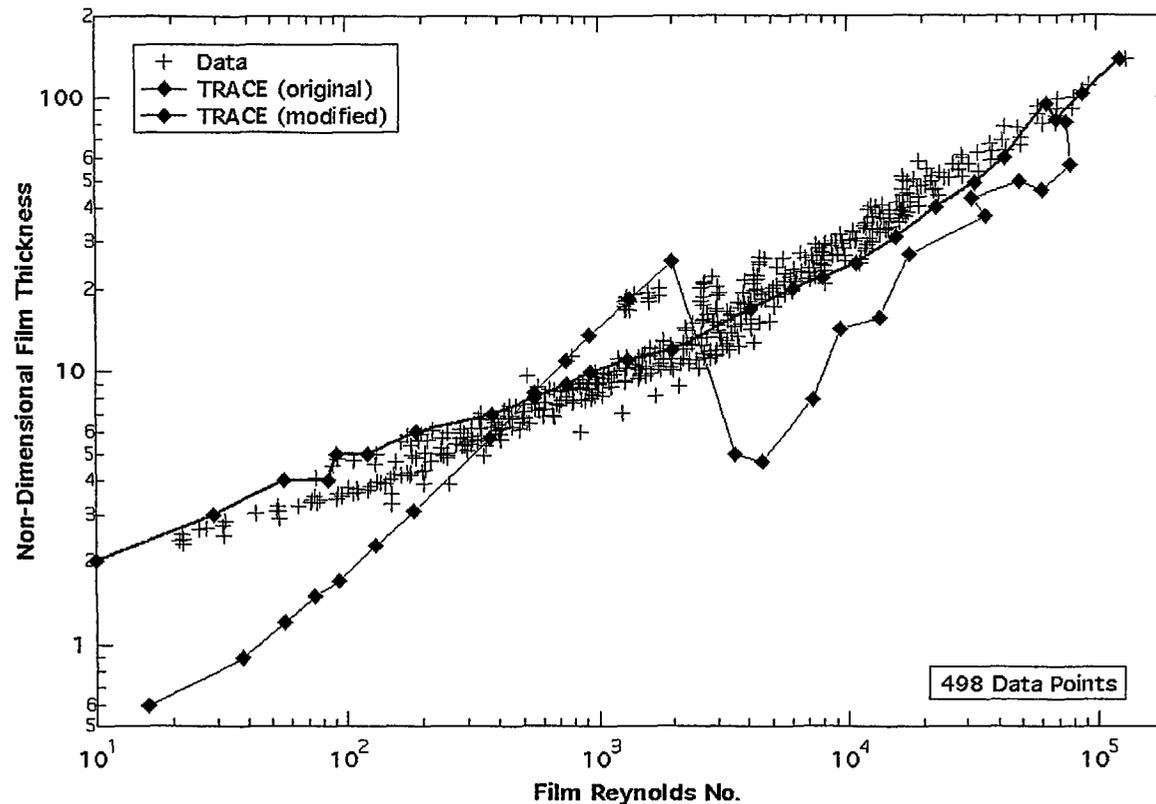
Tube Condensation: Model Development Effort

- Film Thickness: Falling Film
 - Wall Friction Factor - Proposed Model



Tube Condensation: Model Development Effort

- Film Thickness: Falling Film
 - TRACE Results



Tube Condensation: Model Development Effort

■ Film Thickness: Sheared Films

● Selection of Interfacial Friction Model

➔ Use data of Andreussi-Zanelli for co-current downflow

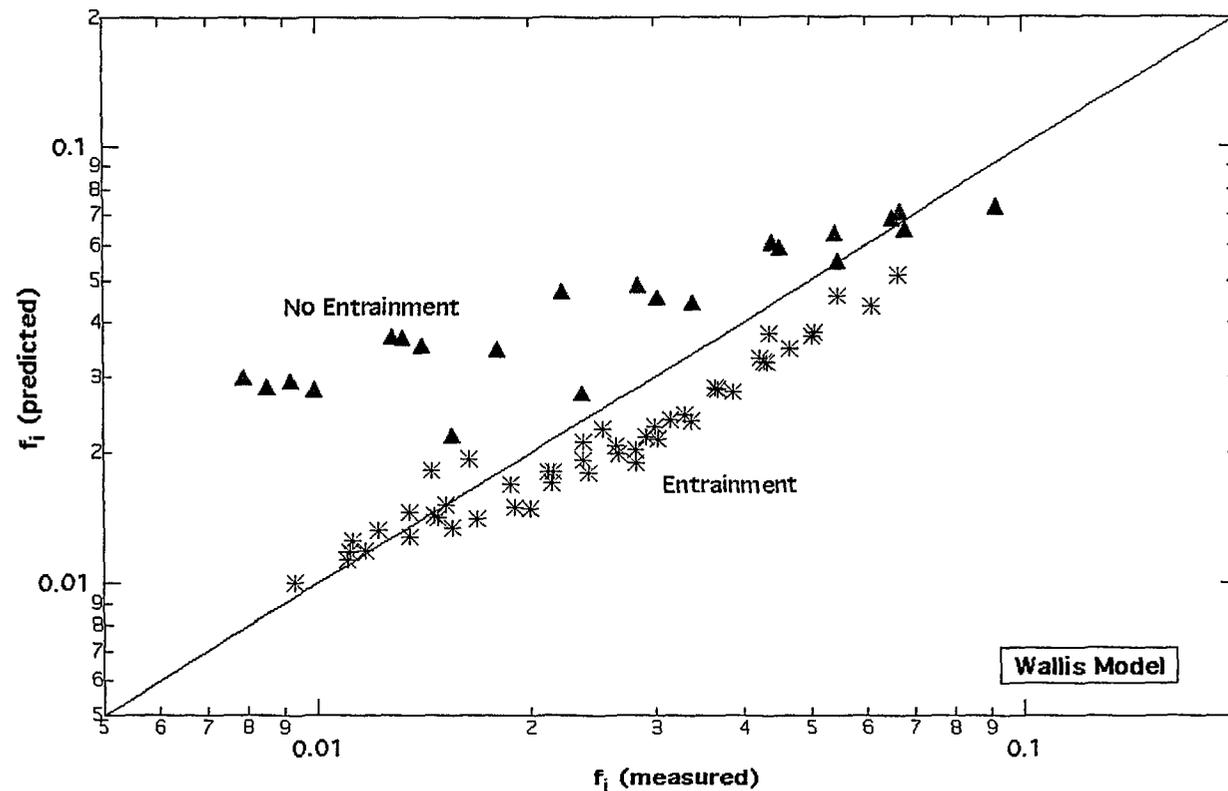
- Measured film thickness, pressure gradient and entrainment fraction.
- Reduced data to give values of the interfacial friction coefficient.

➔ Compare interfacial friction models of

- Wallis (1969)
- Modified Wallis
 - » uses friction factor as $f_n(\text{Re})$
- Henstock-Hanratty (1976)
- Bharathan (1979)
 - » developed for counter-current flow
- Asali-Hanratty (1985)
 - » models with and without entrainment
- Jayanti-Hewitt (1997)
 - » ripple & disturbance wave models

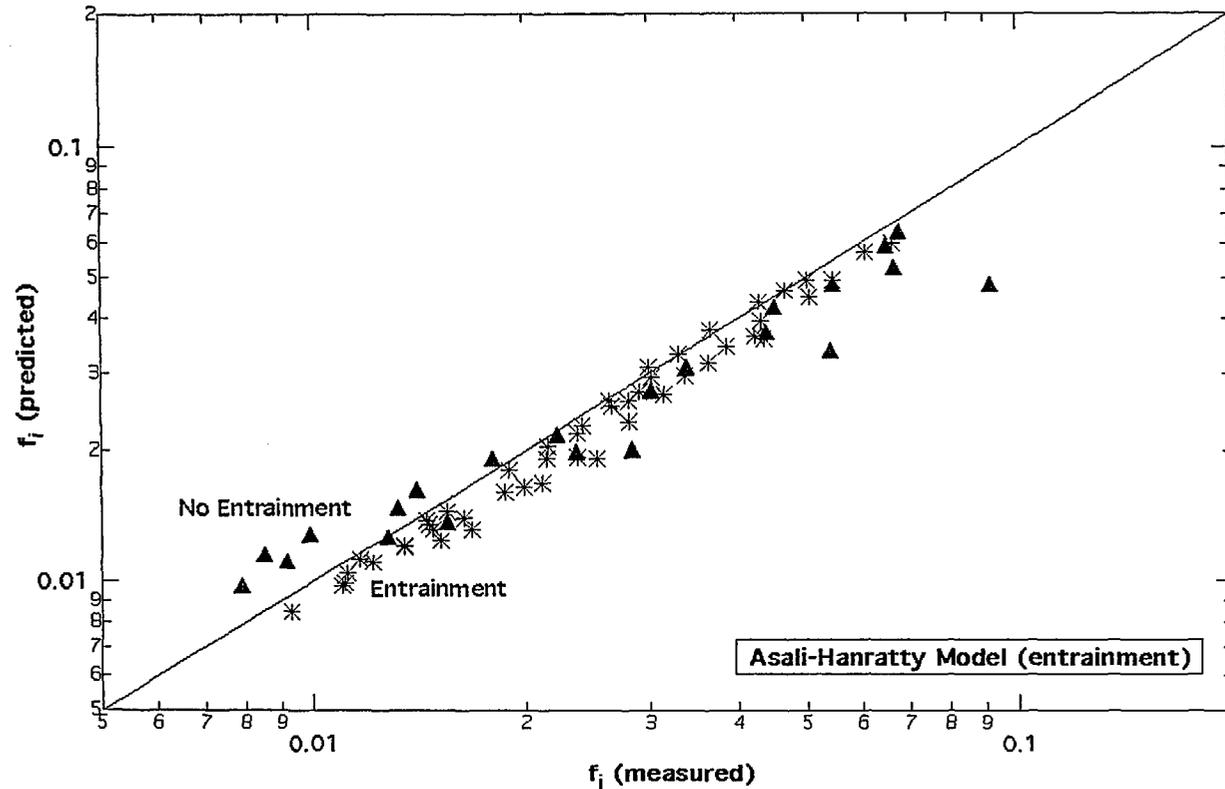
Tube Condensation: Model Development Effort

- Film Thickness: Sheared Films
 - Selection of Interfacial Friction Model



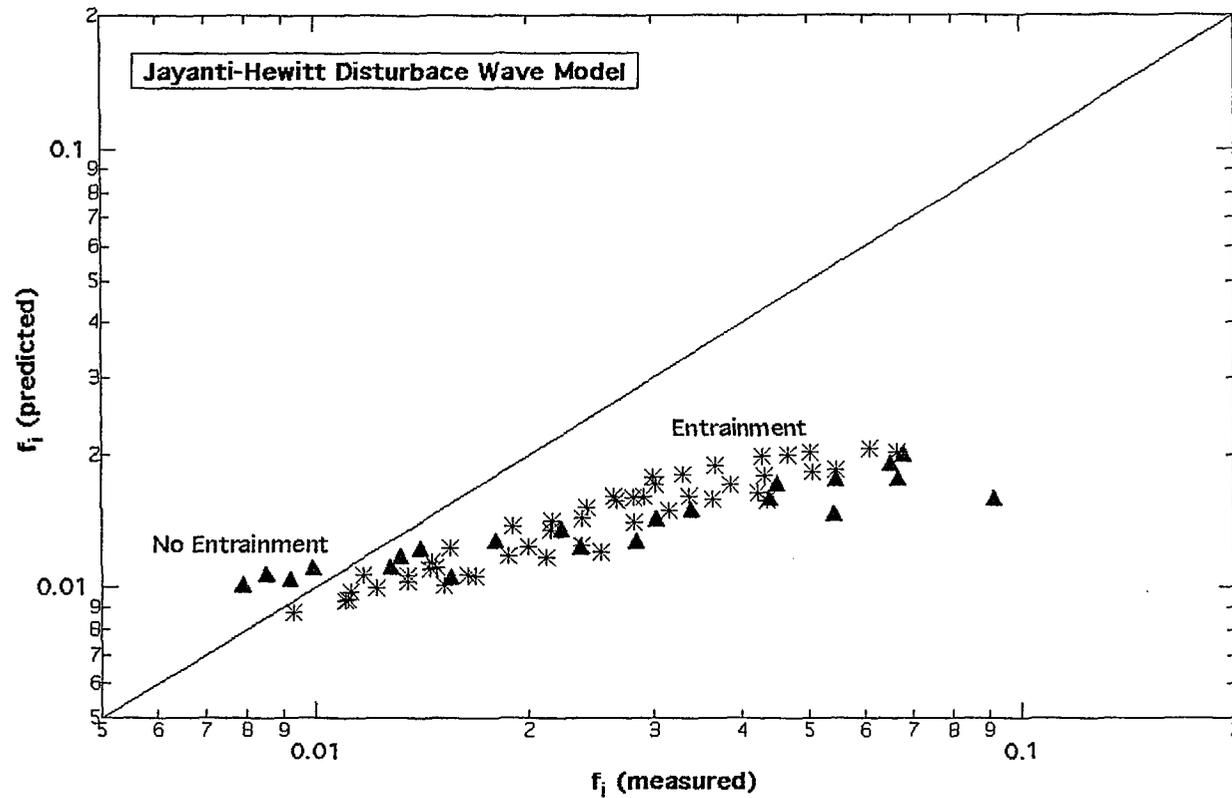
Tube Condensation: Model Development Effort

