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NUCLEAR REGULATORY COMMISSION

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

MARCH 16, 2000

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This transcript had not been reviewed, corrected and edited and it may contain inaccuracies.

1 UNITED STATES OF AMERICA

2 NUCLEAR REGULATORY COMMISSION

3 ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

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6 MEETING: MATERIALS AND METALLURGY

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9 Room 2B-3

10 Two White Flint North

11 11545 Rockville Pike

12 Rockville, Maryland

13 Thursday, March 16, 2000

14

15 The subcommittees met, pursuant to notice, at 8:35

16 a.m.

17 MEMBERS PRESENT:

18 WILLIAM J. SHACK, Chairman,

19 Materials and Metallurgy Subcommittee

20 GEORGE APOSTOLAKIS, Chairman,

21 Reliability and Probabilistic

22 Risk Assessment Subcommittee

23 THOMAS S. KRESS, ACRS Member

24 MARIO V. BONACA, ACRS Member

25 DANA A. POWERS, Chairman, ACRS

1 PARTICIPANTS:

2 SAM DURAISWAMY, ACRS Staff

3 NOEL F. DUDLEY, ACRS Staff

4 EDWIN HACKETT, NRS

5 SHAH MALIK, NRS

6 DEBORAH A. JACKSON, NRS

7 LEE ABRAMSON, NRS

8 MARK CUNNINGHAM, NRS

9 NATHAN SIU, NRS

10 MARK KIRK, NRS

11 DOUG KALINOUSKY, NRS

12 ROY WOODS, NRS

13 WILLIAM GALYEAN, Idaho National Engineering and

14 Environmental Laboratory

15 ROBERT HARDIES, Baltimore Gas & Electric

16 TERRY DIXON, Oak Ridge National Laboratory

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

2 [8:35 a.m.]

3 DR. SHACK: The meeting will now come to order.
4 This is a joint meeting of the ACRS Subcommittee on
5 Materials and Metallurgy and on Reliability and
6 Probabilistic Risk Assessment.
7 I am Dr. William Shack, Chairman of the Materials
8 and Metallurgy Subcommittee. Dr. George Apostolakis is
9 Chairman of the Reliability and Probabilistic Risk
10 Assessment Subcommittee.
11 The other ACRS members in attendance are Mario
12 Bonaca, Thomas Kress, and Dana Powers.
13 The purpose of this meeting is for the
14 subcommittees to review the status of activities related to
15 the staff's pressurized thermal shock screening criterion
16 reevaluation project. The subcommittees will gather
17 information, analyze relevant issues and facts, formulate
18 proposed positions and actions, as appropriate, for
19 deliberation by the full committee.
20 Mr. Noel Dudley is the Cognizant ACRS Staff
21 Engineer for this meeting.
22 The rules for participation in today's meeting
23 have been announced as part of the notice of this meeting
24 previously published in the Federal Register on February 25,
25 2000.

1 A transcript of this meeting is being kept and
2 will be made available as stated in the Federal Register
3 notice. It is requested that speakers first identify
4 themselves and speak with sufficient clarity and volume so
5 that they can be readily heard.
6 We have received no written comments or requests
7 for time to make oral statements from members of the public.
8 I don't think I have any comments here to start
9 with and we will now proceed with the meeting and I will
10 call upon Mr. Ed Hackett, acting Chief of the Materials
11 Engineering Branch, Office of Nuclear Regulatory Research,
12 to begin.
13 MR. HACKETT: Thank you, Dr. Shack. I'm pleased
14 to be able to be back here to go over some progress. I
15 think it was about a year ago that it was Mike Mayfield,
16 Farouk Eltawila, and Mark Cunningham briefed the committee
17 on the project. This information is already stated.
18 Where we started off, and I guess this is even
19 more than a year ago now, was with at least the hope that
20 recent technical developments indicated the potential for
21 increasing the accuracy in these analyses, and these are
22 just some of the categories; improved estimates for flaw
23 density and distribution, embrittlement correlations, and
24 statistical bases for fracture toughness for the first time.
25 We initiated the project about April last year.

1 It's fully participatory with the industry. The industry is
2 represented here in the form of the MRP and NEI and EPRI.
3 We have briefed the committee, as I mentioned. I think the
4 first one was last February, but also last summer, and then,
5 of course, today. We are also planning on a briefing, I
6 believe it's in the fall will be the next one.
7 The project is organized in three key technical
8 areas. I think the subcommittee, the Thermal Hydraulics
9 Subcommittee already heard some of the results of progress
10 in thermal hydraulics yesterday. Today we will be focusing
11 on probabilistic fracture mechanics, after this
12 introduction, and then in the afternoon, the information
13 probabilistic risk assessment.
14 Just to put a few bullets down on the overall
15 approach. One of the key points is that this overall
16 approach is for a best estimate analysis for these
17 individual technical inputs, with uncertainty addressed
18 explicitly at each point in the evaluation, and this is a
19 departure from what we've done historically, as you know. A
20 lot of what's been done in the vessel area has been done in
21 a bounding sense, particularly with regard to the fracture
22 toughness evaluation and the fracture toughness curves.
23 The idea then also is to update the technical
24 inputs, as I mentioned, in probabilistic fracture mechanics,
25 thermal hydraulics and PRA, and redo the IPTS studies with

1 this new information.

2 The IPTS studies, you might recall, were conducted
3 on three plants. It was Calvert Cliffs, Oconee and H.B.
4 Robinson. I'll come to a glitch in our progress in a little
5 bit regarding H.B. Robinson, but the idea was to redo those.
6 Those were done in the 1980s. I don't remember the exact
7 completion dates, but largely in the 1980s. So the idea was
8 to redo those, which was the basis for the original rule.

9 In parallel, an important part of this that we
10 felt had to go on in parallel was a reassessment of the risk
11 acceptance criteria, and that's what you'll hear about this
12 afternoon. Of course, that was set, at that time. The
13 basis for that is SECY 82-465, from 1982. That was set at
14 the level of 5E-minus-6. Of course, the NRC has changed its
15 outlook on that area significantly since that time.

16 DR. APOSTOLAKIS: Would you explain the first
17 bullet? I don't understand what the best estimate analysis
18 with uncertainty addressed at each point means.

19 MR. HACKETT: Yes. This is the way, I guess you
20 would argue, it should have been done all along. A good
21 example where it's not done right now is the fracture
22 toughness analysis. When the analysis for PTS is done,
23 either to set the screening criteria or to evaluate an
24 individual plant against the criteria, they're using lower
25 bound curves from ASME, with no uncertainty. It's not a

1 best estimate case.

2 DR. APOSTOLAKIS: I guess you are using best

3 estimate and uncertainty in the same sentence, and that's

4 what confuses me.

5 MR. HACKETT: Okay.

6 DR. APOSTOLAKIS: Best estimate usually does not

7 go with uncertainty analysis, does it?

8 MR. HACKETT: In this case, the entire PTS

9 analysis is designed to be a best estimate analysis. But in

10 the past, criticism, I think valid criticism, we've gotten

11 from the industry is that we've taken -- it's a nested chain

12 of correlations and so on that get you to the screening

13 criteria or are assessed against the screening criteria, and

14 in each one of those, we typically, in the past, have made

15 bounding assumptions.

16 Now we're trying real hard to make best estimate

17 assumptions and --

18 DR. APOSTOLAKIS: So you mean to use the best

19 models.

20 MR. HACKETT: To use the best estimate model,

21 right.

22 DR. APOSTOLAKIS: Then you put an uncertainty on

23 it.

24 MR. HACKETT: Right, and then build uncertainty

25 in. I just flagged this up because that is very different

1 from what we've done in the past.

2 DR. APOSTOLAKIS: Okay.

3 DR. KRESS: Well, your re-look at the risk

4 acceptance criteria you think incorporate the uncertainty in

5 some way then.

6 MR. HACKETT: Yes, absolutely, and I don't know

7 who is going to address that this afternoon.

8 MR. MALIK: Mark Cunningham.

9 MR. HACKETT: Mark will address that. Okay. I

10 think that's at 1:00. So that will be the case then. I

11 just thought I'd summarize status real quick. We have made

12 some significant progress, kind of in fits and starts, I

13 think. There's been a lot of meetings between us and the

14 industry and there's been a lot of progress, there's also

15 been a lot of discussion, a lot of arguments, but I think

16 it's moving.

17 Sometimes it's one step forward, two steps back,

18 but it is moving forward.

19 In particular, in probabilistic fracture mechanics

20 area, we have an expert elicitation which is hopefully going

21 to give us a generic flaw distribution that's really based

22 on cutting up old vessel welds and looking at those

23 carefully and also statistically.

24 We're hoping to have that largely in hand by about

25 May of this year. That's underway right now.

1 We do have revised embrittlement correlations,
2 thanks to the work of Ernie Eason at Modeling and Computing
3 Services, and also Bob Odette at the University of
4 California-Santa Barbara.
5 They have a basis now, a database that supports
6 these correlations. It's about five times larger than the
7 one that went into Reg Guide 1.99 Rev. 2, which is what is
8 used right now.
9 We are looking at statistical bases for fracture
10 toughness. The Oak Ridge Laboratory, Mark Kirk, I think
11 Professor Natishan and others in the room here have been
12 involved in doing that for the first time on a statistical
13 basis.
14 Then another important feature is plant-specific
15 flux maps are being developed for the plants that we will be
16 evaluating. I didn't mention it earlier, but Palisades is
17 obviously very interested in participating in this project
18 and has been very cooperative, and so we are also looking at
19 evaluating the Palisades plant.
20 The wrinkle that I mentioned earlier, you can see
21 the dates here when these are supposed to be completed, the
22 Beaver Valley plant is the furthest out because about a
23 month or two ago, the Beaver Valley plant wasn't part of
24 this evaluation. We were originally going to have Robinson.
25 Robinson had some concerns about participating in the

1 project and basically opted out of the project.

2 We are very lucky, through the work of the MRP

3 particularly, that the Beaver Valley plant volunteered to

4 become part of the project.

5 Without that, we would have been without a

6 Westinghouse plant, which I think would have been a very

7 weak point for this whole project.

8 DR. POWERS: Can I come back to your expert

9 elicitation for the flaw distribution? When you described

10 that, you said that you had lots of information from cut-up

11 welds.

12 MR. HACKETT: Right.

13 DR. POWERS: How about the free sheet?

14 MR. HACKETT: Excuse me?

15 DR. POWERS: How about the free sheet? The

16 unwelded portion.

17 MR. HACKETT: The unwelded portion, yes. It does

18 also include that. It has not been focused on that, but

19 typically in the cut-ups that are done, we will take at

20 least several inches to a foot on the sides of the welds.

21 So there is information in the ultrasound exams.

22 DR. POWERS: That only means something if I know

23 what it is relative to the heat-affected zone.