- Film Thickness: Sheared Films
 - Selection of Interfacial Friction Model



Tube Condensation: Model Development Effort

- Film Thickness: Sheared Films
 - Selection of Interfacial Friction Model



Tube Condensation: Model Development Effort

- Film Thickness: Sheared Films
 - Selection of Interfacial Friction Model

Model	Average Error	Maximum Error	RMS Error
Wallis ($f_s = 0.005$)	-0.176	-2.801	0.517
Wallis ($f_s = f(Re)$)	0.400	5.055	1.480
Henstock-Hanratty	2.266	11.13	1.489
Asali-Hanratty (no entrainment)	-0.165	-0.642	0.049
Asali-Hanratty (entrainment)	-0.076	0.364	0.0226
Bharathan	1.425	6.160	6.612
Jayanti-Hewitt (ripple wave)	-0.396	-0.8252	0.212
Jayanti-Hewitt (disturbance wave)	-0.453	0.718	0.302

Tube Condensation: Model Development Effort

■ Film Thickness: Sheared Films

● Selection of Interfacial Friction Model: Asali-Hanratty

$$\frac{f_i}{f_s} - 1 = 0.45 \cdot \text{Re}_g^{-0.2} \cdot (m_g^+ - 5.9)$$

⊗ where

$$m_g^+ = m \cdot \sqrt{\frac{\tau_i}{\rho_g}} / v_g$$

➔ Problem:

- ⊗ model uses the interfacial shear stress to calculate the interfacial friction factor and is thus implicit.

➔ Solution:

- ⊗ substitute for the interfacial shear stress and solve quadratic eq. to create an explicit formulation.

Tube Condensation: Model Development Effort

- Film Thickness: Sheared Films
 - Selection of Interfacial Friction Model: Asali-Hanratty
 - ➔ Explicit formulation

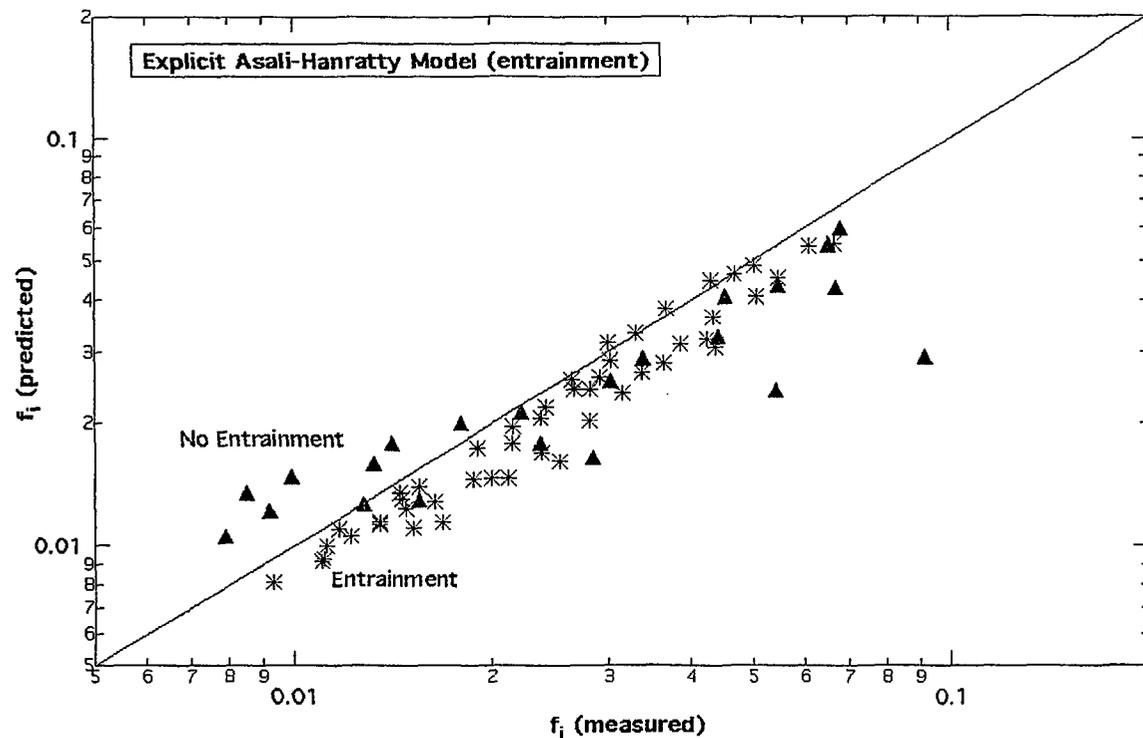
$$f_i = \left\{ \frac{-b + \sqrt{b^2 - 4 \cdot c}}{2} \right\}^2$$

● where

$$b = -\frac{0.45 \cdot f_s \cdot m \cdot V_{rel}}{\sqrt{2} \cdot \text{Re}_g^{0.2} \cdot v_g}$$
$$c = f_s \cdot \left(-1 + 5.9 \cdot \frac{0.45}{\text{Re}_g^{0.2}} \right)$$

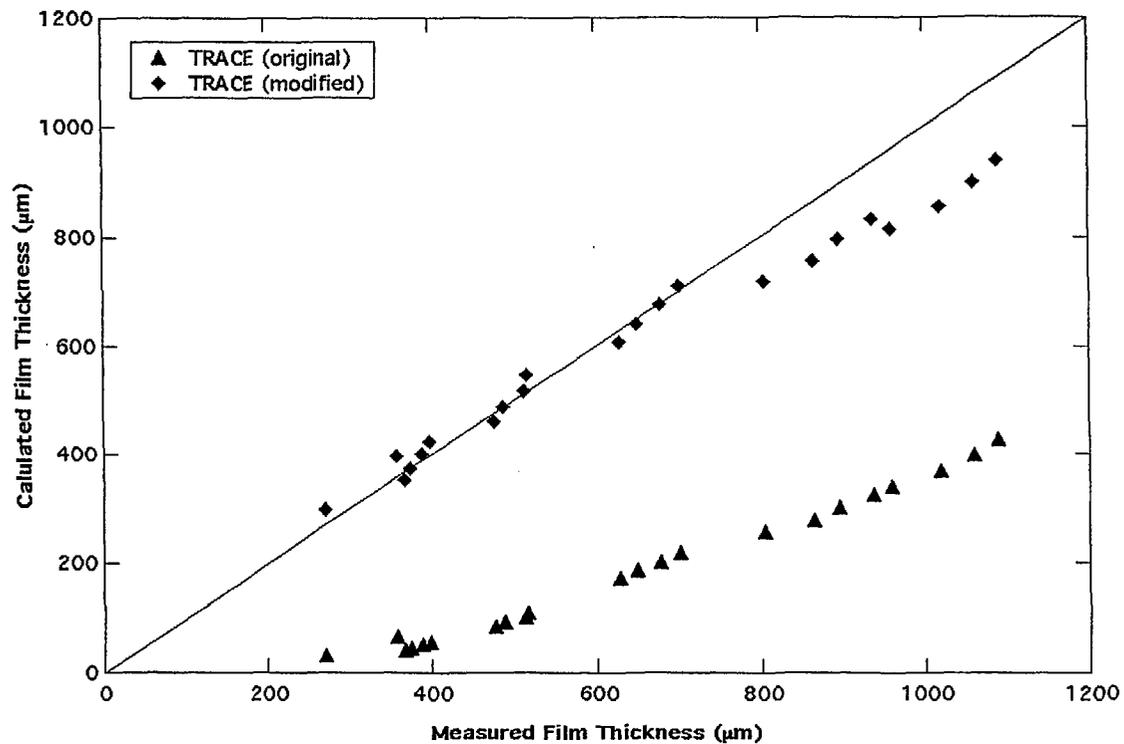
Tube Condensation: Model Development Effort

- Film Thickness: Sheared Films
 - Selection of Interfacial Friction Model: Asali-Hanratty
 - ➔ Explicit formulation



Tube Condensation: Model Development Effort

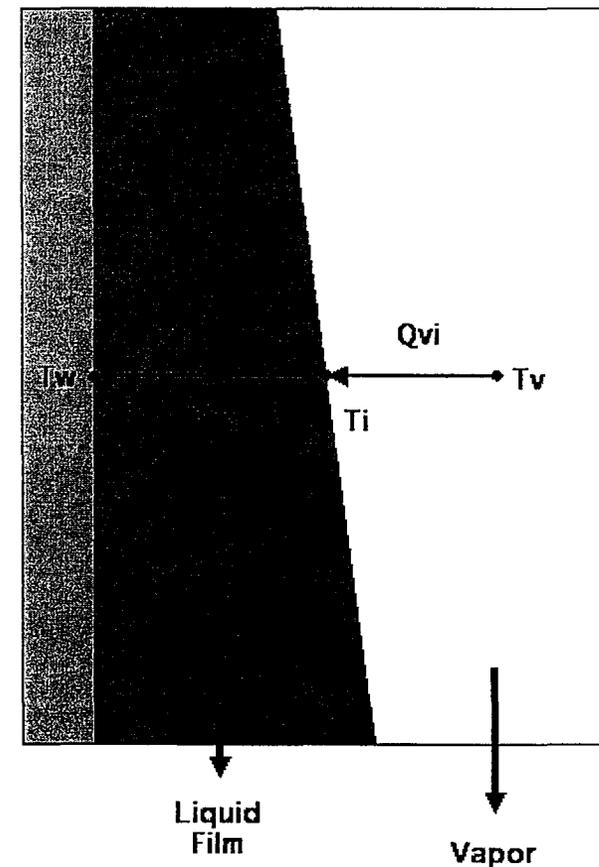
- Film Thickness: Sheared Films
 - TRACE Results for data of Andreussi & Zanelli
 - ➔ Data points with no entrainment



Tube Condensation: Model Development Effort

■ Film Condensation

- Model Requirements
 - ➔ Condensation with pure steam and steam-NC gas mixtures
 - ➔ Applicable to both falling and sheared films
- Models Needed
 - ➔ Film Thickness
 - ⊙ Wall Friction
 - ⊙ Interfacial Shear
 - ➔ Wall Heat Transfer
 - ⊙ Wall-Liquid HTC
 - ➔ Interfacial Heat Transfer
 - ⊙ Liquid-Interface HTC
 - ⊙ Vapor-Interface HTC
 - ⊙ Non-Condensable Gas Effect



Tube Condensation: Model Development Effort

■ Film Condensation: Falling Films

● Data Base:

- ➔ Only includes surface averaged data (not local HTC's).
- ➔ Data presented in terms of non-dimensional Nusselt no.

$$\langle Nu^* \rangle = \frac{\langle h_L \rangle \cdot \delta_0}{k_l}$$

$$\delta_0 = \left[\frac{\mu_l^2}{g \cdot \Delta\rho \cdot \rho_l} \right]^{\frac{1}{3}}$$

- ➔ Data show significant enhancement over Nusselt.

$$Nu_0 = \frac{h \cdot \delta}{k_l} = 1$$

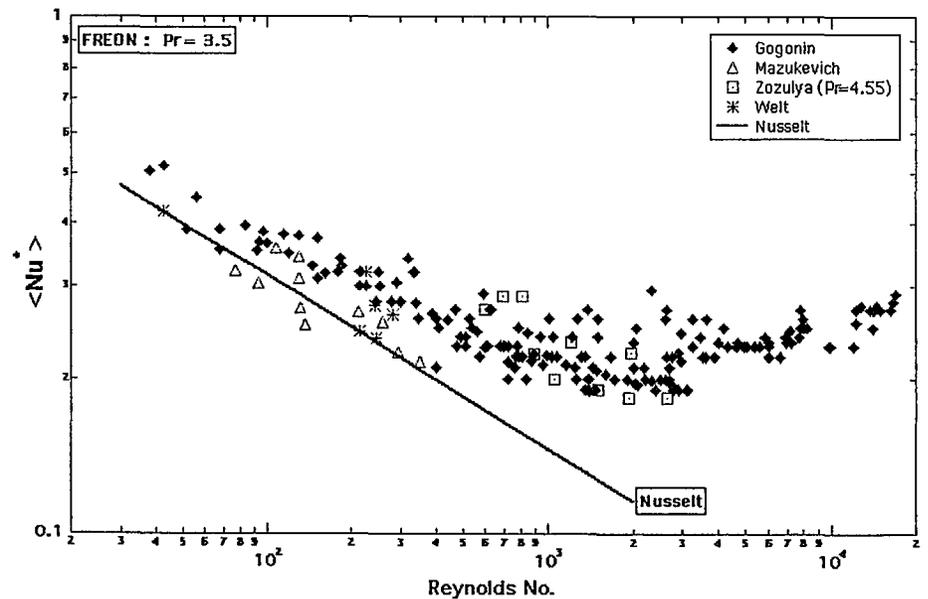
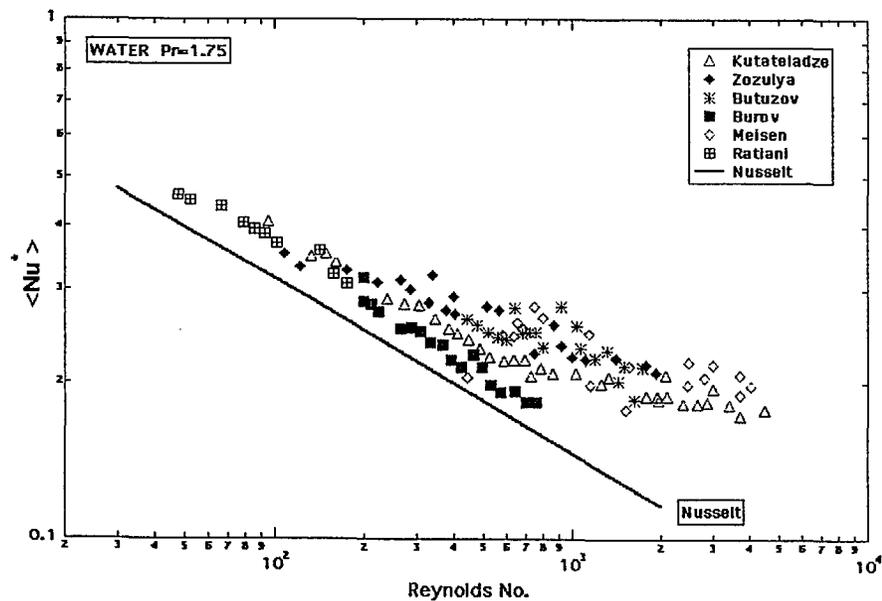
$$Nu_0^* = \frac{Nu}{\delta^*} = \frac{1.10}{Re_f^{\frac{1}{3}}}$$

$$\langle Nu_0^* \rangle = \frac{1.47}{Re_f^{\frac{1}{3}}}$$

Tube Condensation: Model Development Effort

■ Film Condensation: Falling Films

● Data Base Example:



Tube Condensation: Model Development Effort

■ Film Condensation: Falling Films

● Laminar Model Selection:

➔ Nusselt

$$\langle Nu_0^* \rangle = 1.47 \cdot Re_f^{-\frac{1}{3}}$$

➔ Kutateladze

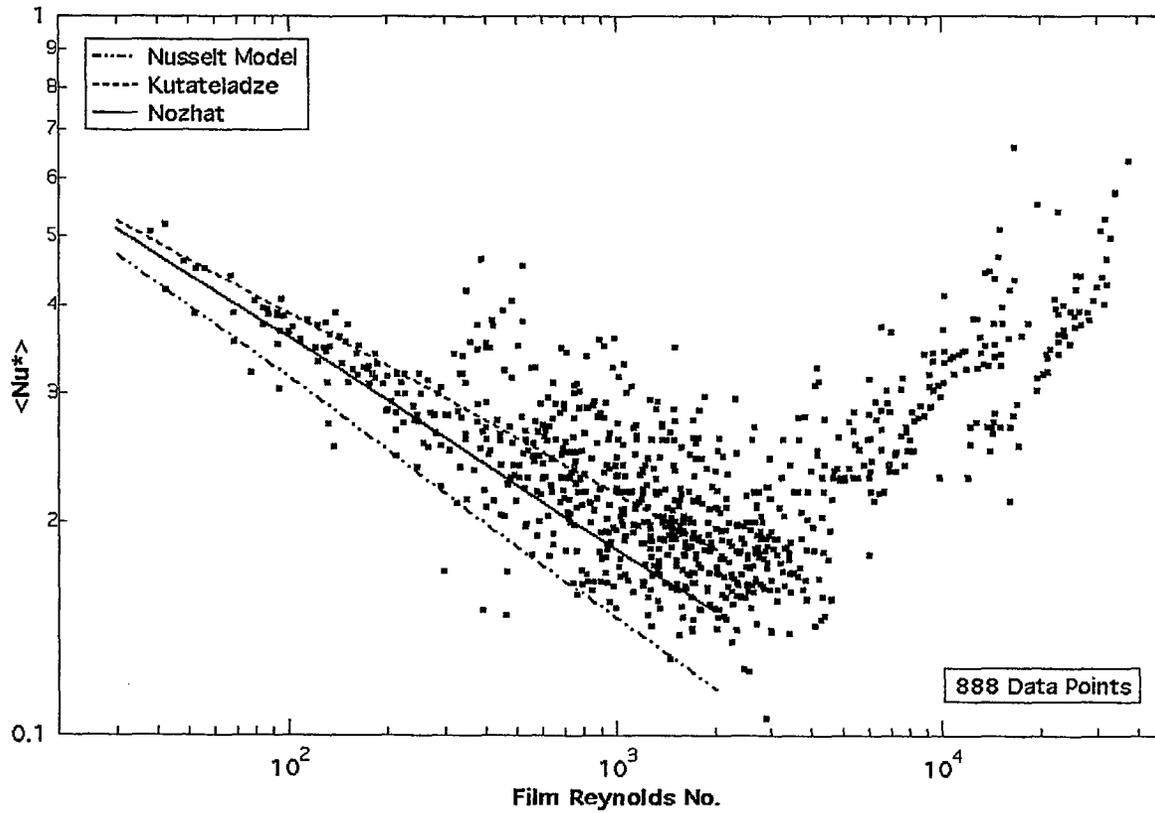
$$\langle Nu_0^* \rangle = 1.23 \cdot Re_f^{-\frac{1}{4}}$$

➔ Nozhat

$$\langle Nu_0^* \rangle = 1.28 \cdot Re_f^{-0.263}$$

Tube Condensation: Model Development Effort

- Film Condensation: Falling Films
 - Laminar Model Selection:



Tube Condensation: Model Development Effort

■ Film Condensation: Falling Films

● Laminar Film Model:

➔ We now have a model for the condensation HTC, however, the code needs both a wall-liquid HTC and a liquid-interface HTC.

➔ From an energy balance:

$$h_c \cdot (T_{sat} - T_w) = h_{wl} \cdot (T_l - T_w) = h_{li} \cdot (T_{sat} - T_l)$$

➔ Thus, if we know the wall-liquid HTC, the interfacial HTC is given by:

$$h_{li} = \frac{h_{wl} \cdot h_c}{h_{wl} - h_c}$$

➔ We can determine the wall-liquid HTC from film heating data.

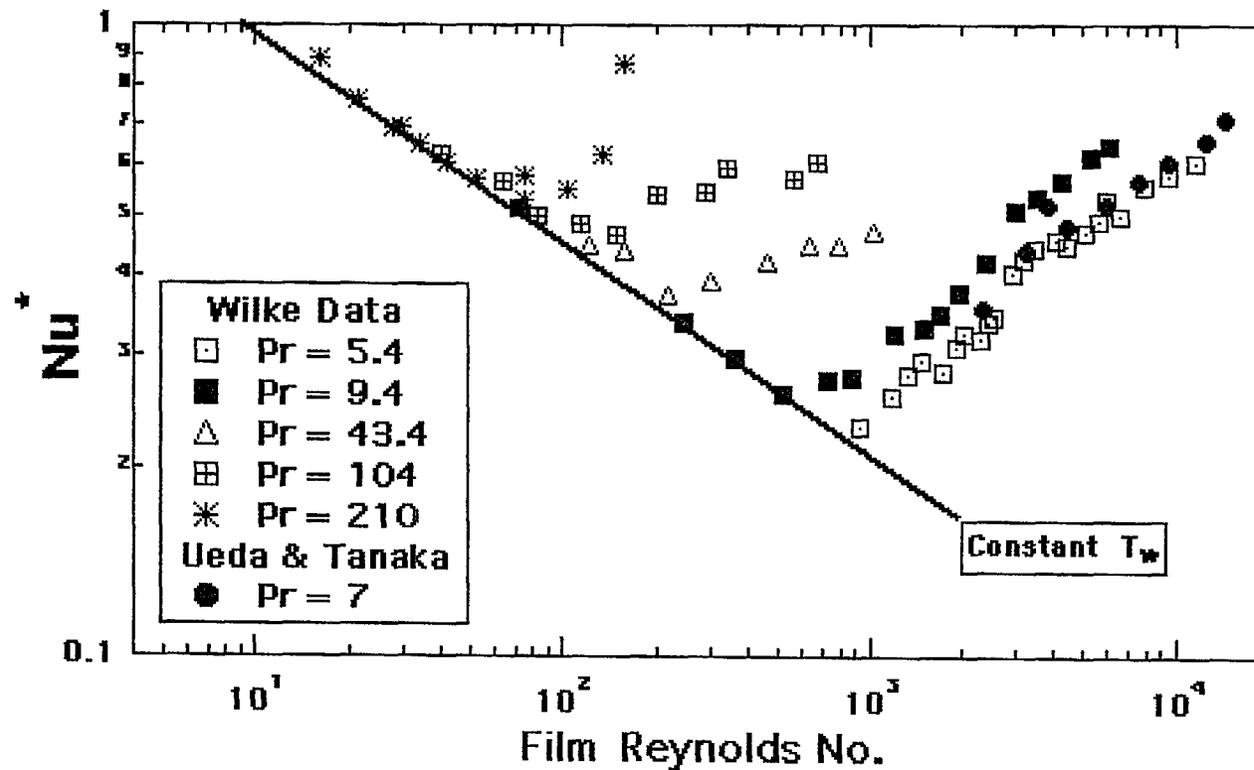
● Displays negligible enhancement due to ripples, and is correlated by

$$Nu_{heat} = 1.88$$

$$Nu_{heat}^* = 2.07 / Re_f^{\frac{1}{3}}$$

Tube Condensation: Model Development Effort

- Film Condensation: Falling Films
 - Laminar Model: Film Heating Data



Tube Condensation: Model Development Effort

■ Film Condensation: Falling Films

● Laminar Film Model:

- ➔ Unfortunately, this approach doesn't work as the correlations for condensation and heating intersect at $Re \sim 1000$.
- ➔ Alternative, for a smooth laminar film, the parabolic velocity profile with linear temperature profile yields a bulk liquid temperature

$$T_l = \frac{5}{8} \cdot T_{sat} + \frac{3}{8} \cdot T_w$$

- ➔ Thus

$$Nu_{wl} = \frac{8}{5} \cdot Nu_c$$

$$Nu_{li} = \frac{8}{3} \cdot Nu_c$$

- ➔ Therefore, use the Nozhat model for the wall condensation HTC, and apportion it between the wall-liquid and interfacial heat transfer using the above ratios.

Tube Condensation: Model Development Effort

■ Film Condensation: Falling Films

● Turbulent Film Model

➔ Difficulty:

- Falling film database does not have local heat transfer data, only values averaged over the entire heat transfer surface, as this implies integrating over both laminar and turbulent regions, the available data cannot be used in a straightforward model selection process.

➔ Approach:

- For the wall-liquid HTC, turbulent film heating data will be used for model selection.
- Several models for interfacial heat transfer will be selected from the literature for consideration.
- A well-established turbulent falling film correlation will be used to determine which combination of wall-liquid and interfacial HTC is acceptable.
 - » Correlation of Labuntsov will be used as it approximates the mean of the other correlations.