24 MR. HACKETT: Right. Typically, we mention welds,

25 but a lot of these defects are focused on the heat-affected

1 zone, and also not just the heat-affected zone adjacent to
2 the structural weld itself, but the heat-affected zone that
3 results on the weld metal or in the base metal from the
4 cladding application.
5 So those are all captured. The plate actually is
6 captured obviously to a lesser degree than the HAZ or the
7 weld, but obviously the rationale for that is you expect a
8 greater defect rate in the weld or the heat-affected zone.
9 But we are capturing plate information, too.
10 DR. POWERS: Is the distribution strictly size or
11 is it orientation, location?
12 MR. HACKETT: It's everything. I guess maybe one
13 of the biggest drivers, of course, is the density, how many
14 of them are there, but then, of course, a differentiation is
15 being made now for the first time on whether they're
16 volumetric or planer. When they're volumetric, like, say,
17 for instance, it's spherical, turns out when you run the
18 fracture mechanics analyses that they don't matter, they
19 really don't count.
20 Also what we're finding is that an awful lot of
21 the defects are small, two millimeters, three millimeters.
22 When you run those through the probabilistic fracture
23 mechanics code, what you find is they don't participate in
24 any kind of failure projection, either. It's only when
25 they're larger. Basically, they've got to be larger, at

1 least four millimeters, and planer, to really contribute to
2 the failure frequency.
3 DR. POWERS: What happens when I have a cluster of
4 defects such that they act as -- how close do they have to
5 be to act as a single large defect?
6 MR. HACKETT: Good question. ASME has what they
7 call proximity rules to address that, both for surface
8 breaking and subsurface, and those rules are incorporated
9 into this assessment.
10 DR. POWERS: Is that a hidden conservatism that
11 you're putting in here?
12 MR. HACKETT: It would be, because in a lot of
13 cases, as you can imagine, that's --
14 DR. POWERS: I think you'd really want to flag
15 that. I don't know that you've got any alternative on what
16 to do, but I think you want to make it clear where your
17 conservatisms are and not say that I've universally expunged
18 conservatisms in here. I don't think you can.
19 MR. HACKETT: Right. That's a good point. You
20 can't. You can't ever do that one completely. We do the
21 best that we can with that, but that will always be there.
22 Thermal hydraulics, some of you may have heard
23 about yesterday, because I know there's overlap between the
24 committees, but by about the April timeframe this year,
25 we're looking at having a determination of the key

1 transients to be analyzed. I think these will follow
2 probably closely what was done before for 82-465, but we
3 have been examining more than that.
4 There is also this time, hopefully, going to be
5 some verification from testing at the Oregon State
6 University, the APEX facility, which my understanding is
7 that that will model very closely the behavior of the
8 Palisades plant.
9 With PRA, and this will be this afternoon, Mark
10 Cunningham's presentation, the idea is to take the criteria
11 that was used previously and then look at consistency with
12 the more recent NRC risk-informed guidance, particularly
13 these areas here, the reg guide, core damage frequency and
14 in LERF, also.
15 The way it's being done right now is Mark has
16 drafted a Commission paper that presents options for policy
17 decisions in this regard that will be presented for your
18 consideration and also for the Commission's consideration,
19 and Mark will be discussing that this afternoon.
20 DR. POWERS: It seems to me that there is a
21 potential difficulty in acquiring some feedback from the
22 fracture mechanics folks and the people doing these thermal
23 hydraulics and PRA. Unfortunately, I didn't attend the
24 thermal hydraulics meeting yesterday, so I don't know what
25 they said, but I do know that there is a tendency in the PRA

1 community to analyze accidents that are as if the operators
2 went away and took a break.
3 MR. HACKETT: Right.
4 DR. POWERS: Something like that. There's no
5 human involvement. And they're attempting to be bounding
6 when they do that. But that leads to some peculiarities in
7 the accident analysis that you get accidents that don't look
8 like TMI.
9 MR. HACKETT: Right.
10 DR. POWERS: Okay. And it's not clear that the
11 accidents that are bounding or somehow poles that are useful
12 in PRA for risk analysis will, in fact, be suitable for
13 looking at the fracture mechanics problem.
14 It seems to me that you guys would be very
15 concerned about accidents in which operators inadvertently
16 turned on water or something like that.
17 MR. HACKETT: Right. That historically hasn't
18 been addressed previously. My understanding is it will be
19 addressed this time around much more explicitly. That's a
20 concern.
21 The linkage particularly between the three areas
22 is critical in this project, as you noted. One of the
23 things that's critical, for instance, just as an aside or it
24 could be far more than aside, depending on how it pans out,
25 is our assumption of the effects of any kind of thermal

1 plume or thermal streaming in the thermal hydraulics sense.
2 We're assuming -- the assumption going in is that
3 there is good mixing there, that we're not going to have to
4 worry about more than realistically a 1D or 2D problem. If
5 it's a 3D problem, for instance, our fracture mechanics code
6 doesn't address that right now, so that kind of thing could
7 be a showstopper.
8 We have evidence that seems to indicate that's not
9 the case, but that's something we need to look at closely.
10 DR. KRESS: On that slide, before you take it off.
11 If you would give me a little more detail about that last
12 bullet. Risk-informed guidance, what is that?
13 MR. HACKETT: Well, basically, and Mark can
14 probably talk about this much more articulately than I can,
15 but the Regulatory Guide 1.174, as you know, has become kind
16 of a motherhood document for the NRC on how to evaluate risk
17 or evaluate issues like this on a risk-informed basis.
18 DR. KRESS: So the first sub-bullet really means
19 this kind of stuff that's in Reg Guide 1.174.
20 MR. HACKETT: Right. Basically, first off, the
21 consideration of risk, but also proper consideration of
22 defense-in-depth and the other elements that go into the reg
23 guide. A lot of those criteria, of course, are set
24 nominally at the 1E-minus-6 level when you're looking at
25 core damage frequency. The PTS criteria is set at

1 5E-minus-6.

2 Nathan may want to make a few remarks.

3 DR. KRESS: You're going to try to make those two

4 consistent some way.

5 MR. SIU: This is Nathan Siu, Office of Research,

6 PRA Branch. Again, Mark will talk about this more in the

7 afternoon, but I think the point is that he's raising

8 options that might be broader than just Reg Guide 1.174.

9 There's a whole variety of guidance concerning how to use

10 risk in decision-making.

11 So we're opening the question what's the

12 appropriate guidance here and I think the first bullet just

13 simply says we want to be consistent with past guidance to a

14 reasonable extent.

15 DR. KRESS: Thank you.

16 MR. HACKETT: The major issues I thought I'd

17 summarize here. Like I said, actually, things have been

18 going fairly well. But we did become aware about a month or

19 so ago that the H.B. Robinson plant was not going to be able

20 to participate in the project. As I said, that was a major

21 wrinkle, since that would have eliminated a Westinghouse

22 plant.

23 Roy, did you have a comment?

24 MR. WOODS: Yes. I'm Roy Woods, Office of

25 Research, PRA Branch. You've got the right bottom line.

1 H.B. Robinson will not be the plant that we're using for the
2 Westinghouse example. However, they didn't exactly decline
3 to participate. They were participating and they were
4 giving us information about thermal hydraulic
5 characteristics and we had been talking to them and they ran
6 into a problem with the status of updating their PRA model.
7 They were a few months away from putting out a
8 revised PRA model and they were afraid it would cause them
9 problems if they released the old model to us and it was
10 going to end up in our having to develop a model ourselves,
11 which would be quite inefficient.
12 So we went to see if we could find someone else
13 that would be able to participate in a more timely fashion
14 with their PRA model and we made the change. But they were
15 willing to participate to a fairly high degree and it just
16 wasn't quite enough to do what we needed to do.
17 DR. KRESS: That might even be an advantage to
18 have a newer plant rather than the same three.
19 MR. WOODS: I agree. Right.
20 MR. HACKETT: Another particularly interesting
21 aspect of this shift is, of course, Robinson is projected
22 right now by the NRC or themselves to have relatively no
23 problem on pressurized thermal shock, even for their license
24 renewal term, whereas Beaver Valley is projected to be right
25 about at the criteria at the end of their current license.

1 So there's a higher level of interest there on the part of
2 the plant.
3 The other thing is Dr. Powers mentioned the plate
4 defect distribution. Beaver Valley is a plate-limited
5 plant. So that will put another interesting spin on it from
6 the materials perspective.
7 I guess in summary, of course, we're here to do
8 these presentations as an informational briefing for the
9 committee. We are obviously very interested in any
10 feedback, particularly if you think we may be heading off in
11 the wrong direction somewhere. But probably it would be
12 good to have some kind of feedback in writing from the
13 committee on a periodic basis and maybe after this would be
14 an appropriate time after these several days of briefings.
15 With that, I guess I'll sit down and have Dr.
16 Malik come up and start to go through the probabilistic
17 fracture mechanics, unless there are any other questions.
18 Thank you.
19 MR. MALIK: I am Shah Malik. This will be the
20 presentation on progress made in probabilistic fracture
21 mechanics as it relates to PTS reevaluation project. I will
22 be helped by Mark Kirk and Doug Kalinousky in several of the
23 subject matters that I present here.
24 We will be going through the status of the PFM,
25 probabilistic fracture mechanics, activities, and also we'll

1 look where it fits into the PTS reevaluation project as a
2 whole, and then we'll go step by step in progress made in
3 major PFM technical areas and some concluding remarks after
4 that.
5 In the PFM area, we have this being a fully
6 participatory type of project. We are having open public
7 meetings involving staff, contractors, industry
8 representatives, as well as public, and we had several
9 meetings here in '99 and at least one in 2000 year, as well
10 as we are going to have some more recent.
11 In these meetings, we decide about what are the
12 order of issues and what could be a near-term and long-term
13 action plan that we need to work on, and depending upon
14 that, we are assigning some tasks.
15 In addition, we coordinate with PRA as well as the
16 thermal hydraulics group, so that we can have proper
17 interface from their output or input together.
18 DR. SHACK: What does this fully participatory
19 mean?
20 MR. MALIK: It means from the very beginning, the
21 industry and public are very much involved in the process.
22 We laid out all the items that we are doing, what our
23 thinkings are, and they come up and provide their feedback;
24 well, this is not the way it should be done, it should be
25 done this way.

1 So we kind of have a mutual understanding of each
2 other's viewpoint, rather than doing it in the end when
3 everything is done, and then it's not easy to interface and
4 bring new ideas into the picture.
5 DR. APOSTOLAKIS: But this confuses me a little
6 bit. What are the issues that have to be discussed with the
7 public? Is this a technical issue?
8 MR. MALIK: Yes, they are technical issues.
9 DR. APOSTOLAKIS: Like what?
10 MR. MALIK: Technical issues, how do we implement
11 fracture toughness, how do we implement multiple flaws, how
12 do we implement embrittlement correlation, what are the
13 different -- because those things are still continuing to be
14 developed, and at what stage we put it in, because you
15 always find some more time to do some more work and bring
16 that in.
17 DR. APOSTOLAKIS: So you settled on one model or
18 one approach for each one of these.
19 MR. MALIK: We are trying to settle on those, yes.
20 DR. APOSTOLAKIS: And there are no disagreements,
21 no dissenting views?
22 MR. MALIK: There will always be some dissenting
23 views, because you can always find a better mousetrap. So
24 we keep on working on that.
25 DR. APOSTOLAKIS: But the question is why didn't

1 you do it like NUREG-1150, handling the severe accidents? I
2 mean, if there is a number of approaches, then you try to
3 accommodate all of them and you simply assign weights to
4 them by eliciting expert judgment.
5 MR. MALIK: Approaches are still like ideas that
6 are being thought out and made. So they are not mature
7 technologies. Those are ideas that --
8 DR. APOSTOLAKIS: That's where you need this kind
9 of approach.
10 MR. HACKETT: Maybe I'll try. This is Ed Hackett,
11 again. That's a real good point. The major place that's
12 being done right now -- well, actually, it is -- that sort
13 of integration is being done all throughout the project, but
14 the one where it's most striking is this issue with the flaw
15 distribution. That's a very -- has been historically a
16 fairly contentious aspect of this evaluation.
17 Also, it happens to be a very large driver to what
18 comes out in failure frequencies.
19 So what we decided to do, I guess it was about
20 eight or nine months ago now, was exactly to take that type
21 of suggestion and we're doing an expert elicitation process
22 there. So not only do we have the data, but then we're
23 talking, we're eliciting the expert opinion of various
24 experts throughout the country, also internationally, to get
25 opinions on flaw distribution, fabrication techniques,

1 welding, metallurgy, distributions like that.

2 So that type of thing is going on continuously in

3 the project. That's just the case where it's most

4 explicitly being done.

5 DR. KRESS: Along the same line of George's

6 question, I would be interested in whether such public

7 meetings with all the stakeholder participation have been

8 useful or not. Have you changed your mind about anything

9 you were going to do as a result of these meetings?

10 MR. MALIK: Well, it brings some fresh ideas to

11 look into and to improve our technical basis. So it has

12 helped us in ways to have all the things ready before we are

13 ready to present all those things. Yes, it has helped us.

14 DR. KRESS: You think it's been worthwhile.

15 MR. MALIK: Yes, it has been worthwhile.

16 DR. APOSTOLAKIS: Six of them, all six of them

17 have been worthwhile.

18 MR. MALIK: Well, there are times we had some

19 heated discussions in those, as well, yes.

20 MR. HACKETT: I guess I could make another comment

21 there. This is Ed Hackett, again. Also, the industry has

22 also brought a significant amount of resources to bear on

23 this project which are well over and above what the NRC was

24 able to do. So I think that's been a significant help in

25 the project. Bob wanted to make a few remarks.