Tube Condensation: Model Development Effort

■ Film Condensation: Turbulent Falling Films

➔ Colburn (1933) $Nu^* = 0.056 \cdot Re_f^{0.2} \cdot Pr_f^{\frac{1}{3}}$

➔ Kirkbride (1934) $Nu^* = 0.0084 \cdot Re_f^{0.4}$

➔ Kutateladze (1949)
$$Nu^* = \frac{0.0429 \cdot Re_f \cdot Pr_f^{0.4}}{\left(Re_f^{\frac{5}{6}} - 149.2 + 66.7 \cdot Pr_f^{0.4}\right)}$$

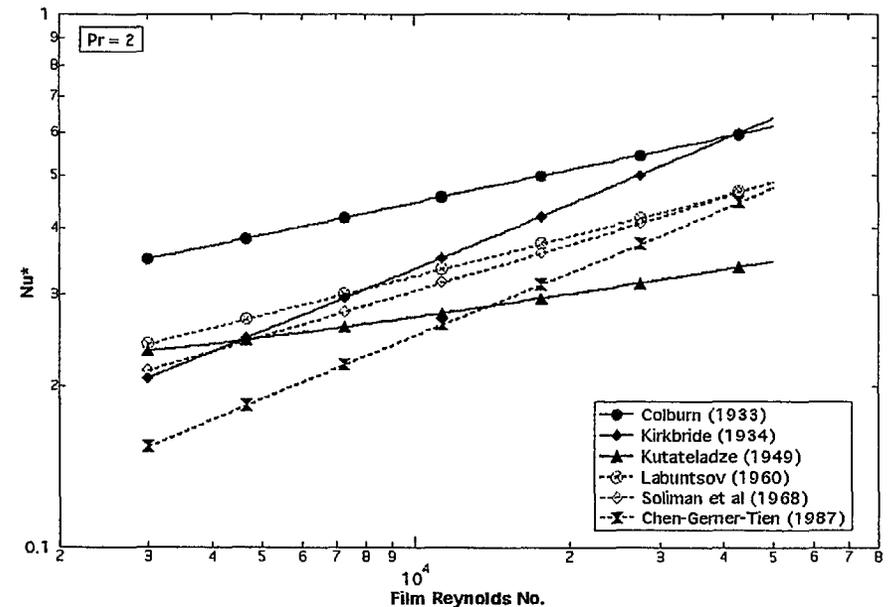
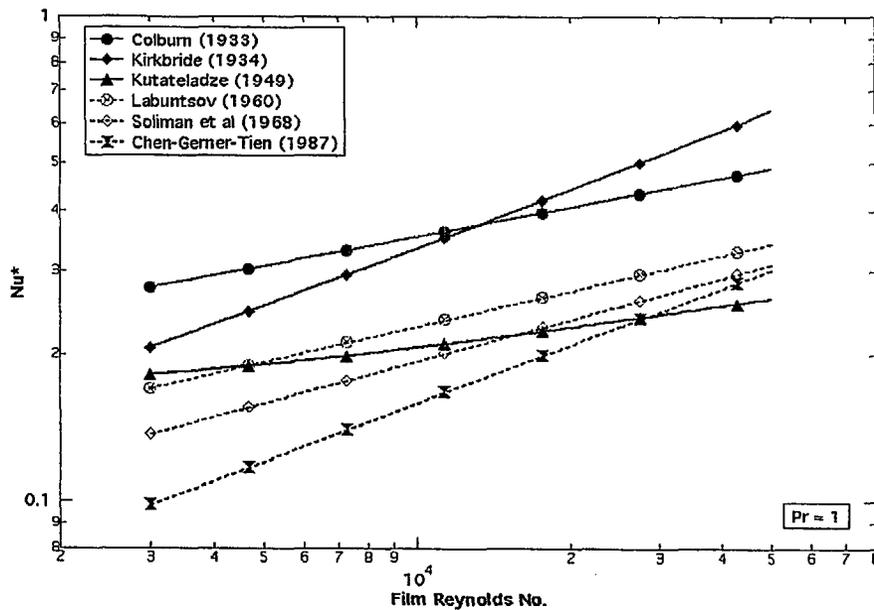
➔ Labuntsov (1960) $Nu^* = 0.023 \cdot Re_f^{0.25} \cdot Pr_f^{\frac{1}{2}}$

➔ Soliman et al (1968) $Nu^* = 0.0132 \cdot Re_f^{0.292} \cdot Pr_f^{0.65}$

➔ Chen, Gerner & Tien (1987) $Nu^* = 0.004 \cdot Re_f^{0.4} \cdot Pr_f^{0.65}$

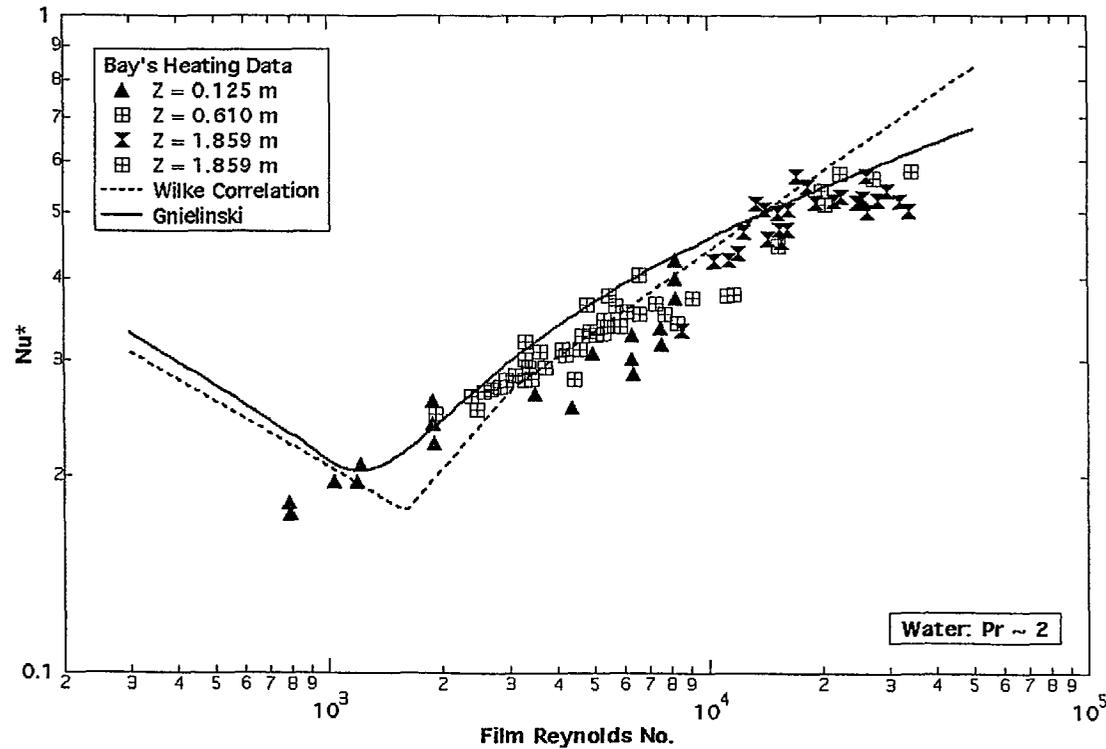
Tube Condensation: Model Development Effort

■ Film Condensation: Turbulent Falling Films



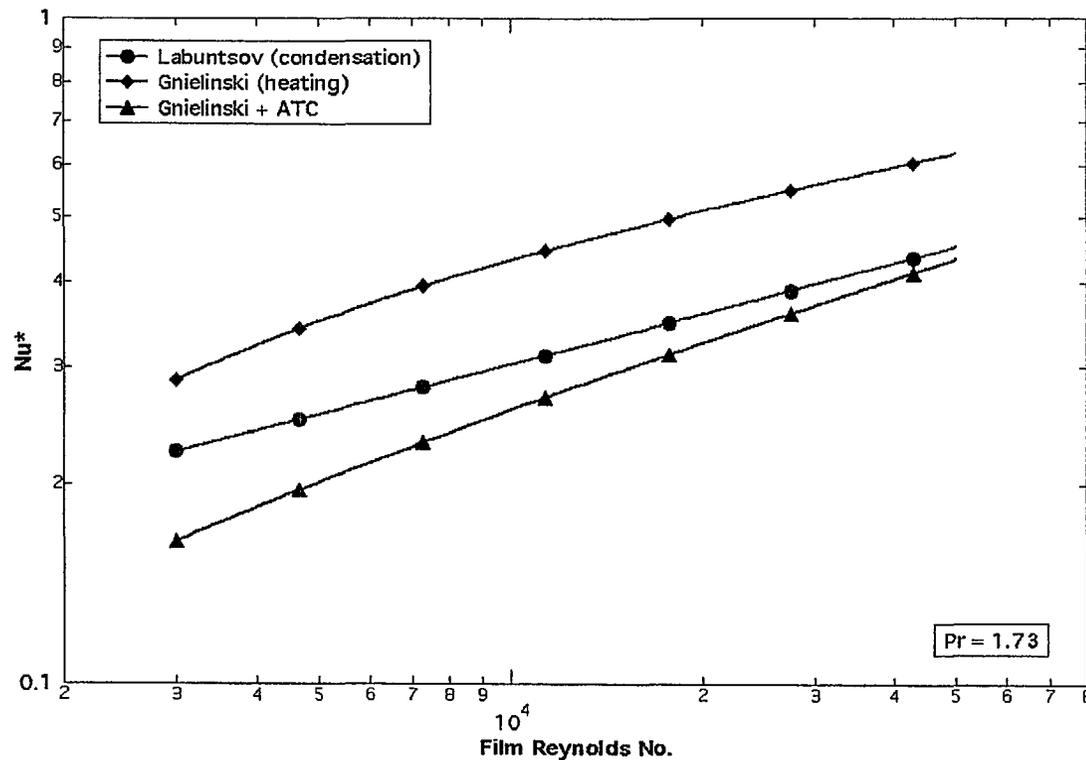
Tube Condensation: Model Development Effort

- Film Condensation: Turbulent Falling Films
 - Example of correlations for film heating:



Tube Condensation: Model Development Effort

- Film Condensation: Turbulent Falling Films
 - Example of proposed approach:



Tube Condensation: Model Development Effort

■ Film Condensation: Sheared Films

● Observation:

- ➔ Primary mechanism by which interfacial shear enhances condensation heat transfer is by thinning of the liquid film.

● Approach:

- ➔ Use heat transfer models developed from falling film data.
- ➔ Translate to sheared film by using calculated film thickness.

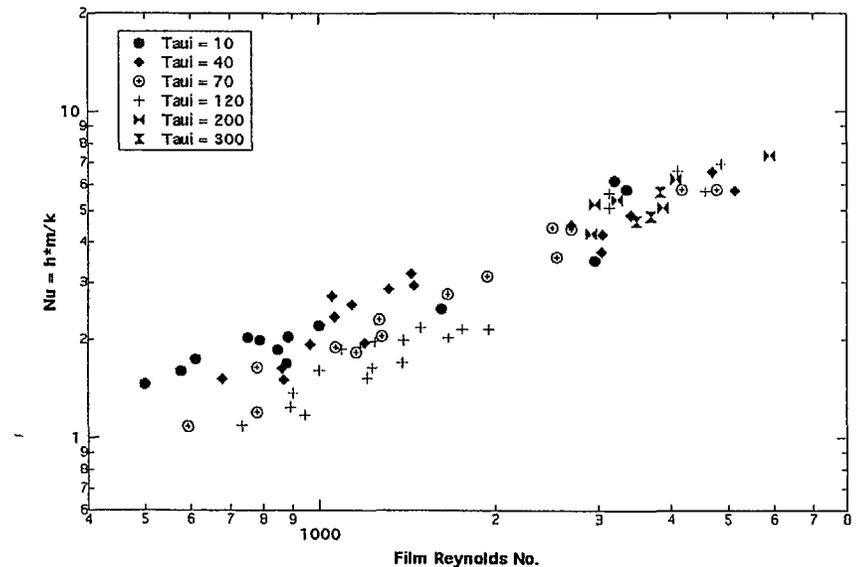
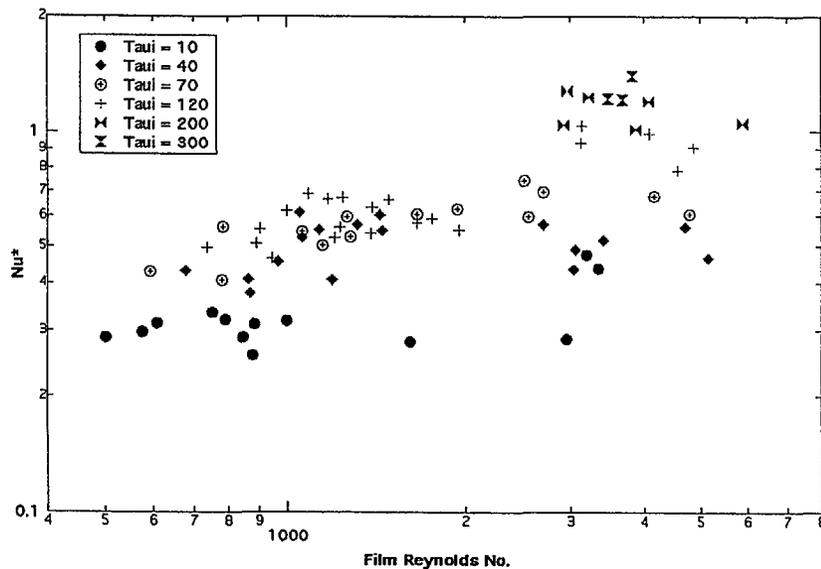
● Assessment:

- ➔ Ueda et al
- ➔ Blangetti & Schlunder
- ➔ UCB-Kuhn Pure Steam Tests
- ➔ NASA-Goodykoontz

Tube Condensation: Model Development Effort

■ Film Condensation: Sheared Films

- Example of proposed approach: data of Ueda et al.



Tube Condensation: Model Development Effort

■ Film Condensation: Non-Condensable Gas Effect

● Approach:

- ➔ Use a mechanistic approach such as the mass transfer conductance model described by Kuhn, Schrock & Peterson (1994).