1 MR. HARDIES: This is Bob Hardies, from Baltimore
2 Gas & Electric Company, and I'm chairman of a reactor vessel
3 integrity group with the MRP, an EPRI group, an we're
4 participating in this task.
5 Our participation includes sort of coordinating
6 the efforts of all the utilities who are providing input to
7 this effort. So a significant portion of those six public
8 meetings is coordinating our contributions of our PRA, our
9 thermal hydraulics models and the data on the materials in
10 the plants.
11 In addition to that, we have technical input and
12 technical opinions, and you asked for an example of an area
13 of disagreement and one was warm pre-stressing. The way the
14 models were performed in the past, when you had an
15 unisolable leak, they're still treated as if that leak is
16 isolated, and we make the argument that if it's unisolable,
17 then it should be treated as if it's isolable.
18 The way we work that out is that the modeling gets
19 done with warm pre-stressing not credited, but we do, the
20 industry does sensitivity studies using that model to figure
21 out what the effect would be if it was incorporated. In
22 that way, our needs are accommodated and NRC needs are
23 accommodated.
24 DR. KRESS: On the last bullet there, FAVOR, is
25 that a new and improved version of OCA-P?

1 MR. MALIK: Yes. It includes OCA-P plus VISA,
2 which was an NRC code, also. So it combines the best effect
3 of both.
4 DR. KRESS: Are we going to sometime see the
5 details?
6 MR. MALIK: Yes. In this presentation, we're
7 going to have details of that, as well.
8 DR. KRESS: Is there plans to have it be given a
9 peer review of some sort?
10 MR. MALIK: In these meetings, we are doing some
11 comparative analyses and comparison.
12 DR. KRESS: So sort of.
13 MR. MALIK: So it's an ongoing process and if the
14 committee wants to hear more details, we can work on that
15 one, too.
16 You mentioned that the PFM, probabilistic fracture
17 mechanics, code developed by Oak Ridge has a release of
18 October to the industry for their review and application and
19 see what things they need to work on.
20 This is sort of an overall flowchart. As you can
21 see, it starts out from the right and it flows toward the
22 left side. Here we have differences in terms of
23 uncertainty. All the red boxes here show where there are
24 uncertainties in the model. For example, when starting with
25 the probabilistic fracture mechanics, we are performing a

1 stress analysis. So we have like a thermal mechanical
2 properties uncertainties, clad differential, thermal
3 coefficient of expansion enthalpy.
4 The Young's model is another quantity that goes
5 into developing thermal mechanical, thermal stress as well
6 as pressure stress.
7 In turn, depending on what are the thermal
8 hydraulic transients that are being brought in, so there
9 will be some uncertainty in them. And then you calculate
10 the stresses with another set of uncertainties going in and
11 along with that, we also include effect on weld, residual
12 stress in the weld parts of the region. So there is
13 uncertainty on that, as well.
14 So we feed all of those --
15 DR. POWERS: Let me ask. Before you feed all
16 that, let me ask a question. Especially under thermal
17 mechanical property uncertainties, you have a lot of thermal
18 mechanical property values that show up in there. How do
19 you treat the correlation among uncertainties; that is, if
20 your density is high, your Young modulus is going to be
21 high. So there has to be a correlation in the uncertainties
22 there someplace.
23 MR. MALIK: Yes. In the first set of analyses, we
24 will have something like what is called mean or best
25 estimate type of values and then there will be a set of

1 values selected for them to perform a set of calculations.
2 This will be like an overall loop here and in that we'll
3 have a set of best estimate values selected for that range
4 of values, and those will go into --
5 DR. POWERS: I find that an interesting
6 uncertainty analysis. I'm not sure how it works. You pick
7 a mean value for everything, there's no correlation -- I
8 mean, there's 100 percent correlation. The means correlate
9 with the means then. Is that factually correct?
10 If I have a mean value of the density, do I have a
11 mean value of thermal conductivity?
12 DR. APOSTOLAKIS: In other words, when you select,
13 after you do the mean value calculation, a set of values,
14 are these values correlated? If the alpha tends to be high,
15 would the other parameters also be high or are they sampled
16 independently?
17 MR. MALIK: They will be sampled independently, I
18 would think so.
19 DR. APOSTOLAKIS: So the correlation is ignored.
20 MR. MALIK: At the moment, yes.
21 MR. HACKETT: That's how you're doing this.
22 DR. POWERS: Well, I don't think that's an
23 advisable way to do things.
24 DR. APOSTOLAKIS: That is what?
25 DR. POWERS: I don't think that's the right way to

1 do things. I think you have to take into account
2 correlations exclusively.
3 DR. APOSTOLAKIS: If they are important, yes.
4 DR. POWERS: And what are the chances that the
5 material properties aren't going to exhibit an enormous
6 amount of correlation?
7 Similarly, what are the chances that the
8 uncertainty and the weld residual stress is then correlated
9 with the properties?
10 MR. KIRK: Mark Kirk, Office of Research. I have
11 a question. Do you mean correlated for physical reasons or
12 just they happen to trend with each other? Is there a
13 causal relation for the correlation?
14 DR. POWERS: Yes. I would assume that there is
15 some underlying causal relation. I mean, I don't know what
16 they are.
17 MR. KIRK: I'm on the materials side, so I can't
18 speak directly to anything thermal hydraulic, but the intent
19 in this process is if there are causal physical
20 relationships between the variables, if there are
21 uncertainties in any of the relationships that are shown by
22 the connection points, that that's all fully captured.
23 The degree to which it's captured really depends
24 upon our process, depends upon how well we elicit the -- and
25 I shouldn't say that, because that has a specific meaning.

1 It depends on how well the technical area experts in the
2 areas of materials and thermal hydraulics express their best
3 understanding of the physical bases for these relationships
4 that you're talking about.
5 To the extent that that knowledge is captured,
6 this model will capture it.
7 DR. POWERS: Did you ask them specifically about
8 correlations?
9 MR. KIRK: Certainly.
10 DR. APOSTOLAKIS: I don't think -- is the PRA
11 group going to see this? The PRA group will see the end,
12 right? The conditional probability of RPD failure.
13 MR. KIRK: This is the format, and we'll get into
14 this type of input a little bit more in -- a little bit
15 later when we talk about materials, but this is really going
16 to be the form of the input, the way that the understanding
17 of the physical relationships between all the input
18 parameters and the input models, this is the type of
19 information that the technical area experts at least in
20 materials and I assume in thermal hydraulics are feeding to
21 the PRA group. So it is going to get captured.
22 DR. SHACK: Well, some of these sources of
23 uncertainty, when I look at the flaw distribution
24 uncertainty, any uncertainty I have in Young's modulus is
25 going to be somewhere after the --

1 MR. KIRK: It will be swamped.

2 DR. SHACK: -- the 14th decimal place.

3 MR. KIRK: Yes.

4 DR. SHACK: And certainly the thermal mechanical
5 properties that I can think about, the yield stress will
6 probably have the widest distribution, the toughness is --
7 things like density and thermal conductivity.

8 DR. KRESS: And you're only looking for
9 correlations of the uncertainties, not the correlations
10 between the properties. That will automatically get taken
11 care of. The correlations of the uncertainties. If you
12 have a high uncertainty in one, do you have a high
13 uncertainty in the other?

14 DR. POWERS: Well, I think you also want to look
15 for correlations in the values, but that tends to be a lot
16 easier thing to do.

17 DR. KRESS: Normally you factor that into it
18 automatically. But I don't know how you go about getting
19 correlations between the uncertainties, unless you have just
20 a lot of data that tells you.

21 DR. POWERS: That's the only way you can, is to
22 find out that they're correlated or have a physical model
23 for how they're correlated.

24 DR. APOSTOLAKIS: He is right, though. The flaw
25 distribution.

1 DR. POWERS: Then just leave out all this stuff.
2 Just put nominal values in and just leave all this stuff
3 out. If you're going to make that judgment, what I do is
4 nonsense on the first part of it, don't make a big deal
5 about it.
6 DR. KRESS: Unless it's easy to do and doesn't
7 cost much time.
8 DR. POWERS: Well, the thing that Joe is worried
9 about is what you know intuitively sometimes turns out to be
10 wrong. I know not in Shack's case, ever, but in my case,
11 what I know intuitively often turns out to be flat wrong
12 when I do these integrated analyses like this. That's why
13 you like to do these integrated analyses.
14 DR. SHACK: Coming back to uncertainties, one of
15 the things I do notice is that we're always dealing strictly
16 with fabrication flaws and there's never any allowance for
17 growth. Have we done enough analyses to convince ourselves
18 that there is no significant growth of these flaws?
19 MR. MALIK: For the PWR environment, I don't think
20 there is any growth going on.
21 DR. SHACK: So all that work you did all those
22 years on cyclical flaw growth of BWRs wasn't necessary.
23 MR. MALIK: Well, in this particular case, flaws
24 are the most significant contributor for PTS type of
25 analyses, yes.

1 We combine this with crack flaw size to come up
2 with crack driving force in terms of the stress as far as
3 crack length and crack depth. Then we combine it, compare
4 it with fracture toughness, again. We'll have material
5 resistance uncertainty, such as fracture toughness, as well
6 as fluence, which go into defining the fracture toughness at
7 a given point in the reactor vessel's life.
8 Once we compare it with crack value and fracture
9 toughness, we also take into account how many flaws are
10 present. To perform this analysis, there are a number of
11 flaws that are present in the vessel. With that, we find
12 the conditional probability of failure for a particular
13 thermal hydraulic transient and when we combine this with
14 initiating event frequency to come up with an overall
15 probability of reactor vessel failure per reactor year, that
16 is vessel failure frequency.
17 And to perform this analysis, we are selecting
18 several plants, as you can see, four plants, Oconee-1,
19 Calvert Cliffs, Oconee is a B&W plant, Calvert Cliffs and
20 Palisades are CE plants, and Beaver Valley, three-loop,
21 Westinghouse plant.
22 In addition, we are also redoing generic SECY
23 82-465 analyses which were done in the early '80s and they
24 were a part of the PTS screening criteria, as well as PTS
25 rule development.

1 So we will be redoing those along with these
2 plant-specific analyses to come up with information related
3 to reengineering of that PTS screening criteria. There will
4 be some sort of curve coming out, early vessel failure
5 frequency as a function of RT, NDT or some other factor into
6 the vessel, and together with that we can decide whether the
7 screening criteria needs to be adjusted accordingly.
8 DR. APOSTOLAKIS: What is this criteria again?
9 MR. MALIK: Screening criteria presently for axial
10 weld and plate material, RT and limiting RTNDT should not be
11 more than 270 degrees three years before the plant is --
12 actually, they have to estimate and say three years
13 beforehand, when they are going to reach their 270 degrees
14 for axial welds and plate or for circumference welds of 300
15 degrees. So they have to know three years in advance of
16 that.
17 DR. KRESS: You can see that corresponds to a
18 given vessel failure frequency and so you can start with
19 vessel failure frequency as your acceptance criteria and
20 work down to the screening.
21 My question is now that you've got this nice band
22 around the uncertainty band, how will you factor uncertainty
23 into this criteria? I presume we're going to hear that this
24 afternoon.
25 MR. MALIK: Yes, there will be a whole set of

1 information provided.

2 DR. KRESS: I just wanted to alert them that

3 that's going to be a question we'd like to address.

4 DR. APOSTOLAKIS: Is there a distinction between

5 the square and the triangular? Do they mean different

6 things?

7 MR. MALIK: It's like a choice. It's K for

8 material resistance is greater than the crack value, yes or

9 no, and here is a selection, how many times you select.

10 DR. APOSTOLAKIS: But the triangle there, what

11 does it mean? The triangle with the circle in the middle.

12 MR. MALIK: Yes.

13 DR. APOSTOLAKIS: Yes. Is that different from the

14 square to the left? Does it mean anything different?

15 MR. MALIK: The only thing here is you're making a

16 selection to say yes or no for answer coming out, where here

17 you're selecting, picking up a value.

18 There are six different technical areas. The

19 first one or the most important one which we're working on

20 is fabrication flaw distribution in RT beltline materials.

21 That includes welds and plates and forgings.

22 The next item is regress statistical

23 representation of fracture toughness, crack initiation, as

24 well as crack arrest, K-1-c and K-1-a. Along with that will

25 be improved irradiation embrittlement correlation to predict

1 the shift in RTNDT and improve the stress distribution for
2 material chemistry like nickel and copper, as well as
3 initial RTNDT. RTNDT-0. So item four feeds into item three
4 and item three in turn feeds into item two. That's how it's
5 built up.
6 And coupled with that is a detailed map of
7 beltline neutron fluence for the four plants and application
8 of all those into the PFM computer code, as it's being
9 revised to accommodate all these developments.
10 DR. SHACK: Shah, just on that, three and four, is
11 one of the products that's going to come out of here a
12 revision of Reg Guide 1.99?
13 MR. MALIK: Yes. Item three, it will be discussed
14 in a few minutes, yes.
15 DR. SHACK: Okay. So there will be no
16 inconsistency between --
17 MR. MALIK: No. We want to work in parallel, yes.
18 I am providing a brief overview on fabrication flaw
19 distribution. Debbie Jackson will be presenting a good
20 presentation on our work for this, but I'm going to just
21 point the discussion on that.
22 DR. APOSTOLAKIS: How do you know it's going to be
23 good?
24 MR. MALIK: Pardon? The objective is to determine
25 generalized flaw sizes, density, that is number of flaws per

1 unit volume, the location of those flaws in welds, plates
2 and forging in the RPV beltline region, and we are using
3 non-destructive examination, as well as destructive
4 examination techniques, and coupling it with expert judgment
5 process, a form of expert judgment process, and the RES
6 contacted staff, Deborah Jackson, and Pacific Northwest
7 National Laboratory is performing the destructive and
8 non-destructive one, as well as helping with the expert
9 judgment process.
10 We have already performed destructive and
11 non-destructive examination of weld in one reactor vessel,
12 called pressure vessel research user facility. It was
13 located at Oak Ridge. And we are continuing to inspect
14 several of the vessels. There is parallel work going on
15 between industry and NRC, so they do similar kind of NDE
16 work and we do our NDE work and compare the results.
17 DR. KRESS: Whether you're looking for is the
18 number of laws per unit volume.
19 MR. MALIK: Yes.
20 DR. KRESS: How do you get that by inspecting the
21 vessel, just looking at that?
22 MR. MALIK: For example, if we have a piece of
23 weld we have cut out, we have done examination to find what
24 are the flaw indications. Once we have located those flaw
25 indications, we section the small pieces out from the weld

1 and cut it where they actually exist and what their size is.
2 So there is verification using destructive examination as
3 well.
4 DR. KRESS: How deep do you go in order to
5 determine this volume?
6 MR. MALIK: The depth will depend on how deep the
7 flaw indication is showing. There were flaws as big as 17
8 millimeters found. So they were destructively examined and
9 found that they were in some kind of repair weld, as well as
10 some kind of complex multiple flaws clustered together.
11 MR. HACKETT: This is Ed Hackett. I think I'll
12 make comment there, too. I think Dr. Kress may be referring
13 to how much of the volume is actually being examined and to
14 what level of detail.
15 DR. KRESS: Yes.
16 MR. HACKETT: The answer is the entire wall, of
17 course. If it's an eight-inch-thick wall, we're looking at
18 all eight inches. Not necessarily with the same level of
19 resolution on the entire way. The expectation, of course,
20 is that you'd probably find most of your laws, like the
21 previous conversation with Dr. Powers, in the heat-affected
22 zone or near the cladding interface, and we're focusing very
23 detailed examinations there.
24 DR. KRESS: So when you come up with the value for
25 this number of flaws, is it distributed?

1 MR. HACKETT: It is distributed. Right. Exactly.
2 DR. KRESS: Thank you.
3 MR. MALIK: There will be some non-destructive
4 examination of plate, as well, which is always from the weld
5 region. So we will have, in the middle of the plate, there
6 will be some flaw distribution coming out from there, as
7 well.
8 And the data is being collected for that during
9 the month of March and April for the plate material. We
10 expect that generalized flaw distribution using the expert
11 judgment process to be completed in the May to June
12 timeframe.
13 The next cycle is by Mark on fracture toughness
14 and he will also be going over embrittlement correlation.
15 MR. KIRK: Okay. Thank you. My name is Mark
16 Kirk, from the NRC Office of Research, Materials and
17 Engineering Branch, and I'm going to be -- today I'm going
18 to be going through with you two separate technical topics.
19 The first one is the uncertainty analysis for
20 fracture toughness and the second one is an update on our
21 progress on developing some new embrittlement trend curves.
22 So first, the first topic is fracture toughness.
23 The objective of this activity is to revise the
24 toughness distribution curves based on expanded data and
25 physical knowledge of the physics that underlies cleavage

1 fracture that's been gained since the models were developed
2 that we're currently using, and they were largely developed
3 over 25 years ago.
4 Those distributions that we're using today are
5 just simply based on data really from the early 1970s.
6 There are about 170 crack initiation data points, about 50
7 crack arrest data points, and that's the basis of the curves
8 that we use today, both in the ASME code, but more
9 importantly, for this discussion, in FAVOR.
10 In SECY 82-465 and the IPTS studies, ad hoc
11 statistical distributions were developed from these data in
12 the ASME lower bound curves, and I'll be showing you some
13 graphs of that in just a minute.
14 The RES staff involved in this activity include
15 myself, Shah Malik and Nathan Siu from PRA, and the
16 contractors involved in this activity include the Oak Ridge
17 National Laboratory and the University of Maryland, and,
18 again, I'll be filling you in on everybody's roles in just a
19 moment.
20 That gives you sort of an overall flowchart of who
21 is doing what and when in the fracture toughness evaluation.
22 Where we started out was assembling all available LEFM valid
23 K-1-c and K-1-a data. That was a task performed by us, by
24 our contractors at the Oak Ridge National Laboratory.
25 They collected the data and significantly expanded

1 our existing database. They performed a purely statistical
2 assessment to get us some interim curves based on the best
3 empirical data that's available today to use in some testing
4 runs of FAVOR that are going on now and also we can look at
5 those data to illustrate some likely overall changes in the
6 current FAVOR model relative to the model that was used in
7 IPTS and SECY 82-465.
8 I will fill you in on some of the details of that,
9 but that activity is basically concluded at this time.
10 Where we moved on to from there is to establish sources of
11 uncertainty in a way that's fully consistent with existing
12 PRA methodologies. Here we're involving contractors for the
13 University of Maryland, and, again, I'll go into more
14 details on this in a minute.
15 We're doing a root cause analysis of
16 uncertainties, so we don't just have to look at the end data
17 distribution, say, in fracture toughness or in RTNDT. We
18 can pick apart the uncertainties so that the uncertainties
19 are appropriately ascribed to different situations and not
20 just treated in bulk, as they've been done in the past.
21 Underlying this root cause analysis is we're
22 looking back at the physical basis, the physical causes for
23 these uncertainties, so that we can properly distinguish
24 between aliatory and epistemic uncertainty causes, and, as I
25 mentioned, we're doing with this and we're working with

1 Nathan to ensure that the methodologies that we're using is
2 consistent with the current PRA framework and we're also
3 working with Nathan and his contractors to make sure that
4 we're -- that the materials experts are describing their
5 state of knowledge to the PRA folks in a way that basically
6 everybody can understand.
7 So first, I'd like to just spend a few slides
8 reviewing our data collection effort and then I'll go on to
9 update you on where we are in the uncertainty analysis.
10 In data collection, Oak Ridge searched and
11 collected additional data. Basically, we had a 50 percent
12 increase in the crack initiation data and an over 100
13 percent increase in the crack arrest data relative to the
14 statistical basis that was used in SECY 82-465 and IPTS
15 studies.
16 They developed some Weibull distributions for us
17 to use in the FAVOR code, just strictly based on the data
18 fit. There is also a large K-1-c and K-1-a database that
19 was developed in Japan in the late '80s and early '90s.
20 It's been an ongoing activity here at the NRC, even
21 predating the PTS reevaluation, to obtain that data. We
22 hadn't succeeded on that. We still haven't succeeded on
23 that, but now the Japanese workers who put together this
24 database have released the data to the Pressure Vessel
25 Research Council and we're in the process of hopefully

1 crossing the T's and dotting the I's to get access to that
2 data.
3 So that's an ongoing activity in data collection.
4 This just sort of shows you on one slide the
5 culmination of the Oak Ridge effort. I'd like to focus your
6 attention first on the left-hand side, for you. This is a
7 plot of the initiation fracture toughness K-1-c versus the
8 normalized temperature. So that's the temperature of the
9 test relative to the reference no ductility temperatures
10 defined in ASME.
11 As I said, this represents about a 50 percent
12 increase in the statistical evidence that we had relative to
13 our previous work, and the thing that I'd like to point out,
14 and I'll point it out again over here, the black curves are
15 the statistically derived uncertainty bounds that Oak Ridge
16 fit to this particular data set.
17 The red curves are what was being used in the
18 FAVOR model up until about six months ago. Similarly, over
19 here, this is a plot of the crack arrest fracture toughness
20 relative to temperature normalized to the no ductility
21 reference temperature. Again, you see the red curves that
22 were being used in FAVOR versus the black curves. It's the
23 current best statistical representation of the data.
24 A message I'd like you to come away from this
25 slide with is that the old FAVOR scatter bands were just too

1 narrow to represent what was really going on.

2 We have performed some scoping studies using FAVOR
3 to see what effect going from the red distributions to the
4 black distributions has on the predicted probability of
5 vessel failure. Perhaps not surprisingly, whether the new
6 predictions are higher or lower than the old predictions is
7 highly dependent upon the transient. We've done some runs
8 where we get many more flaws initiating and going through
9 the wall and then we have other transients where we have
10 many less.

11 So the ballot is sort of still out as to the end
12 effect on this and just points out that we can't allow
13 ourselves to be moved around too much emotionally by changes
14 in where we believe we were versus where we are now. We
15 need to look at this in an integrated fashion.

16 On the next slide, slide number 12 in your packet,
17 which I will skip, is just a mathematical representation of
18 some of the curves that were on the previous slide for your
19 reference, and that's all been detailed in reports that are
20 now in NRC publication.

21 So just to orient you, I've gone through the data
22 collection and the statistical assessment and I'm now going
23 to move on to the root cause analysis.

24 There were questions raised earlier in the morning
25 about a fully participatory process and whether that's had

1 any practical benefits or not, and Bob Hardies certainly
2 addressed some areas where the EPRI and the MRP has brought
3 together input from the utilities.
4 I'd like to highlight here what I see as being a
5 very key benefit in terms of the industry bringing in expert
6 technical knowledge that wasn't available to the NRC and
7 wouldn't be available unless we were in a fully
8 participatory process.
9 This is the work on the uncertainty analysis of
10 the K-1-c and K-1-a curves being conducted at the University
11 of Maryland. It's being conducted at the University of
12 Maryland by contractors that are working from separate
13 funding sources. Professors Modarres and Mosleh have been
14 working with Nathan Siu in the PRA area for some time.
15 Through EPRI and the MRP, they brought in the expertise of
16 Professor Marjorie Natishan, who is sitting in the back of
17 the room, to help us out from the physical basis in
18 identifying the root causes of uncertainties on the
19 materials side.
20 These two researchers are collaborating in this
21 effort, but basically the handoff here is in Professor
22 Natishan's work and I will detail some of that, because
23 that's basically where we are.
24 She's been identifying the reasons for the
25 underlying uncertainties in the bulk data that you saw there

1 and describing that in a systematic way that's then taken by
2 the PRA folks and expressed mathematically to get us to our
3 end result, which is a recommended program structure for
4 FAVOR that treats the uncertainties in a way that's
5 consistent with the underlying physical process.
6 Now, Shah had used one of the root cause diagrams
7 and, again, this is -- the use of this type of diagramming
8 format has come about as a direct consequence of EPRI's
9 funding of Professor Natishan and I think it's brought us to
10 a very good place in terms of being able to look at existing
11 methodologies and express them a systematic fashion.
12 It was perhaps not a good idea to use this
13 diagramming process without explaining it first, so I'm a
14 little bit late on this, but we'll try it here.
15 The idea is that the diagram expresses both
16 parameter uncertainties in the input parameters and really
17 what can go into any of these yellow boxes is a distribution
18 of values. For example, and I will show you some real
19 examples in a minute, say this could be RTNDT and there
20 would be some distribution of RTNDT values which you could
21 look at.
22 Well, that arises due to uncertainties and a lot
23 of different things, a lot of process things and a lot of
24 parameter things. Back here you might have some of the
25 chemical composition elements. So distributions of chemical

1 composition, say, of copper and nickel could flow through
2 the physical model and give rise to a distribution of RTNDT
3 values, which then you'd ascribe some uncertainty to. So
4 that's the basic idea.
5 So in the diagram format, parameters with
6 distributions go in the boxes and at the nodes, those
7 represent different relationships between the parameters.
8 You can have equations that are correlations which, in fact,
9 have their own uncertainties associated with them based on
10 the data that they were drawn from and based on the
11 underlying physical basis of the correlation.
12 You can have nodes that are choices, you pick one
13 or the other, and you can have nodes that are comparisons,
14 min's, max's, things like that.
15 Just some things to say about the process, and,
16 like I said, this has been very helpful in both focusing our
17 attention on what the models are that we really are using
18 today, and also in involving a lot of different experts from
19 different technical areas and getting all their input into
20 one framework.
21 One very nice thing is it displays a complex
22 process in a very logical format and it's the only thing
23 I've personally seen that allows you to look at the big
24 picture, while still also capturing the details.
25 You can look at these diagrams at any level and