● Assessment:

- ➔ UCB-Kuhn Steam-Air Tests
- ➔ UCB-Kuhn Steam-Helium Tests
- ➔ MIT-Siddique Steam-Air Tests
- ➔ MIT-Siddique Steam-Helium Tests
- ➔ TAEK Steam-Air Tests

Tube Condensation: Model Development Effort

■ SUMMARY

- Original TRACE condensation models were investigated and found deficient both for pure steam condensation and condensation with non-condensable gases.
- Development of a constitutive package appropriate for the condenser tubes in the ICS and PCCS systems of the ESBWR design is underway.
 - ➔ Improvements for both wall drag and interfacial friction were made.
 - ➔ Models for condensation in laminar falling films have been identified.
 - ➔ Models for wall-liquid and interfacial heat transfer for turbulent films are being investigated.
 - ➔ Sheared films will be treated by using the calculated film thickness.
 - ➔ Mechanistic approach for the non-condensable gas effect will be used.
- Extensive assessment will be performed.

Steam Generator Internal Loading Following MSLB or FWLB

Response to GSI-188

William J. Krotiuk
US Nuclear Regulatory Commission



SG Loading Following MSLB or FWLB

- Generic Safety Issue (GSI) 188
**Steam Generator Tube Leaks or Ruptures Concurrent With
Containment Bypass from Main Steam Line or
Feedwater Line Breaches**
- Use TRACE to assess loads on a Steam Generator tube support plate and tubes following a MSLB or FWLB.



SG Loading Following MSLB or FWLB

- Specific Activities:

- (1) Perform thermal-hydraulic analyses using TRACE to develop loads on tube support plates (TSP) and primary tubes following a MSLB and FWLB.
- (2) Perform sensitivity studies on code and model parameters, and compare TRACE code predictions to test results which are related to the SG behavior.
- (3) Develop a conservative load estimate and evaluate against similar analyses.



TRACE Verification Effort

- Effort required to verify code predictions, especially the ability to:
 - (1) follow acoustic wave transmission during system depressurization of a subcooled liquid vessel,
 - (2) assess “pool swell” effects.

- Experimental comparisons completed for:
 - Edwards Pipe Blowdown Experiment
 - LOFT Semiscale Blowdown Test
 - GE Vessel Blowdown Tests
 - Westinghouse Steam Generator Model Boiler (MB-2) Tests.



Edwards Pipe Blowdown Experiment

- Objective:

- Study subcooled water depressurization in a horizontal pipe.

Pipe Length	4.096 m (161.26 in.)
Pipe ID	0.073152 m (2.88 in.)
Glass Rupture Disk Flow Area	$3.6566 \times 10^{-3} \text{ m}^2$ (best estimate)
Initial System Pressure	$7.0995 \times 10^6 \text{ Pa}$ (1030 psia)
Initial System Temperature	$\sim 505\text{K}$ ($\sim 449^\circ\text{F}$)

- Three models created using:

- 37 nodes of 0.1107 m (4.36 in.) each,
- 74 nodes of 0.05535 m (2.18 in.) each, and
- 161 nodes of 0.02544 m (1.00 in.) each.

- TRACE calculational options assessed:

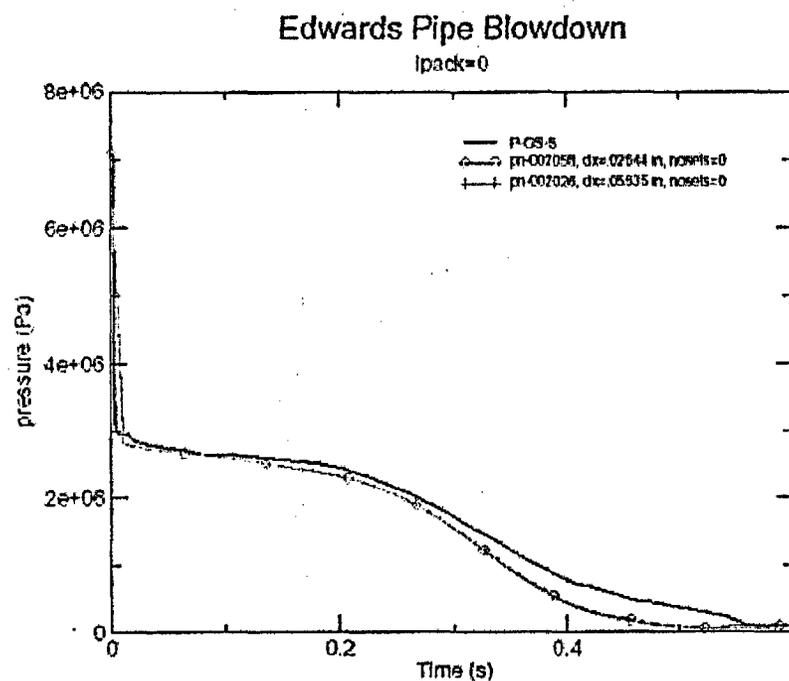
- One step semi-implicit numerical solution method (NOSETS=1)
Timesteps limited by Courant stability criteria.
- Two step semi-implicit numerical solution method (NOSETS=0)
Permits timesteps to exceed the Courant stability limit.



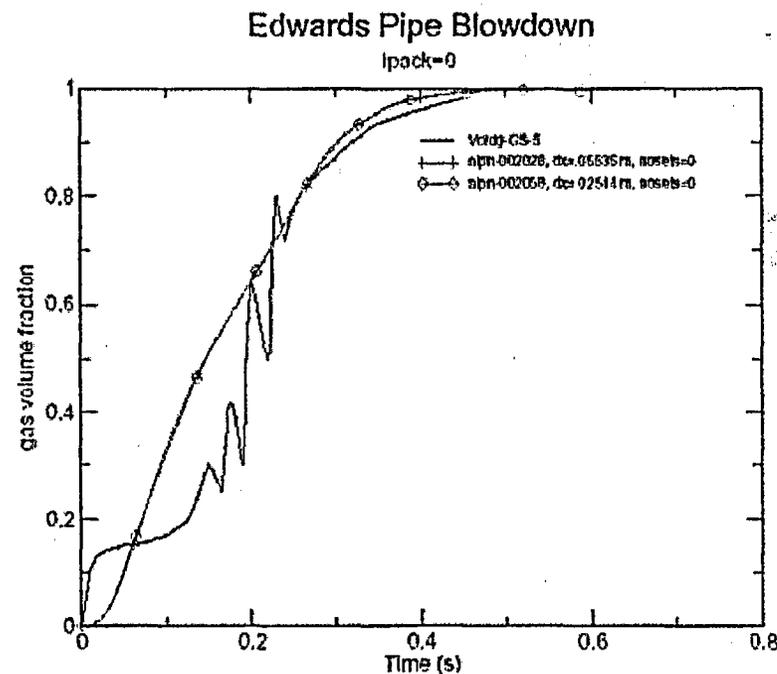
Edwards Pipe Blowdown Experiment

• Conclusions:

- Results using two step semi-implicit solution (NOSETS=0) were close to test measurements.
- Results with a node size of 0.05535 m, which is comparative to pipe diameter, are almost identical to analysis using smaller 0.02544 m nodes.
- Results with large node size of 0.1107 m differ from other two analysis results.



Position 1.469 m from Closed End



Position 1.469 m from Closed End



LOFT Semiscale Blowdown Test

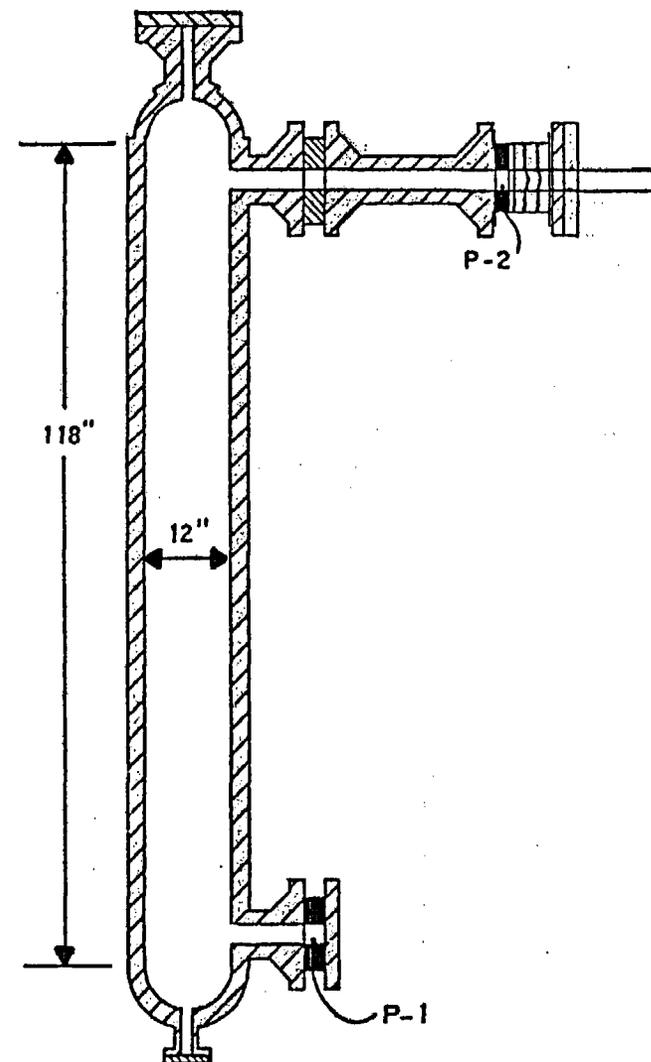
- Objective:
 - Study subcooled water blowdown from and acoustic wave travel in a vertical vessel at high pressure.
- TRACE results compared to experimental measurements and calculations from the method-of-characteristics code, WHAMMO CII.

Vertical Tank Length (not including hemispherical heads)	118 inches (2.997 m)
Vertical Tank ID	12 inches (0.3048 m)
Upper Pipe Length (approximate)	42 inches (1.0668 m)
Upper Pipe ID	4 1/16 inch (0.10319 m)
Lower Pipe Length (approximate)	12 inches (0.3048 m)
Lower Pipe ID	4 1/16 inch (0.10319 m)
Orifice Diameter	1 inch (0.0254 m)
Initial System Pressure (assumed at rupture disk)	2300 psig (15.9593x10 ⁶ Pa abs.)
Initial System Temperature (best estimate)	525°F (547K)
Rupture Disk Decompression Time (best estimate)	300 x 10 ⁻⁶ sec.



LOFT Semiscale Blowdown Test

- Two models created using:
 - 2 inch long volumes, and
 - 4 inch long volumes.
- TRACE calculational options assessed:
 - One step semi-implicit numerical solution method (NOSETS=1)
 - Timesteps limited by Courant stability criteria.
 - Two step semi-implicit numerical solution method (NOSETS=0)
 - Permits timesteps to exceed the Courant stability limit.

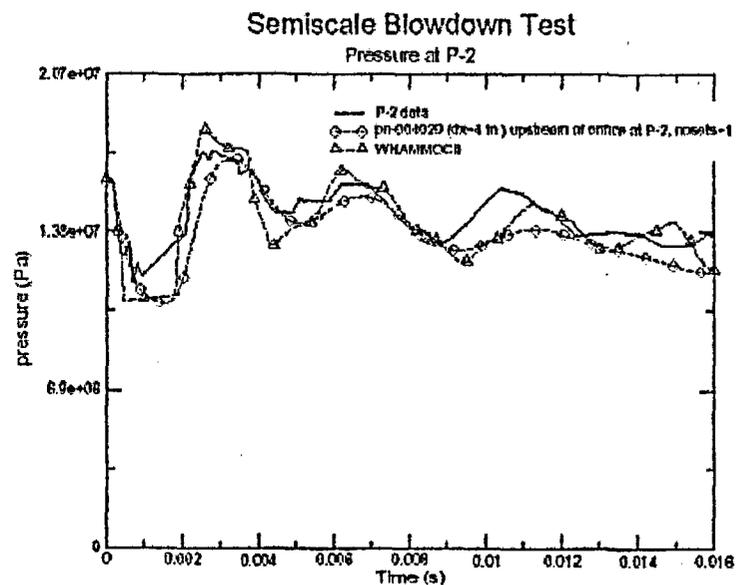
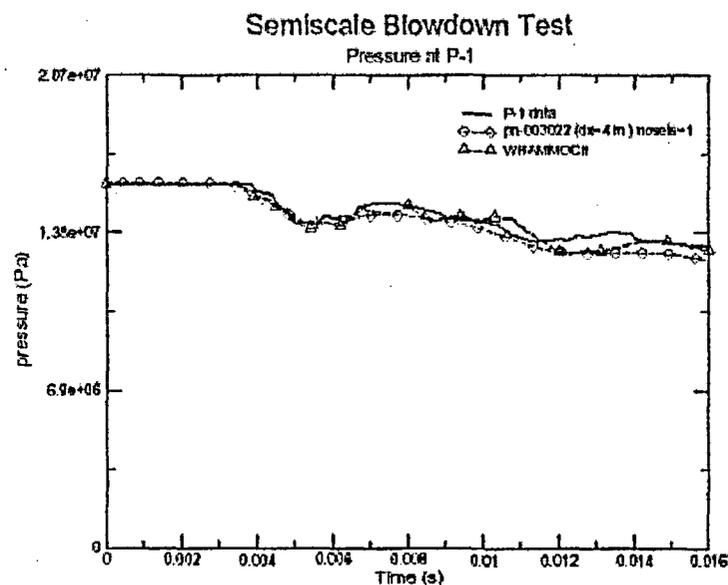