1 you don't have to hide anything if you don't want to. It's
2 been very useful in going through this process with experts
3 from within the NRC and also experts in the industry in
4 building consensus, because it really provides a common
5 language for discussion.
6 You will have people come in and say, well, copper
7 is very important as a cause of embrittlement. Yes, indeed,
8 it is very important, but where copper comes in is somewhere
9 way down here and if you try to treat copper way up here,
10 you're going to get stuck with gross empiricisms that are a
11 cause of a lot of the over-conservatisms that are endemic to
12 our current process.
13 So yes, everybody agrees that copper is very
14 important and you'll have people pounding the table and
15 saying that and you'll agree with them, but you're not going
16 to treat it properly and you're not going to capture it
17 properly in the mathematical model. It goes to the PRA
18 people and then eventually gets reflected in FAVOR, unless
19 you understand that copper is somewhere way past that wall
20 and not up there.
21 So this has really allowed people to put this
22 together and understand it as a group.
23 It also streamlines the critique, because you can
24 lay it down in front of someone and have them see how it
25 goes and I will warn you in advance, you may find some

1 errors in the diagrams that I'm about to show you, because
2 they are works in progress, and it seems like every time we
3 put them up, somebody finds something that's perhaps not
4 quite right. Hopefully we're converging on a solution.
5 One thing I do want to point out, and I think I
6 have pointed it out already, is this treats both
7 uncertainties in the input parameters, say copper and
8 nickel, measurements of temperature, as well as
9 uncertainties in the models which are represented by the
10 nodes.
11 So I have included more diagrams than this in the
12 packet and I would be happy to discuss them in detail, if
13 people would like, but what I would like to do is just sort
14 of show you one very high level diagram and then go into one
15 -- in a little bit of detail to focus on some of the things
16 that the process does. If you want to get into the details,
17 that's fine. That wasn't my initial intent.
18 So at the highest level, we're looking for a
19 distribution, and I shouldn't have used the word uncertainty
20 here. You assess the uncertainty as a result of the
21 distribution the model predicts, but we get a distribution
22 of K-1-c values. That's related to the K-1-c data that was
23 used in FAVOR and it's also related to the RTNDT in the
24 irradiated condition, because you do your K-1-c test and
25 then you plot it not versus temperature, but versus

1 temperature normalized to RTNDT, irradiated, in this case,
2 end of license.
3 RTNDT irradiated, based on our current modeling
4 methodology, is a direct function of the unirradiated RTNDT.
5 So the RTNDT measured before operation begins and the shift
6 in the Charpy 30-foot-pound energy, which we take to be
7 equal to the shift in RTNDT. So right there, even at this
8 high level, you see an assumption. We can talk about
9 whether it's a good assumption, bad, whether it's a big
10 error or a small error relative to other things that are in
11 the model, but that's going to get captured here because
12 what you put in is data and physical understanding.
13 I have included all of -- more diagrams here and
14 they then go on further. What I'd like to do is just show
15 you the T30 shift diagram, because that will enable me to
16 make a few points that I'd like to about really more the
17 process than what's in particular on the diagram.
18 I will step through it just very briefly. The way
19 we get the shift in 30-foot-pound transition temperature in
20 this -- and this is a -- this is basically a diagram of
21 what's in either staff position or 10 CFR 50.61/Reg Guide
22 1.99 Rev. 2.
23 First, you have to decide if you do or do not have
24 credible surveillance. If you don't have credible
25 surveillance or you have surveillance and it's -- or you

1 don't have surveillance, you use the embrittlement trend
2 curves. If you do have credible surveillance, you construct
3 a best estimate of the T30 shift based on testing of your
4 surveillance capsules. You then adjust that value for any
5 potential differences in the chemistry between that little
6 lump of material that you tested and your whole, say,
7 beltline weld, if that's what is limiting.
8 You also adjust that best estimate of T30 based on
9 your surveillance samples due to -- for any differences in
10 irradiation temperature that may have occurred, for example,
11 if your limiting material was irradiated in another vessel.
12 Then that goes on and flows down, as I said. Cooper is
13 obviously a key embrittling element, but you see it doesn't
14 occur early on in the diagram and, in fact, this diagram
15 then goes to another one where we get our T30 values.
16 In terms of the points that I would like to make,
17 and these are reflected on slide 20, so I will just say them
18 here and then we an skip slide 20.
19 A lot of times, when people look at these
20 diagrams, and I've already pointed out that this isn't the
21 end, this continues on, sometimes people get despondent
22 because they say this is possibly complex, we could never --
23 we could never reach the milestones that it laid out if we
24 go through this.
25 One thing I want to point out is that you can

1 enter your parameter data at any point on this diagram. You
2 don't have to go all the way to the far right to enter your
3 data and, in fact, in most cases, we don't. We might come
4 in here and say, okay, we have measured values of the
5 30-foot-pound transition temperature. We could go all the
6 way back to the raw Charpy data and refit it and do all
7 that, or we could enter here, or we might decide that we've
8 already done that and we could enter with Charpy shift
9 values.
10 That's going to be a decision that has to be made
11 by the technical experts involved in the process in terms of
12 what our quality of knowledge is at any particular level.
13 But I just wanted to point out that just because
14 we're trying to get this basically all the way down to
15 measurement error and material inhomogeneity, in most case,
16 we won't be entering the diagrams at that point with
17 parameter data.
18 I've pointed this out before. This appropriately
19 incorporates all the uncertainty sources, both uncertainties
20 in the parameters, any possible correlation between the
21 parameters, and also uncertainties in -- and it's not maybe
22 well reflected on this diagram, but any uncertainties in the
23 relationships between the parameters. Each of these
24 equations, it's not just simply the equation that the
25 materials folks are going to pass to PRA, but it's our best

1 understanding of is this an exact model, is this a
2 correlation, are there other potential correlations, and
3 that then will be treated in an appropriate way by the folks
4 in PRA.
5 It's probably obvious, from what I've said right
6 now, but the diagrams are much more than schematic. They,
7 in fact, represent mathematical models and will be used as
8 the basis for simulation studies to understand what the
9 uncertainties are.
10 And there are a few things that this process does
11 that our old way of doing things, which Ed pointed out was
12 lower bounding, can't do and doesn't do, is that we find
13 that when you diagram the process in this way, you find that
14 uncertainties split at certain levels. For instance, every
15 time you encounter a choice node, if, for any particular
16 situation, the uncertainty in a 30-foot-pound transition
17 shift is either going to be the uncertainty that's down here
18 from using the trend curve or the uncertainty that's up here
19 from using surveillance, it can't ever possibly be both,
20 because you have to pick one or the other.
21 Whereas if you just came in and did a statistical
22 assessment or a statistical analysis, I should say, of delta
23 T30 values at the end of this, you'd be wrapping all those
24 together and you wouldn't be appropriately treating it.
25 So by taking the process apart, we can make sure

1 that uncertainties that are appropriately burdened onto
2 appropriate situations and we also have the ability to
3 eliminate double-counting of uncertainties, which is a very
4 real potential, for instance, at this particular node, you
5 feed an embrittlement trend curve without -- right now, you
6 feed embrittlement trend curves without use of copper,
7 nickel, end of license fluents and product form, whereas the
8 equation at node four was, in fact, derived from some of
9 those same data.
10 That needs to be treated appropriately and will be
11 in this process.
12 So I'm going to -- I have included in your packet
13 diagrams for RTNDT and irradiated in K-1-c. If it's
14 acceptable to everyone, I'm just going to skip over those,
15 because like I said, I sort of viewed my role here as trying
16 to describe the process we were taking a bit more than going
17 into the details.
18 What I would like to do now is to shift gears and
19 move on to the irradiation embrittlement correlations. I
20 have borrowed a diagram from the last presentation to
21 indicate that everything that I'm about to talk about is
22 ultimately going to impact this box on the uncertainty
23 diagrams and everything to the right of it.
24 So the objective in this activity is to develop or
25 perhaps I should say revise, refine, improve a model to

1 predict the shift in -- and I want to be specific -- this is
2 a shift in the 30-foot-pound Charpy transition temperature
3 which we take to be equal to the shift in RTNDT in current
4 regulations, due to irradiation embrittlement.
5 Why are we doing this now? Well, we've got a heck
6 of a lot more data than we did the last time this was
7 revised, which is over a decade ago. In that larger data
8 set, we've got a much better coverage of the primary
9 variables, the primary embrittlement variables of copper and
10 nickel and so on. We've got much longer time exposures and
11 consequently we've got exposures to higher fluences.
12 The only data that is being directly considered in
13 this trend curve development is data from commercial reactor
14 surveillance. We're using data from test reactors and the
15 physical understanding from test reactors and theories to
16 help guide our models and that's where the physical
17 understanding comes in, but those data are not being
18 directly used in the correlations.
19 We're using rigorous statistical methods to try to
20 parse out the effects, which is a continuing challenge, and,
21 as I said, we're trying to bring in -- this is not going to
22 be a purely empirical model. It's a highly non-linear
23 model. The variables are -- a lot of the variables are
24 highly cross-correlated and in order to have any sensibility
25 to this, we need to bring in a fairly sophisticated

1 understanding of the underlying physical process of
2 irradiation embrittlement, so we know forms to try to fit
3 the data.
4 This activity provides guidance to -- actually,
5 the activity started and stands as a separate milestone on
6 all of our charts as Reg Guide 1.99 Rev. 3, for which we're
7 on the hook to provide the technical basis for in December
8 of this year and then Reg Guide 1.99 Rev. 3 will go out for
9 public comment sometime in June or July of '01.
10 But we also needed to sort of crank up the
11 activity to provide input to the PTS reevaluation project,
12 and what we're trying to do is to get to Shah and his group
13 a new embrittlement trend curve and a new assessment of the
14 uncertainties which will be rolled back into the model that
15 the University of Maryland is developing for us sometime in
16 the April timeframe.
17 The RES staff that is working on this is myself,
18 Carolyn Fairbanks, Shah Malik, and the NRC contractors that
19 are involved include the Oak Ridge National Lab, Modeling
20 and Computing Services out in Boulder, Colorado, and
21 Professor Bob Odette of the University of California at
22 Santa Barbara.
23 Just to give you a brief perspective on what's
24 changed data-wise. This just shows you the size of the
25 empirical data set that we're working for in terms of number

1 of Charpy shift values. So each of these values represents
2 at least two Charpy transition curves, one irradiated and
3 one at some level of fluence.
4 When we developed Reg Guide 1.99 Rev. 2, sometimes
5 known as the Randall-Guthrie-Odette correlation and Rev. 2
6 hit the books in '88, we had a bit shy of 200 shift values.
7 In the mid '90s, the NRC let contracts with both Modeling
8 and Computing Services, Ernie Eason and Joyce Wright, and
9 also with Professor Bob Odette at UCSB, to do an updated
10 assessment of the embrittlement trend curves. When they
11 published a NUREG for us in 1998, we were up just a bit over
12 600 data points.
13 That model was subsequently critiqued, sort of in an
14 informal sense within ASME and E-900 community. That led to
15 some of the NSSS vendors coming to us with about 200
16 additional data points which have now been included in our
17 assessment. So we're up just a little bit shy of 800 shift
18 values.
19 I'm going to put an equation here and not explain
20 it, which is the only safe thing for me to do. But I do
21 want to highlight how the model has changed, other than just
22 getting longer. The 1988 Reg Guide 1.99 Rev. 2 model is a
23 multiplicative model for Charpy shift. We have all the
24 chemistry factors in one term that's called the chemistry
25 factor and then we have fluence in a completely separate

1 term.

2 That reflected pretty much just a pure empirical
3 fit to the data. In the new equation, and this is just -- I
4 just put this up as an example. It's just one of the
5 candidates that are currently being considered and we're
6 hoping to finalize on the best end model sometime in the
7 next two months, but what we see, some features to
8 highlight, like I said, we've got physically motivated --
9 we've got physically motivated reasons for the forms and the
10 functions that we've selected. We've got separate terms for
11 the stable matrix defects in the A term and the copper rich
12 precipitates in the B term, which is in good agreement with
13 the underlying damage -- the underlying reasons for damage.

14 And it's not particularly apparent here, but there
15 are copper saturation limits being included, reflecting the
16 fact that beyond a certain point, copper is not soluble in
17 the matrix and will not cause damage.

18 Some terms that are currently under consideration
19 include terms accounting for phosphorous, and I should note
20 that there was a phosphorous term in Reg Guide 1.99 Rev. 1
21 that was subsequently removed. We're looking at long time
22 effects and irradiation temperature effects, largely as a
23 result of the fact that we can now see this in the data, and
24 I suppose it is open to some expert debate as to whether we
25 can see it or not.

1 Some of the models tell us that we should expect
2 to see it and as we collect more surveillance data, at long
3 times, we're beginning to see some effects.
4 Also, a big change, not so much in the equations,
5 but in the underlying philosophy, is it's quite likely --
6 DR. SHACK: These long time effects, this is what,
7 growth of the copper precipitates to some point where
8 they're no longer as effective?
9 MR. KIRK: Yes, or thermal -- a combined thermal
10 irradiation effect, any number of things. I'll get into
11 this just briefly. We spent a lot of time trying to develop
12 what I'm going to call a gating criteria. There is no
13 absolute truth here, of course. We've got some Heinz
14 variety of empirical knowledge and physical knowledge and
15 we've tried to come up with some criteria to help focus
16 ourselves on, okay, what gets in and what has to wait for
17 Rev. 4.
18 I'll get to that in just a minute. But one thing
19 I want to point out that's very much more procedural and
20 philosophical than the equation is there is definitely a
21 feeling among the staff that we want to move to the use of
22 surveillance data as a check of the correlation rather than
23 as an index to the correlation.
24 The diagram that I showed you before for delta
25 T30, if you remember, it had the choice branch, where you

1 decided if you had credible surveillance data or not, where
2 credibility was judged as to whether you had more than two
3 points or not.
4 So right now, if you've got more than two points
5 and they're reasonably close to the mean, you change the
6 whole embrittlement trend curve by moving it up or down to
7 those two data points. From discussions among the staff and
8 indeed discussions that have gone on within the ASTM
9 irradiation embrittlement community, there's, I would say,
10 definitely a consensus developing that that's not really a
11 very appropriate engineering procedure and what we should do
12 is move towards use of surveillance data as a check, which
13 is to say we still encourage the licensees to do
14 surveillance.
15 It provides more data. It keeps us from going
16 wrong. But we're not going to change unless the
17 surveillance data is just way off the mean curve, perhaps
18 more than three sigma out, and that still needs to be
19 determined.
20 It doesn't seem appropriate to change the whole
21 view of embrittlement of that particular material based on
22 two data points, when you've got 800 sitting back here
23 saying no, no, no, it's going some other way.
24 So like I said, that's a procedural and
25 philosophical change --

1 DR. POWERS: Before you take that equation off.
2 MR. KIRK: Yes.
3 DR. POWERS: It is remarkable for its level of
4 parameterization with 600 data points. It looks to me,
5 however, that you don't have a saturation effect built into
6 this equation for copper. You have a saturation effect
7 built in for fluents crossed with copper.
8 MR. KIRK: Yes. This is the danger of putting up
9 a particular equation. I honestly can't tell you if this is
10 the one with the copper saturation or not. But the one
11 that's being considered in the end is -- if I had to give
12 you my best guess right now, nine chances out of ten, you're
13 going to have the copper saturation term.
14 If you don't see it here, my error in putting up
15 the equation.
16 DR. POWERS: I just look at it.
17 MR. KIRK: Yes.
18 DR. POWERS: There's no cap on the effect of
19 copper.
20 MR. KIRK: Yes.
21 DR. POWERS: There's a cap on the cross with
22 copper and the fluents term.
23 MR. KIRK: Yes.
24 DR. POWERS: And it seems that you get a cross
25 also with nickel in a peculiar fashion, and it's remarkable

1 in light of the phase diagram.

2 MR. KIRK: Like I said, the problem of putting up

3 an equation for illustration purposes when you're not

4 prepared to talk about it.

5 But this was just one of many and is not going to

6 be the final one, because it's being revised as we speak.

7 So hopefully depending --

8 DR. POWERS: there must be an enormous amount of

9 structure to your data set.

10 MR. KIRK: Yes. We could go on forever.

11 DR. POWERS: I mean, usual metallurgical data like

12 this has enough scatter that straight lines and things like

13 that seem like appropriate.

14 MR. KIRK: That's, in fact, one -- those are some

15 of the things that, of course, we've struggled with and

16 that's one thing -- well, the process that we're going

17 through right now is we're writing the tech basis document

18 to support whatever equation one of us might show you at a

19 future date boxed in yellow.

20 And this is part of the process that I'm showing

21 here. Another part of the process that I think we need to

22 -- well, let me back up.

23 It's very easy to put up a graph of some effect

24 based on data and standing in a room and convince people

25 that you know what's going on. I find it much more

1 difficult to convince people that you know what's going on
2 if you force the investigators involved, and I include
3 myself in this, to put down the graph and basically write
4 the paper.
5 So convince me, let's write the technical basis,
6 and that's what we're -- that's the rigor that we're trying
7 to put ourselves through in terms of getting any particular
8 effect into this model. Let's convince ourselves that we
9 have an appropriate combined physical and statistical basis
10 for these effects, and this is our sort of provisional
11 strategy for focusing our attention on this, is that we sort
12 of divided a physical basis into a well accepted physical
13 basis, perhaps a plausible one, and one that's just not
14 established, that we don't know what's going on.
15 And then we can look at our statistical evidence
16 and say we either have strong evidence for an effect, say, a
17 correlation coefficient in excess of 95 percent, or a weak
18 statistical effect, perhaps a correlation or a confidence in
19 excess of 70 percent, but still with a coefficient you can
20 calibrate.
21 And what we did is we just sort of boxed this up
22 and said, okay, well, certainly if we had a well accepted
23 physical basis and a strong statistical basis, that effect
24 would be included in the model.
25 And if you had weak and not established, you'd

1 never consider putting it up. Obviously, there is a huge
2 gray zone in between. In our initial thoughts on this,
3 we've placed perhaps a bit more stock in the statistical
4 evidence than in the physical evidence and we felt that if
5 we had something that was a very strong and demonstrable
6 statistical effect within the power reactor database, even
7 if we couldn't establish a physical basis for it, we felt
8 that that was something that, from a regulatory perspective,
9 probably would be included in the model, accepting that it
10 would be going under a lot of scrutiny.
11 Conversely, if you had something with a weak
12 statistical basis and perhaps only a plausible physical
13 basis, that would be a little bit more dicey in terms of how
14 it gets in.
15 Obviously, there are no -- it's hard to draw a
16 line on this, but this is sort of a process we're trying to
17 put ourselves through. And ultimately what we'll be doing
18 is publishing a reg guide for public comment, publishing a
19 tech basis where each and every term is gone through in this
20 way.
21 The staff authors and the contractor authors will
22 basically have to come to the table and say here is where we
23 think it is and then it will open for -- the whole process
24 will be open for public critique.
25 So what at least the goal of this committee is to

1 get the debates squarely on a technical level and not on any
2 other level. It's the only way to proceed.
3 The status right now is that we're finalizing the
4 model or trying to. We've frozen the database. That's sort
5 of a necessary procedural step, because there's always one
6 more data point showing up and at some point, you've just
7 got to draw the line.
8 We've at least proposed a gating criteria for term
9 admission and right now, in order to try and get an
10 embrittlement model to Shah and to Terry and for them to
11 use, what we're doing is we're writing mini basis documents
12 so that we can try to get an embrittlement correlation to
13 them in the April timeframe that is hopefully no different
14 and, if anything, not much different than that which is
15 supported by the final tech basis document, which is due in
16 December.
17 And I think I just said all this. We're trying to
18 get this to Shah and his workers by April-May and then once
19 we've got the sort of the mean curve established, then all
20 of this knowledge feeds into the K-1-c and K-1-a uncertainty
21 framework and analysis that's being done by the University
22 of Maryland.
23 The deadlines for Reg Guide 1.99 Rev. 3, tech
24 basis document in December of 2000, draft for public comment
25 available middle of next year, and also just point out other

1 activities in the public domain is that ASTM E-10 has
2 ongoing technical interest in this area and they will be
3 evaluating the model for potential use in the E-900
4 standard.
5 With this, that's my last slide. So if there are
6 any questions now, I'd like to entertain them.
7 DR. POWERS: I guess I'd like know -- I'd like to
8 understand better about the rigor with which you are
9 approaching this problem. If we could look at your slide
10 29.
11 MR. KIRK: I'm sorry?
12 DR. POWERS: Is this one of your slides, 29?
13 MR. KIRK: No, sir.
14 DR. POWERS: Okay. Then I can't ask the question.
15 MR. KIRK: You'll have to get the next guy. Any
16 questions on slides lower than 26? Less than or equal to.
17 As my parting shot, I wanted to point out the next speaker
18 will be Doug Kalinousky, also from Office of Research,
19 Materials Engineering Branch. He is going to be talking
20 about statistical analysis of chemistry and RTNDT data and,
21 again, just to express it in the overall uncertainty
22 analysis framework, where this goes into the diagrams, RTNDT
23 unirradiated is up here, feeding into K-1-c uncertainty,
24 whereas the copper and nickel values are way back here in
25 the embrittlement correlation.

1 I'd just point out one other thing. This is a
2 diagram of the current embrittlement correlation process in
3 Reg Guide 1.99 Rev. 2. We put this up so we have something
4 to talk about. Ultimately what goes into this analysis is
5 going to be different than this because we're going to have
6 a new process and a new correlation and new data.
7 DR. POWERS: Let me ask you. You've mentioned
8 several times the word rigor in your statistical analysis.
9 It's been my experience that rigor is a relative thing. Can
10 you give me an idea, some understanding about the strictness
11 of your rigor?
12 MR. KIRK: The short answer is no. I think that
13 would have to be something that you would judge when you see
14 the product.
15 The problem -- and I'm not a statistician, so I'm
16 probably not going to provide you with an acceptable answer.
17 As I understand it, the problem with non-linear analysis
18 such as these is there is no one single right answer. If
19 this was Y equals MX plus B, we could talk about rigor.
20 It isn't and therein lies the problem. So you've
21 got a lot of engineering judgment going into what you then
22 apply fairly routine statistical tests, like student T and
23 analysis of variance type things, too.
24 So once -- really the points for discussion, at
25 least I think, and this might be a better question when we

1 can present you some more of those results and maybe that's
2 something you'd like to ask for next time, I think the
3 points of discussion are perhaps not going to be so much in
4 terms of the statistical tests that are applied, because the
5 statistical tests that are applied are, in fact, first year
6 statistics.
7 It's going to be on the engineering judgment that
8 we use to say, okay, this is an appropriate subset of the
9 data to try to apply a student T test to. That's what we
10 keep arguing about at least. So I think that's where it
11 comes in and so that's going to be an argument of
12 engineering judgment that's motivated by people's
13 understanding of embrittlement damage mechanisms, in that
14 case.
15 MR. HACKETT: This is Ed Hackett. Let me try a
16 slightly different take on Dr. Powers' question. One of the
17 areas where we have introduced, I believe, a high level of
18 rigor to this process is in screening and selection of the
19 data that went into the database, and there I can cite the
20 benefit of working jointly and cooperatively with the
21 industry on this.
22 For instance, some of the temperatures for the
23 irradiations previously involved melt wires and other forms
24 of selection. It was very rigorously scrubbed by the
25 industry and the ASTM folks this time around to just use

1 downcomer temperature.

2 So there was a lot of -- that's just one example,
3 but there was a lot of rigor that went into selection and
4 screening of the data that are in this database, and then I
5 agree with what Mark said subsequent to that, but there's a
6 fair bit more rigor in that process now than there was in
7 the previous version of the reg guide.

8 DR. SHACK: If there are no more questions, it's
9 probably time for a break. Come back in 15 minutes, 10:25.

10 [Recess.]

11 DR. SHACK: I'd like to come back into session,
12 since I suspect we're going to be running hard-pressed on
13 our schedule today.

14 MR. KALINOUSKY: I'm Doug Kalinousky. I'm with
15 the Office of Research, Materials Engineering Branch. Our
16 objective in this portion is to determine the chemistry
17 variability and RTNDT-0, initial RTNDT variability
18 distributions.