LOFT Semiscale Blowdown Test

• Conclusions:

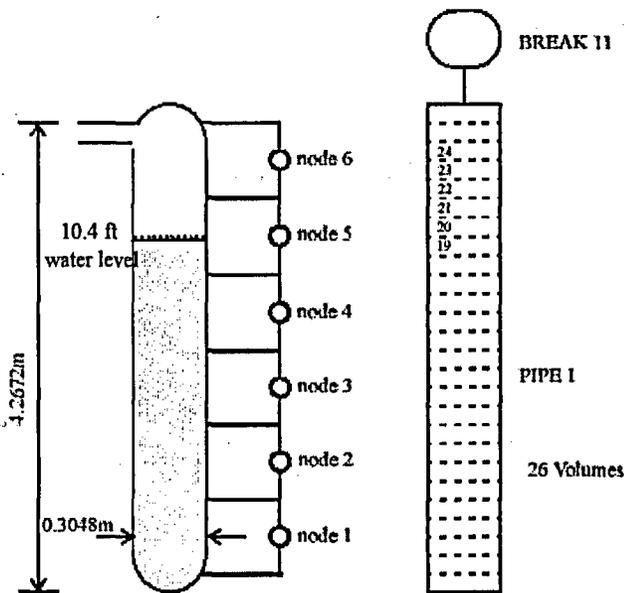
- TRACE predicts acoustic wave transmissions and reflections at area changes including decompression and recompression effects, but exhibits larger pressure attenuation than test results.
- TRACE predictions similar to data and MOC code results.
- Results with node size of 4 inches, which is comparative to pipe diameter, are almost identical to analysis using smaller 2 inch nodes.
- Results using one step semi-implicit solution (NOSETS=1) were closer to measurements and closer to MOC code calculated results.



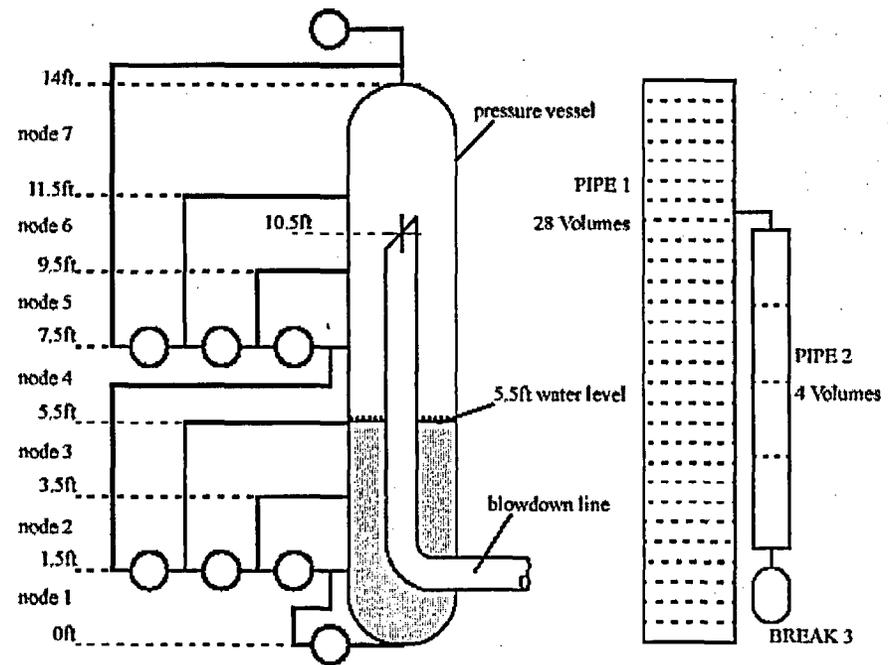


GE Vessel Blowdown Tests

- Objective:
 - Compare TRACE “level tracking” predictions to “pool swell” test data.
- Initial Conditions: 1000 psi (6.895×10^6 Pa), 545°F (285°C)
- Two break tests modeled:
 - Test 1004-3
12 in. ID, 14 ft. long tank
 - Test 5801-15
47 in. ID, 14 ft. long tank



Schematic and Nodalization for Test 1004-3



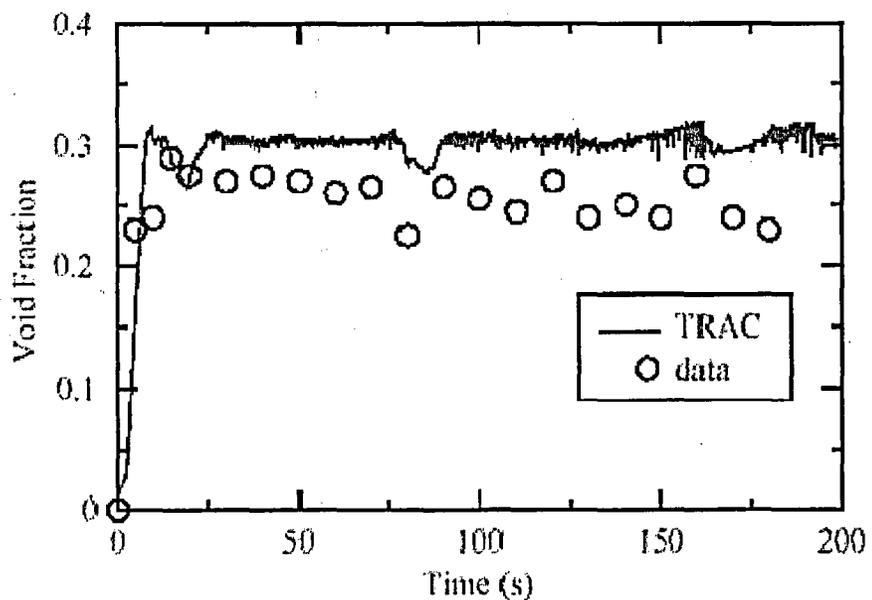
Schematic and Nodalization for Test 5801-15



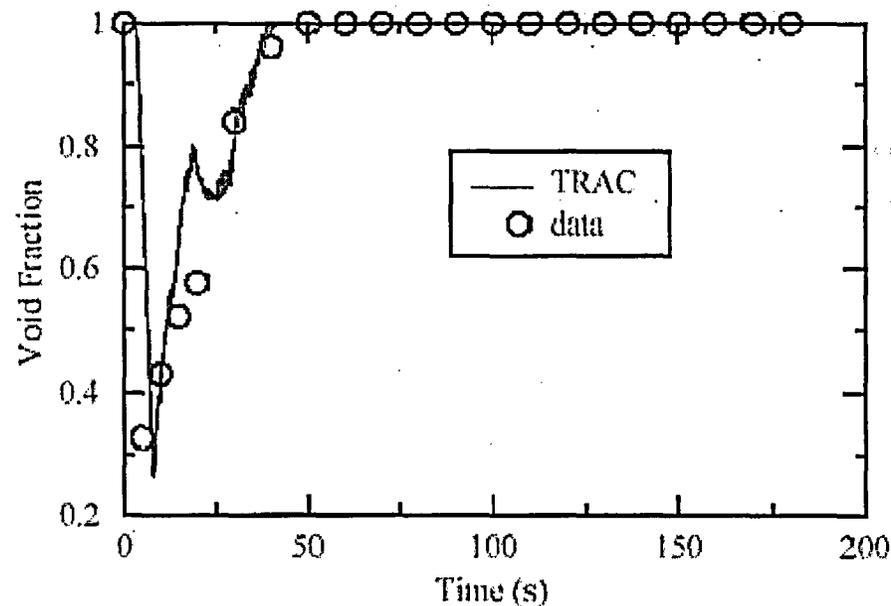
GE Vessel Blowdown Tests

• Conclusions

- TRACE analysis using the “level tracking” model better predicted “swell” effects.
- TRACE successfully predicted the progression of the mixture “swell” for the two tests.
- Differences between predicted and measured void fraction were observed.



Void fraction at 6 ft elevation (node 3) of Test 1004-3



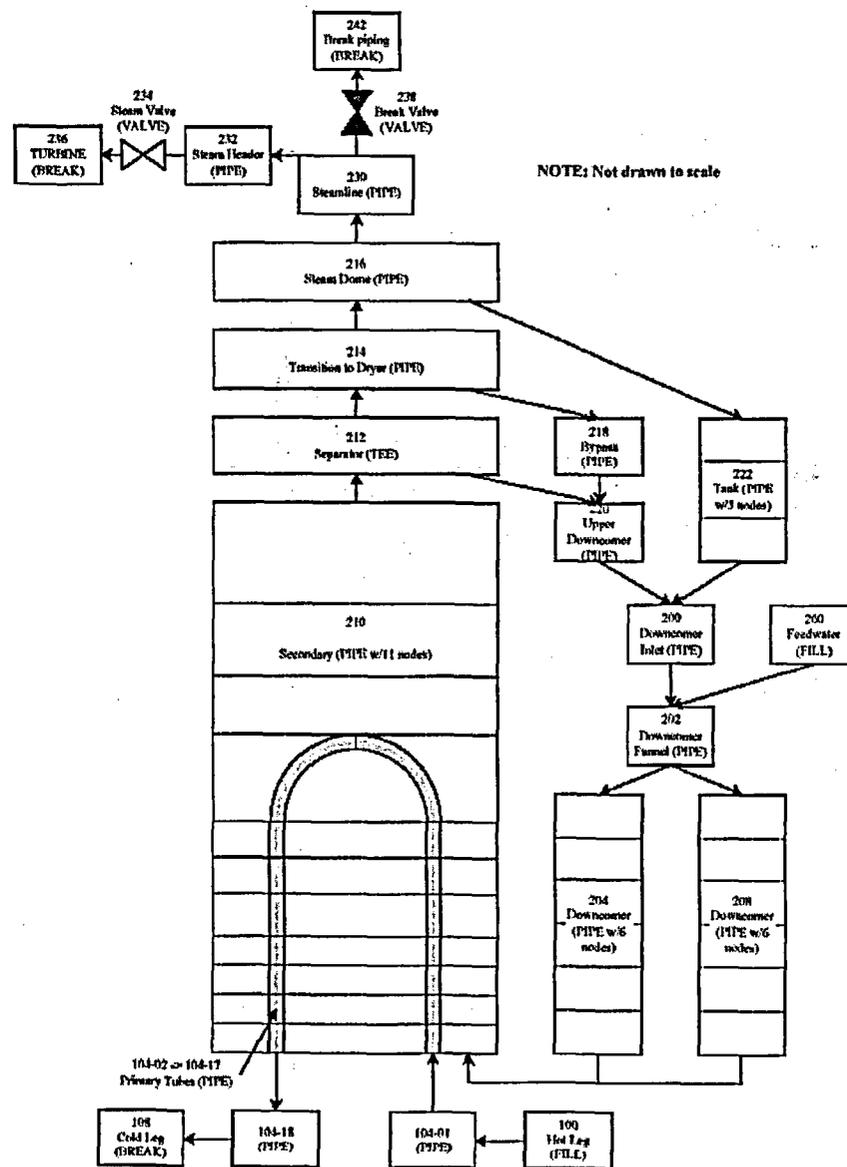
Void fraction at 12 ft elevation (node 6) of Test 1004-3



Steam Generator Model Boiler (MB-2) Tests

- Objective:
Compare TRACE TSP load predictions to results from two MSLB tests.
- Initial Standby Condition and Break Size:

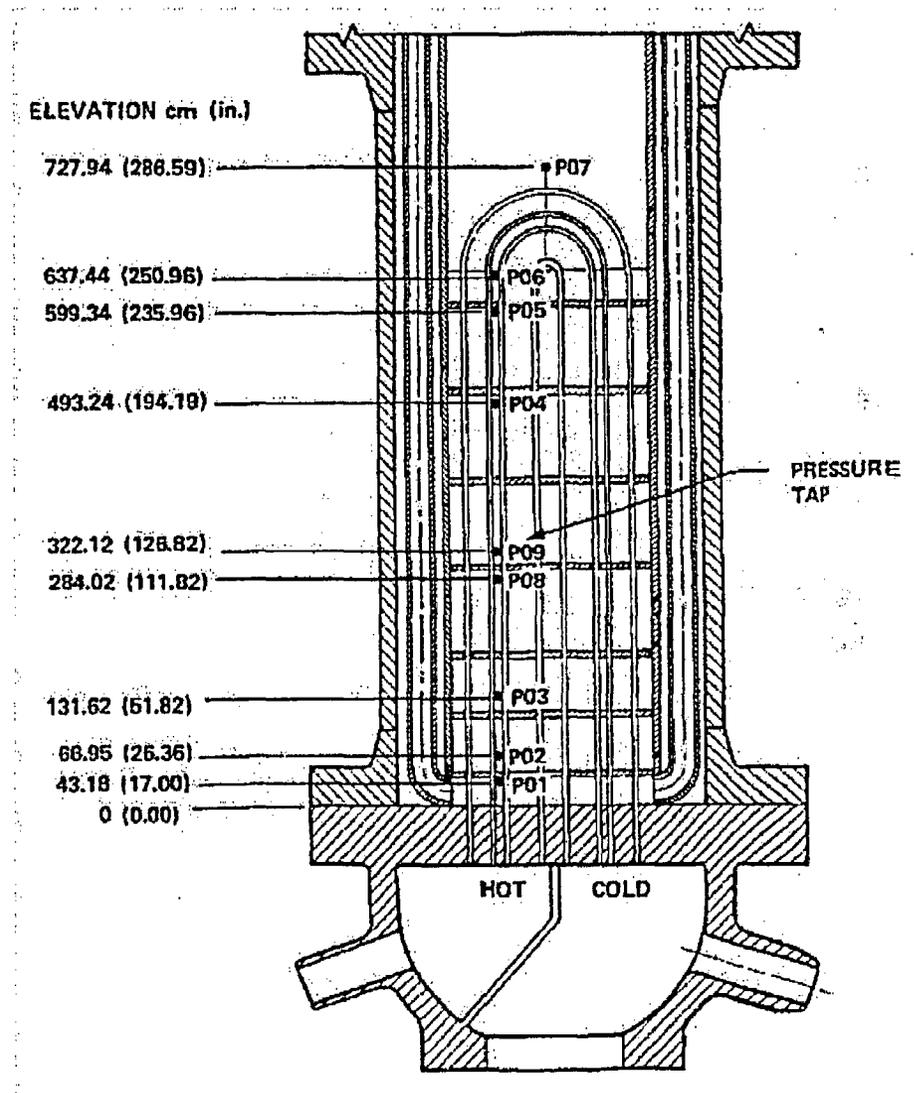
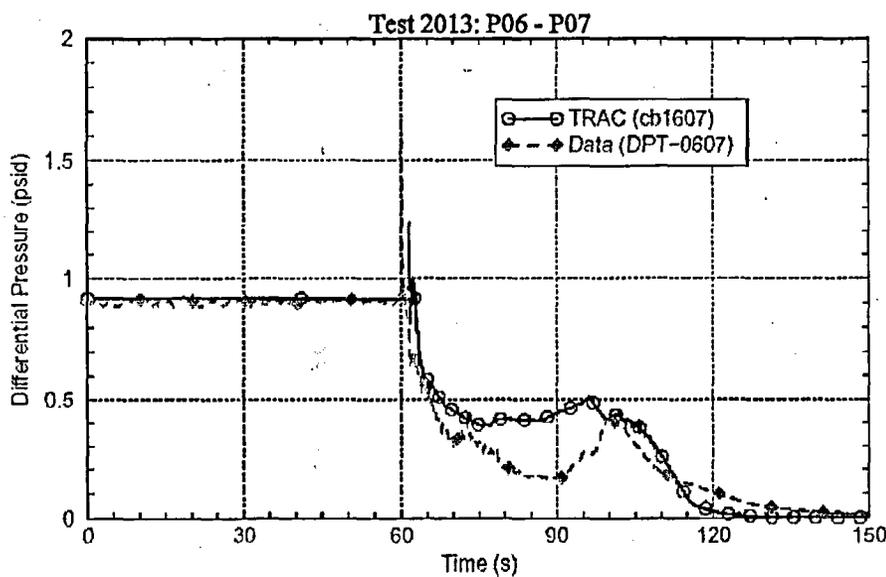
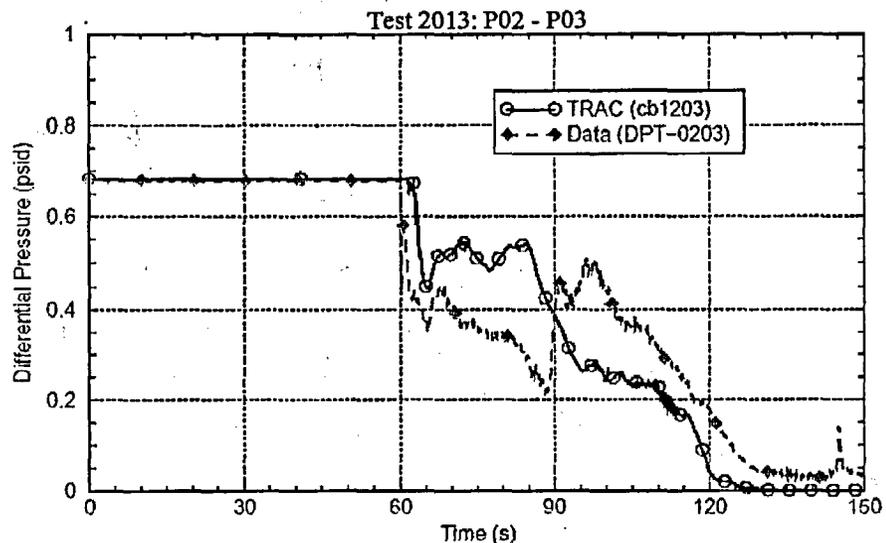
Test 2013	Test 2029
1101 psia	1002 psia
(7.951 MPa)	(6.908 MPa)
100% MSLB	8% MSLB
- 0.8% Power-Scaled W Model F Steam Generator
- TRACE model based on an existing RELAP5 model.





Steam Generator Model Boiler (MB-2) Tests

- TRACE predicted overall system response reasonably well.





SG Loading Study

- TRACE analysis

- Performed for Westinghouse Model 51 SG.
- Compared to Westinghouse reported results obtained using the TRANFLO and RELAP5 computer codes.

- SG initial conditions before break:

- Hot Standby
- 100% Power

- SG loads developed following:

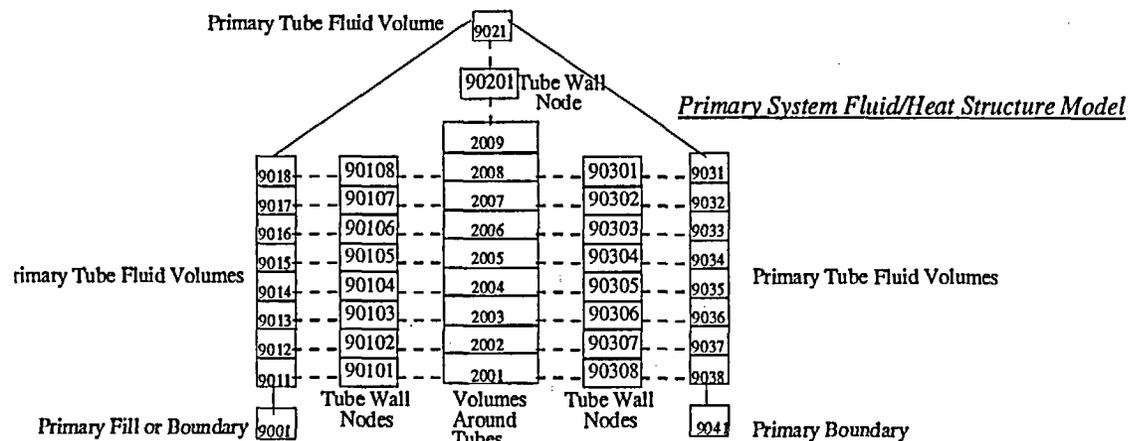
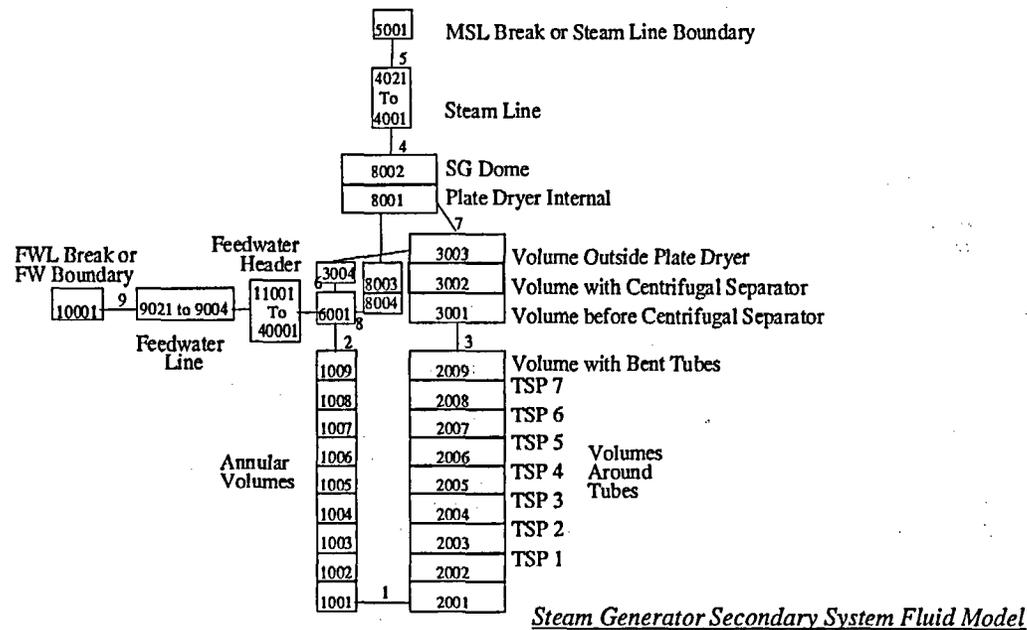
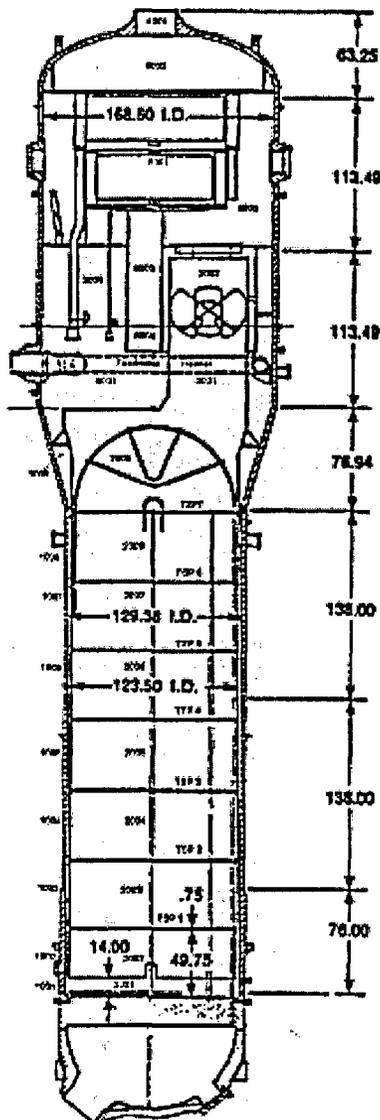
- a 4.6 ft² guillotine MSLB at the main steam nozzle,
- a 1.4 ft² flow restrictor limited MSLB at the main steam nozzle, and
- a 1.12 ft² guillotine FWLB at the FW nozzle.

- SG loading developed for:

- Tube support plates (TSP),
- Primary tubes at tubesheet and at tube bend area, and
- Cylindrical shroud between tube bundle and annular feedwater regions.



TRACE SG Analysis Model





TSP Loadings at Hot Standby

	4.6 ft ² MSLB TRANFLO	4.6 ft ² MSLB RELAP5	4.6 ft ² MSLB TRACE
TSP 7 (top)	2.46 psi (3.69* psi)	9.6 psi	8.57 psi
TSP 6	1.82 psi (2.73* psi)	8.1 psi	5.06 psi
TSP 5	1.25 psi (1.88* psi)	6.1 psi	3.84 psi
TSP 4	0.91 psi (1.37* psi)	4.5 psi	2.63 psi
TSP 3	0.58 psi (0.87* psi)	3.2 psi	1.16 psi
TSP 2	0.31 psi (0.47* psi)	2.0 psi	0.15 psi
TSP 1 (bottom)	-0.12 psi (-0.18* psi)	1.9 psi	-0.33 psi

	1.5 ft ² MSLB TRANFLO	1.4 ft ² MSLB RELAP5	1.4 ft ² MSLB TRACE
TSP 7 (top)	1.67 psi (2.51* psi)	2.26 psi	2.68 psi
TSP 6	1.22 psi (1.83* psi)	2.14 psi	1.70 psi
TSP 5	0.83 psi (1.25* psi)	1.56 psi	1.23 psi
TSP 4	0.53 psi (0.80* psi)	1.35 psi	0.87 psi
TSP 3	-0.28 psi (-0.42* psi)	1.23 psi	0.43 psi
TSP 2	-0.23 psi (-0.35* psi)	1.25 psi	0.08 psi
TSP 1 (bottom)	-0.26 psi (-0.39* psi)	1.12 psi	-0.06 psi

Note, an upward directed pressure differential is defined as positive.