19 We used the NSE database for copper and nickel and
20 initial RTNDT values. We are trying to determine
21 heat-specific distributions, to determine the means of the
22 distributions and the variability, the standard deviation of
23 these.

24 We also are attempting to get the local
25 variability in a small area of the weld or plate.

1 We did this within a little sub-region that's used
2 in the FAVOR code and we are debating still whether the
3 through-thickness as the crack grows or not, because as the
4 crack grows, it might run into different coils that were
5 used in manufacturing the weld. So we're still debating
6 whether that be applied to the code or not.
7 I did this with myself, Tanny Santos, who is off
8 in Canada skiing right now, and Lee Abramson was our
9 statistician that we used as a consultant heavily.
10 DR. SHACK: What is a heat-specific distribution
11 of copper? Is that really the same thing as local
12 variability?
13 MR. KALINOUSKY: That would be the whole heat that
14 we have data for.
15 DR. SHACK: A heat.
16 MR. KALINOUSKY: A heat number. We would try to
17 find the mean from all the different data we have and the
18 distribution about that mean. The local variability instead
19 would be as if in the code, we have broken the welds down
20 and like two to three inch sections and we say the
21 variability in that section.
22 If we already assigned a mean to a point and we go
23 to a different point, what would be the variability between
24 those two points.
25 So we went through -- we used a couple of reports

1 in this thing, one from the CE owners group and one from the
2 B&W owner group, and we used all heats we could find with
3 five or more data points, so we'd have a fair representation
4 of the standard deviation of those mean values. We found 24
5 heats for copper and 39 for nickel.
6 We determined a mean value based on the five or
7 more data points for each heat-specific means. Then we used
8 that to also find the standard deviations.
9 We went ahead and plotted these out, you'll see
10 the next two plots would be the -- next two slides, that is,
11 would be a plot of the standard deviation and the mean. And
12 for the copper, we'll go into this next point as we show you
13 this slide.
14 DR. POWERS: Let me understand this last line.
15 The previous speaker mentioned statistical rigor. You have
16 uncertainty in the mean values and you have uncertainties in
17 the standard deviation values. So you are going to use a
18 linear regression technique that presumes precision in the
19 independent variable. Why?
20 MR. KALINOUSKY: Because we have very little data
21 to go by and there really is -- we did a -- this is what you
22 were referring to, obviously. That was the plot where we
23 had the large scatter. But we noticed that there is
24 definitely a trend as the mean value increases, the standard
25 deviation is increasing.

1 DR. POWERS: That's not an excuse for using
2 linearly squared statistical techniques. They presume that
3 there is no variability in the values for the independent
4 variable. Why wouldn't use something like a min/max
5 procedure?
6 MR. KALINOUSKY: We did what's called a K-ring
7 squared test to test the --
8 DR. POWERS: You can test it till the cows come
9 home. The fact is that you have assumed precision on the
10 horizontal axis here.
11 MR. KALINOUSKY: Yes.
12 DR. POWERS: And there's not. And there's another
13 technique for fitting the line, a min/max technique that
14 takes into account that there is uncertainty both in the
15 independent and the dependent variable. Why not?
16 MR. KALINOUSKY: Because we --
17 DR. KRESS: Does it matter, unless you're going to
18 --
19 DR. POWERS: It's going to change the slope of the
20 line substantially.
21 DR. KRESS: Yes, but that matters only if you're
22 going to extrapolate outside this data, you think?
23 DR. POWERS: Even if you're going to interpolate
24 it, it changes the slope of the line, it's significant.
25 What happens? When you have a non-standard deviation, it

1 tells you that you're plotting the wrong variable. It
2 should be something like the square or the square root or
3 something like that.
4 Okay. But you don't care. All you care about is
5 the linear variable anyway and you'll live with a varying
6 standard deviation, I assume. But now that slope of that
7 line becomes very critical to you and if you've got
8 uncertainty on both axes, you've got to use a statistical
9 technique that's appropriate for that, especially if you're
10 going to advertise it as statistically regressed.
11 MR. KIRK: Mark Kirk, RES. That's certainly --
12 that's a good comment and that's something that we can take
13 away and have Lee Abramson, our statistician look at. But
14 just to clarify, you're concerned about what, measurement
15 error in the mean value?
16 DR. POWERS: You surely have some variability or
17 you wouldn't be plotting standard deviations here.
18 MR. KIRK: Right.
19 DR. POWERS: I assume that you took -- you had
20 five determinations. You found the mean of those five
21 determinations and that's what I'm looking at down here.
22 MR. KIRK: That's correct.
23 DR. POWERS: And then you calculate the standard
24 deviation by squaring the differences and dividing by four
25 or something like that and then doing the square root, and

1 that gave you the standard deviation.

2 MR. KIRK: Right.

3 DR. POWERS: Okay. So there is some variability

4 in that one.

5 MR. KIRK: Well, one thing, if I could just

6 interject momentarily, that I do want to point out is that

7 what Doug is presenting is largely a data collection effort

8 to provide input or what I would call seed information to

9 the uncertainty analysis that's being conducted for us by

10 the University of Maryland contractors and is going to go

11 through the PRA process.

12 So ultimately, for example, if you had a parameter

13 box on the uncertainty diagram that was labeled copper,

14 you'd have two boxes coming out of that that's labeled -- or

15 you'd have one box at least coming out of that labeled

16 measurement uncertainty.

17 So it might not be the -- the goal here is just to

18 inform you as to sort of the status of our data collection

19 effort and present some overall trends. But the analysis

20 methodology is ultimately going to be captured in the

21 overall uncertainty analysis and therein every time we've

22 got a measured variable like temperature, copper, whatever,

23 there is the explicit question asked of do you need to

24 account for measurement uncertainty or not.

25 So I think that's a good point to bring up, but

1 that's also something that's going to be considered.

2 MR. KALINOUSKY: Also, as we did these, not all

3 the -- some of these -- a lot of these points are based on

4 ten values of measurements or more. And basically what we

5 did was I continually filtered out more and more. So I

6 removed the points like less than eight values and I'll

7 remove some of the points with less than ten and I'll remove

8 some more.

9 And the trend is still there and the slope of the

10 line really didn't change that much for the more certain

11 mean values. So that's one we did do to try to validate it,

12 but we can also -- I'll ask Lee Abramson about what you're

13 saying and see if we're going to do another rigorous way of

14 doing that and see if we come up with the same idea or not.

15 One thing also I wanted to point out about this

16 graph is that there's no difference between the CE heats and

17 the B&W heats in this one. They're basically all

18 intermingled. Some of these are CE, some are B&W welds.

19 There really is no trend as in one is high standard

20 deviation and one is low or anything like that, which, in

21 the nickel term, which is the next slide, there is a

22 difference.

23 Here we didn't attempt to put a line through this

24 once we plotted it out, because it's obviously grouped, two

25 separate areas. In this area here, we have -- the majority

1 of these are B&W heats. These are all CE welds. Up here
2 are high nickel addition welds, which are also B&W welds.
3 So we are still looking at this, how we should approach it
4 and how we should use the data the best we can for the heats
5 we're using, because also the same problem we have with the
6 copper is the heats we're using is in the PTS plant analysis
7 aren't all represented here.
8 Some of them only had one reading, so we can't
9 give it a mean or standard deviation, or might have had two,
10 so we didn't have very certain about the standard deviation.
11 So we can't just use the data that we have right now and say
12 that's the heat mean, the heat standard deviation. We have
13 to find some way of we have one plant that has one reading
14 of a mean, so the mean would be about .6 something, and we
15 don't know where to plot it on there, because we have to
16 find some way of making that determination, and we're still
17 looking at that.
18 So based on those plots, and by using the other
19 K-ring squared test I talked about, we've determined that
20 the copper could be either normally or lognormally
21 distributed. The readings for those means we have could be
22 either way. We'll be doing a -- in the final FAVOR code,
23 we'll do a sensitivity study and compare the two.
24 DR. POWERS: How did you determine that the copper
25 could be either normally or lognormally distributed?

1 MR. KALINOUSKY: We used -- we tested both of them
2 and both of them were acceptable to our limits that we were
3 measuring. There might be other ones that would fit. We
4 didn't test every --
5 DR. POWERS: What does it mean you could have a
6 normal distribution with a -- with something other than a
7 constant standard deviation?
8 MR. KALINOUSKY: Say that again, please.
9 DR. POWERS: Your standard deviation isn't
10 constant.
11 MR. KALINOUSKY: For a given mean, it is. At a
12 given point, it's constant.
13 DR. POWERS: For a given mean, it's constant
14 because --
15 MR. KALINOUSKY: This relation here would be based
16 on that line. Basically, it's the equation of that line is
17 what all this is. So you have a given mean, multiply it by
18 this constant value, gives you the standard deviation at
19 that point.
20 DR. POWERS: That's not a constant standard
21 deviation. Well, go on.
22 MR. KALINOUSKY: For nickel, we couldn't do this
23 and we are still looking at it for the same reasons.
24 DR. SHACK: What you're saying is that for a heat
25 with that mean, then you're getting a distribution of copper

1 in that heat. Is that what you're trying to say? Is that
2 what this is trying to do?
3 MR. KALINOUSKY: Right. That's right.
4 DR. POWERS: Whatever that means. I mean, it
5 seems to me that you have prima facie evidence that standard
6 deviation is not constant with copper. How can it possibly
7 be a lognormal distribution? It could well be lognormal
8 distribution on the square, just looking at it, as a guess,
9 the square of the copper concentration of some transform of
10 it, but it's not obvious that -- to me, at least.
11 MR. KALINOUSKY: The next step we did was go for a
12 weld local variability, which is what I said before would be
13 the variability in a small area. We used a CE report we
14 were able to get, had data for eight weldment blocks and we
15 had five measurements at a quarter-T depth. So we used
16 those five measurements from those eight blocks and we just
17 calculated simple standard deviation for both nickel and
18 copper and both of them came approximately about .01.
19 This was also independently done by -- it was
20 Matthew Vaughan and -- who was the other one? Yes. Steve
21 Byrne. It's Steve Byrne and Matthew Vaughan that did those
22 also and they also came up with the number approximately
23 .01, as well.
24 We can't classify what type of distribution it is
25 right now. We still have to look at that and analyze it and

1 -- but the reflexes say it's normal, but we'll have to
2 verify it through some statistical method.
3 Through wall variabilities still needs to be
4 determined. We have some data we can use, if they determine
5 that we should use that in the FAVOR code.
6 DR. SHACK: Again, I'm confused on this one.
7 MR. KALINOUSKY: Okay.
8 DR. SHACK: Are my eight blocks from a single
9 weld?
10 MR. KALINOUSKY: Different weldments, weld blocks.
11 So they made a weld -- a weld heat of -- one type of weld
12 heat, then another type, eight individual ones.
13 DR. SHACK: But the same weld wire.
14 MR. KALINOUSKY: No, different heats, different
15 weld wire heats. Does the backup slide show? This one.
16 MR. MALIK: Right here.
17 MR. KALINOUSKY: Okay. Anyway, it was a weld
18 block, with the weld heat, and simply they just analyzed it
19 for the content for the nickel and copper. Each individual
20 made by different weld wire heats.
21 DR. SHACK: So I've got eight different welds.
22 MR. KALINOUSKY: Right.
23 DR. SHACK: And I take a T-over-fourth block from
24 each one.
25 MR. KALINOUSKY: Right. They measured the T

1 depth.

2 DR. SHACK: What does that have to do with the

3 local variability?

4 MR. KALINOUSKY: Those points would be across the

5 welds, so they would only be half an inch apart, quarter

6 inch apart. So we've got the variability as you go across

7 the weld at a certain depth. These are all -- so basically

8 you're saying how does point --

9 DR. SHACK: I see. You're spacing them over the

10 T-over-four.

11 MR. KALINOUSKY: Yes.

12 MR. KIRK: In the FAVOR -- it's perhaps important

13 to point out that in the FAVOR code, there are sort of two

14 different versions of local. One is you start off in your

15 sample, you generate a sample from a region, which could be,

16 say, the beltline weld or the plate or whatever.

17 So say you take a sample from the beltline weld.

18 That beltline weld is then cut up into iso-fluents regions,

19 regions over which we treat the fluents to be constant based

20 on the fluents maps, which Shah is going to show you.