* TRANFLO values with Westinghouse recommended 1.5 uncertainty multiplier.



TRACE Calculated TSP Loadings

Initial Hot Standby Conditions

	<u>4.6 ft² MSLB</u>	<u>1.4 ft² MSLB</u>	<u>1.12 ft² FWLB</u>
TSP 7 (top)	8.57 psi	2.68 psi	0.050 psi
TSP 6	5.06 psi	1.70 psi	0.041 psi
TSP 5	3.84 psi	1.23 psi	0.034 psi
TSP 4	2.63 psi	0.87 psi	0.030 psi
TSP 3	1.16 psi	0.43 psi	0.026 psi
TSP 2	0.15 psi	0.08 psi	0.022 psi
TSP 1 (bottom)	-0.33 psi	-0.06 psi	0.021 psi

Initial 100% Power Condition

	<u>4.6 ft² MSLB</u>	<u>1.4 ft² MSLB</u>	<u>1.12 ft² FWLB</u>
TSP 7 (top)	6.82 psi	1.49 psi	0.42 psi
TSP 6	5.41 psi	1.27 psi	0.36 psi
TSP 5	4.34 psi	1.09 psi	0.31 psi
TSP 4	3.20 psi	0.87 psi	0.27 psi
TSP 3	1.91 psi	0.61 psi	0.23 psi
TSP 2	0.79 psi	0.33 psi	0.19 psi
TSP 1 (bottom)	0.16 psi	0.21 psi	0.20 psi

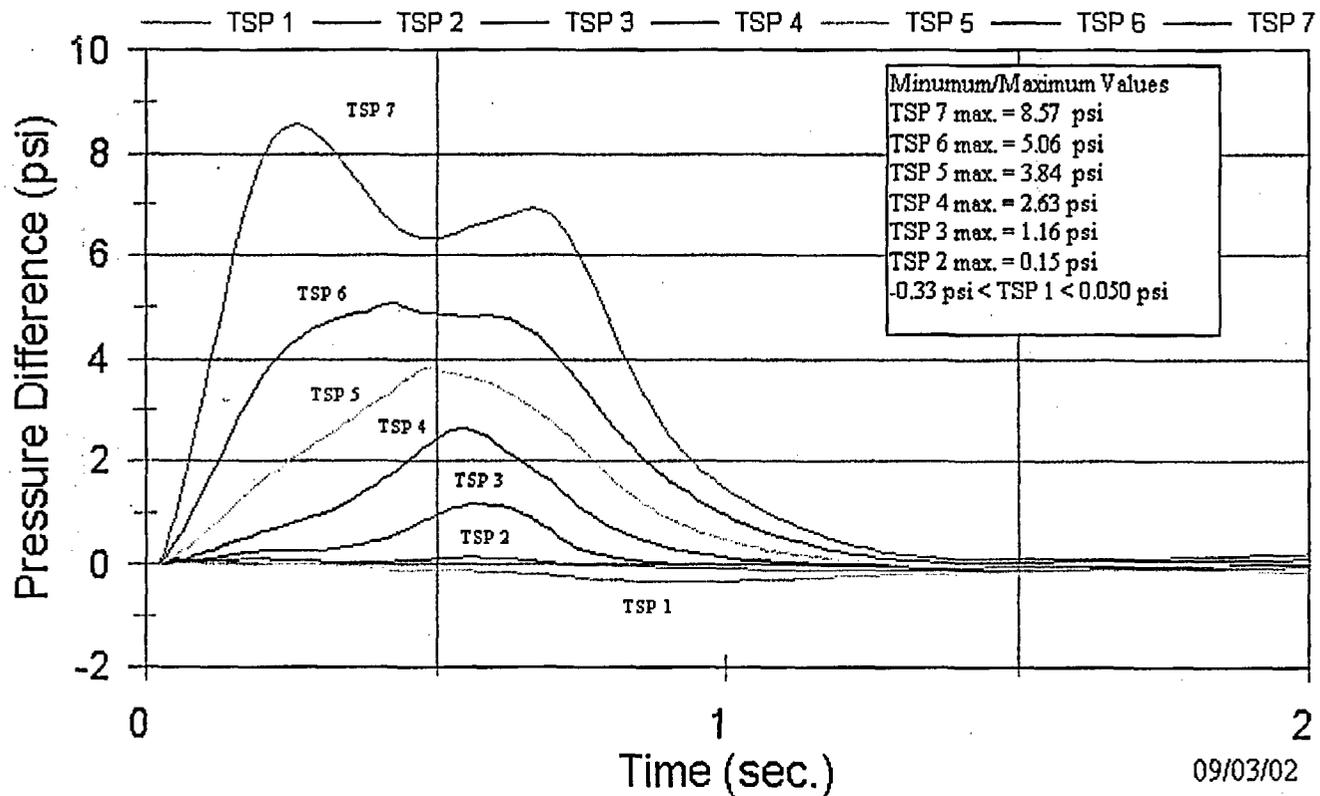
* An upward directed pressure differential is defined as positive.



TRACE Calculated TSP Loadings

MSLB at Hot Standby Conditions

MSLB Area = 4.6 sq ft





SG Conservative Bounding Calculations

- Conservative bounding results compared to TRACE analysis.
- Conservative bounding calculation method
 - TSP loads determined from blowdown calculation methods developed by F. J. Moody for BWRs.
 - Method also uses pressure wave transmission/reflections relations.

Transmission Ratio = Reflection Ratio + 1

$$\frac{P_T}{P_I} = \frac{2 A_1 / A_2}{A_1 / A_2 + 1} = \frac{2 A_1}{A_1 + A_2}$$

For dead end, $A_2=0$, $P_T/P_I=2$

For straight pipe, $A_1=A_2$, $P_T/P_I=1$ (full wave transmission)

For open end, $A_2=\infty$, $P_T/P_I=0$

Reflection Ratio = Transmission Ratio - 1

$$\frac{P_R}{P_I} = \frac{A_1 - A_2}{A_1 + A_2} = \frac{A_1 / A_2 - 1}{A_1 / A_2 + 1}$$

For dead end, $A_2=0$, $P_R/P_I=1$ (reflected pressurization wave)

For straight pipe, $A_1=A_2$, $P_R/P_I=0$ (no wave reflection)

For open end, $A_2=\infty$, $P_R/P_I=-1$ (reflected depressurization wave)

where A_1 is the flow area upstream of the area change.
 A_2 is the flow area downstream of the area change.
 P_R is the reflected pressure change.
 P_I is the incident pressure change.
 P_T is the transmitted pressure change.



SG Conservative Bounding Calculations

	Moody Calculation	TRACE Results at Standby	TRACE Results at 100% Power
Pressure	5.5 x 10 ⁶ Pa 800 psia	5.47 x 10 ⁶ Pa 793 psia*	5.47 x 10 ⁶ Pa 793 psia*
Saturation Temperature	542.7 K 517.2°F	542.7K 517.2°F	542.7K 517.2°F
<u>4.6 ft² Guillotine MSLB</u>	<u>with fL/d = 0.0</u>	<u>at 0.99399 sec.</u>	<u>at 0.31101 sec.</u>
Maximum Break Flow	12730 kg/sec. 28060 lbm/sec.	15489 kg/sec. 34146 lbm/sec.	13402 kg/sec. 29546 lbm/sec.
Discharge Pressure	520 psia 3.585 x 10 ⁶ Pa	486 psia 3.35 x 10 ⁶ Pa	446 psia 3.075 x 10 ⁶ Pa
<u>1.4 ft² MSLB</u>	<u>with fL/d = 1.6</u>	<u>at 3.20706 sec.</u>	<u>at 0.73658 sec.</u>
Maximum Break Flow	3150 kg/sec. 6944 lbm/sec.	2373 kg/sec. 5231 lbm/sec.	2600 kg/sec. 5732 kg/sec.
Discharge Pressure	688 psia 4.744 x 10 ⁶ Pa	644 psia 4.44 x 10 ⁶ Pa	751 psia 5.18 x 10 ⁶ Pa

* Pressure at steam line. The pressures of the TRACE steam generator volumes vary and are slightly larger than 793 psia.



SG Conservative Bounding Calculations

	TRACE Hot Standby Condition	TRACE 100% Power Condition	Moody/Acoustic Calculation ^{&}
<u>4.6 ft² MSLB</u>			$P_{\text{discharge}} = 520 \text{ psia}$
TSP 7 (top)	8.57 psi	6.82 psi	9.0 psi
TSP 6	5.06 psi	5.41 psi	7.6 psi
TSP 5	3.84 psi	4.34 psi	6.4 psi
TSP 4	2.63 psi	3.20 psi	5.4 psi
TSP 3	1.16 psi	1.91 psi	4.6 psi
TSP 2	0.15 psi	0.79 psi	3.8 psi
TSP 1 (bottom)	-0.33 psi	0.16 psi	3.3 psi (1.6 [#] psi)
<u>1.4 ft² MSLB</u>			$P_{\text{discharge}} = 688 \text{ psia}$
TSP 7 (top)	2.68 psi	1.49 psi	3.6 psi
TSP 6	1.70 psi	1.27 psi	3.0 psi
TSP 5	1.23 psi	1.09 psi	2.6 psi
TSP 4	0.87 psi	0.87 psi	2.2 psi
TSP 3	0.43 psi	0.61 psi	1.8 psi
TSP 2	0.08 psi	0.33 psi	1.5 psi
TSP 1 (bottom)	-0.05 psi	0.21 psi	1.3 psi (0.7 [#] psi)

* An upward directed pressure differential is defined as positive.

[&] Differential pressure conservatively calculated ignoring depressurization wave travel through annular feedwater region.

[#] TSP 1 pressure differential adjusted for depressurization wave travel through annular feedwater area.



SG Conservative Bounding Calculations

TSP Peak Pressure Differential Comparisons for 4.6 ft² MSLB
with System Initially at Hot Standby

	TRANFLO	RELAP5	TRACE	Moody/Acoustic Calc. &
TSP 7 (top)	2.46 psi	9.6 psi	8.57 psi	9.0 psi
TSP 6	1.82 psi	8.1 psi	5.06 psi	7.6 psi
TSP 5	1.25 psi	6.1 psi	3.84 psi	6.4 psi
TSP 4	0.91 psi	4.5 psi	2.63 psi	5.4 psi
TSP 3	0.58 psi	3.2 psi	1.16 psi	4.6 psi
TSP 2	0.31 psi	2.0 psi	0.15 psi	3.8 psi
TSP 1(bottom)	-0.12 psi	1.9 psi	-0.33 psi	3.3 psi (1.6 [#] psi)

Note, an upward directed pressure differential is defined as positive.

& Differential pressure conservatively calculated ignoring depressurization wave travel through annular feedwater region.

TSP 1 pressure differential adjusted for depressurization wave travel through annular feedwater area.



SG Conservative Bounding Calculations

TSP Peak Pressure Differential Comparisons for 1.4 ft² MSLB
with System Initially at Hot Standby

	1.5 ft ² MSLB TRANFLO	1.4 ft ² MSLB RELAP5	1.4 ft ² MSLB TRACE	Moody/Acoustic Calc. ^{&}
TSP 7 (top)	1.67 psi	2.26 psi	2.68 psi	3.6 psi
TSP 6	1.22 psi	2.14 psi	1.70 psi	3.0 psi
TSP 5	0.83 psi	1.56 psi	1.23 psi	2.6 psi
TSP 4	0.53 psi	1.35 psi	0.87 psi	2.2 psi
TSP 3	-0.28 psi	1.23 psi	0.43 psi	1.8 psi
TSP 2	-0.23 psi	1.25 psi	0.08 psi	1.5 psi
TSP 1 (bottom)	-0.26 psi	1.12 psi	-0.05 psi	1.3 psi (0.7 [#] psi)

Note, an upward directed pressure differential is defined as positive.

[&] Differential pressure conservatively calculated ignoring depressurization wave travel through annular feedwater region.

[#] TSP 1 pressure differential adjusted for depressurization wave travel through annular feedwater area.



SG Loading Following MSLB or FWLB

- Generic Safety Issue (GSI) 188
 - Perform thermal-hydraulic calculations using TRACE to assess loads on a Steam Generator tube support plate and tubes following a MSLB or FWLB.
- Conclusions:
 - TRACE is capable of calculating the thermal-hydraulic conditions inside a PWR SG following a MSLB or FWLB.
 - TRACE successfully predicts the transient thermal-hydraulic conditions for several acoustically dominated tests.
 - The SG internal loading calculated by TRACE are comparative to conservative bounding calculations and to code results calculated by Westinghouse using RELAP5, but do not agree with Westinghouse TRANFLO calculations.
 - The largest SG internal forces are developed by the acoustic transients occurring in the first seconds following a break.