21 So now you have a region depending upon fluents

22 variability that may be something perhaps big enough to hold

23 in your hand. And the question was raised in some of the

24 public meetings that we had on this that, okay, now, in your

25 analysis of that vessel, you go through and say on run one,

1 you seed a flaw into the circ weld, sub-region B. Then on
2 loop 386, you wind up with a flaw in that same sub-region.
3 So then the question arises, in this analysis of
4 this vessel, you had some Monte Carlo simulation of what the
5 copper, what the nickel, what the composition of that region
6 of material was, and the question came up, on run 386,
7 should I now go and resample from the whole distribution,
8 which is sort of what Doug was showing you earlier, or is
9 there some smaller tighter standard deviation that you
10 should be sampling from.
11 So what we were trying to do was to look at what
12 data is available where you've got reasonably --
13 measurements of material composition reasonably closely
14 spaced to try to make an assessment as to whether that
15 resampling should be done from a smaller standard deviation
16 or not. That's sort of the goal here.
17 MR. KALINOUSKY: These are what they looked like.
18 We were taking these values here across the weld. That's
19 how come I got the local variability there.
20 If you had to do a through thickness, this is what
21 basically we would be using as a data set if we need to do
22 that.
23 So we moved on to plate chemistry and here we have
24 even less data. For every heat, we only had one or two
25 points, so we -- then we couldn't get a standard deviation

1 or any way to really analyze those.

2 So basically what we suggest doing here is just to

3 take the best estimate we have and let's do not sample about

4 it. Just say that's the best estimate and then we'll go the

5 plate local chemistry variability and sample that.

6 For the plate local, here we're able to get three

7 groups of data, once again, not much, with six points per

8 each group. This was -- these came from surveillance

9 specimens from St. Lucie and -- I can't remember the other

10 one offhand right now.

11 Anyhow, we analyzed these and we found standard

12 deviation to be, for the plates to be about .002 for the

13 copper and .005 for nickel. So it's what we expected, very,

14 very small, since plates are very homogeneous.

15 And we'll sample the previous mean using this

16 standard deviation to give us a final value to put into the

17 FAVOR code.

18 Let's move on to the initial RTNDT values. Once

19 again, the amount of data we have is always the hard part

20 here, getting enough data to use. So we pulled data out of

21 RPVDATA. We grouped them by the heats and we used every

22 heat we could find that had three or more measurements, so

23 we have some idea of a standard deviation.

24 And that gives a total of 19 heats and a total of

25 65 data points. What we did here is we did a transformation

1 of the data. We took the -- for each set of data, say, we
2 had five values for that heat, we'd take a mean of it for
3 the heat mean here, and we subtract the measured value to
4 give us a delta value. So basically just transforming the
5 data to a plus or minus around the average.
6 What we did do then was we graphed all those out
7 with a histogram and came up with here -- with the blue
8 would be the data we used and the red would be a fit about
9 that data, and it came out to be a normal -- with a standard
10 deviation of 16.6. So what we propose to do in the FAVOR
11 code would be to generate a random number and let's say we
12 get a .7 or so, go across here till we hit that, come down
13 here and say, oh, it's plus .8. So we had that to our best
14 estimate mean to give us some variability about that mean.
15 And we did the same approach with the plate, as
16 well. Here, once again, we had a little bit more actually,
17 more data for it. We had 128 total data points out of 37
18 heats. We did the same approach, transforming it with a
19 delta value, and we went ahead and plotted that out and we
20 ended up with this type of fitting, where it shows -- comes
21 out pretty normal, the values, in both cases.
22 Any other questions? If not, we'll move on to Dr.
23 Shah.
24 MR. MALIK: The next item in the presentation is
25 developing detailed fluents maps for application of the

1 plant-specific analysis and we have developed end-of-life
2 fluents maps for two plants, and we are using available
3 cycle-to-cycle fuel loading histories.
4 And also along with that, another objective is to
5 determine what is the uncertainty of the fluents. We are
6 starting out to perform in the FAVOR analysis an initial
7 estimate of one sigma in fluents to be roughly like 15
8 percent of the mean, which is much better than earlier from
9 the laboratory, 20 to 30 percent were used. So it's a real
10 improvement from that point on.
11 And the methodology for fluents calculation are in
12 the draft guide on dosimetry, 10.53. It was released in
13 1999 and another NUREG CR-6115 and this work is being
14 monitored at RES by Bill Jones, as well as work is being
15 performed at Brookhaven National Lab.
16 Two plant specific neutron fluents maps have been
17 completed. One was Palisades. There was Robinson, but they
18 opted out, so we weren't able to use that one, and the
19 plants next to be analyzed are Oconee, which we will be
20 finishing up in March, Calvert Cliffs in July, and Beaver
21 Valley we are expecting sometime later on that.
22 We are using defined actual circumferential as
23 well as radial grids to calculate fluents values. For
24 example, Palisades, we have 205 axial, 97 times eight,
25 there's one-eighth symmetry on the circumference.

1 Similarly, like between 20, around 12 to 20 radial grid
2 points have been used in those two.
3 Also, we found that the fluents decay in Reg Guide
4 1.99, which is like minus .24X, is a bit conservative and we
5 will show you a graph on that.
6 Here is a detailed plot, the circumferential
7 horizontal direction, as you go around the circumference
8 from zero degree to 360 degree and you have peaks here in
9 the beltline area. Mid-core area, there is a peak, and as
10 you go around circumference, this happens to be the area
11 core flats are located. Core flats are the region where the
12 reactor core is very close to the reactor vessel. So these
13 four areas are the core flats and the reactor vessel are
14 very close to those, so that's where you see those peaks.
15 And this fluents curve is right at the mid-core as
16 you go along the axial length. At the top of the core is
17 substantial drop-down.
18 Similarly, I have a plot like that for axial
19 variation. Again, in the mid-core level, here is the axial
20 variation, end of the core, top of the core, and here is a
21 mid-core area, where it's the peak values. And you go
22 around the -- this is the core flat area, and other angular
23 locations, these are the values.
24 And because of this variation in fluents, we have
25 to subdivide the region and perform the analysis in the

1 FAVOR code.

2 Here is the exponential decay I was telling you

3 about. These are actual radial distributions of flow

4 through thickness, peak volume in the inner radius, and as

5 you go to the outer radius, it drops down, where minus .24X

6 is used in Reg Guide 1.99 Rev. 2 and this is a straight line

7 on the log graph.

8 Actual -- most of the initiation and all the PTS

9 significant transients with the crack, quarter T on this

10 side, there is very little difference. And even in this

11 area of the graph, actually the crack was just initiated and

12 the crack arrest takes place in this deeper part of the

13 crack depth.

14 DR. KRESS: But cracks closer to zero or two

15 inches, where the curves are pretty close together, are the

16 ones you worry about.

17 MR. MALIK: Yes.

18 DR. KRESS: Okay.

19 MR. MALIK: Okay. The next item is the

20 development of the FAVOR code. FAVOR is number of fracture

21 analysis of vessels in Oak Ridge and it implements refined

22 PFM technology and up-to-date materials data and we are

23 trying to make it consistent with the current PRA, as well

24 as thermal hydraulic input data.

25 In research, it's myself, Nathan Siu and Lee

1 Abramson from PRA site and the contractor -- the main
2 contractor is Terry Dixon, who is present here. And
3 University of Maryland and PRA areas are Professors Modarres
4 and Mosleh, as well as input from Professor Natishan in the
5 fracture toughness area.
6 The code is being used to answer to the kind of
7 question, one, at the given -- at what point in the life of
8 a plant will the acceptance criteria, risk acceptance
9 criteria will be exceeded; for example, at present it's five
10 by 10E-6, because your failure per reactor year. So if you
11 are plotting effective from power year versus risk, in terms
12 of failure, then you want to find out at what point this
13 acceptance criteria is exceeded and plus what would happen
14 if you have improved methodology or mitigative action we are
15 taking, what will the effect of that and how much more plant
16 life can we improve with all of that.
17 As you can see, it involves a number of different
18 items. It starts out with a detailed fluents map, flaw
19 characterization, plates, as well as weldments,
20 embrittlement correlations to define shift in RTNDT, thermal
21 hydraulics transients, and PRA such as event frequency, what
22 are the credible sequence for PTS significance, the reactor
23 vessel integrity database to define material chemistry, as
24 well as industry database.
25 Also, along with that, and the extended fracture

1 toughness initiation and arrest, and the defined fracture
2 analysis methodology. They are all combined together to
3 come up with a method to use for PTS analysis.
4 In addition, we are doing some additional
5 development work here and trying to bring that, such as
6 effect of 3D code, plume and things like that. We are also
7 looking into that, as well.
8 Based on all of these integrated together to come
9 up on a plant specific or on a generic basis analysis to be
10 performed and then they feed in to finally revising the
11 screening criteria.
12 It combines -- the FAVOR code combines the two NRC
13 funded codes. OCA-P was historically developed at Oak
14 Ridge, as well as VISA-II. So those two into a single
15 combined code with all the best feature from the two
16 combined together.
17 It also incorporates the lessons learned from the
18 Yankee Rowe in early 1980s, as well as from IPTS analysis in
19 mid '80s. Now, the code is in the third generation, so we
20 have just in '99 released a version of the code. This plan
21 is to continue development of technology derived from NRC
22 analyzing history, available research and data.
23 This is, again, a list of the same thing, what are
24 the features of flaw characterization in plates and welds,
25 the map, embrittlement correlation, reactor vessel database,

1 fracture toughness, and here we are not using surface
2 breaking, as well as embedded flaw. Both types of flaws are
3 being looked into. This is the first time we are analyzing.
4 So we are taking one big step instead of assuming all flaws
5 to be surface breaking. We are using surface breaking, as
6 well as embedded flaws.
7 And as well as we're including the through wall
8 residual stresses in the reactor vessel welds.
9 As I said earlier, an interim version of the code
10 has been released in October and the next version is planned
11 to be available by May, and we are implementing, with a lot
12 of industry, a discussion on ways to improve it, make it
13 user-friendly and efficient. One of our end goal is to have
14 common understanding, what are the methods that are going
15 into the analysis.
16 Here is a little bit -- a few slides to show what
17 kind of independent verification we are doing. For example,
18 here we went from FAVOR, which is an asymmetric code. We
19 perform analysis using ABAQUS code and tried to compare what
20 were the total gradient through thickness for PTS
21 transients, FAVOR results shown in the red, as well as --
22 sorry -- in the rectangular black color, and ABAQUS results
23 are shown as well.
24 And similarly, this is the resulting hoop stress
25 from a thermal gradient shown here.

1 DR. KRESS: The hoop stress is varying because
2 your pressure is varying. So that's just a plot of how good
3 it predicts pressure.
4 MR. MALIK: This is a plot of temperature and this
5 is the hoop stress through the thickness.
6 DR. SHACK: There is a thermal stress contribution
7 to that.
8 MR. MALIK: Yes.
9 DR. SHACK: But what was this temperature -- I
10 mean, what was the -- you just changed the temperature on
11 the surface? What problem are we really looking at?
12 MR. MALIK: It's for exponential decay
13 temperature.
14 MR. DIXON: Terry Dixon, from Oak Ridge National
15 Laboratory. Actually, there's been many verification and
16 validation problems done. This particular one is for a
17 stylized exponential cool-down rate, but I could just as
18 easily put together slides for discontinuous functions such
19 as repressurizations.
20 It's a finite element based code. So it will
21 handle any thermal hydraulic boundary conditions that you
22 want to impose on the inner surface of the vessel. This
23 particular one is for an exponential decay, thermal, and I
24 believe it was a constant pressure, but this also includes
25 the through wall weld residual stress, as well as the clad

1 based differential thermal expansion.

2 DR. SHACK: But this is all -- this is a truly

3 axisymmetric problem.

4 MR. DIXON: Yes.

5 DR. POWERS: So you're not looking at what the

6 limits are on how much variation you could have asmuthally

7 and still get it.

8 MR. DIXON: No. This is a finite element

9 analysis.

10 MR. MALIK: This is the verification of the

11 stress, again, for this one, I think it was for the region

12 around the crack front and as you can see, both comparing

13 them with FAVOR, using ABAQUS solution as well as FAVOR, now

14 here is the depth point and here is the point along the

15 circumference of the crack, and the K solution are pretty

16 much matching.

17 The reason they are matching here is because the

18 equation that went into the FAVOR code originated from the

19 finite element itself, this should match up very closely.

20 And here is the comparison of -- this is for the

21 surface breaking flaws. Now, this is for the embedded

22 flaws. Here we are showing three definition solutions here

23 and both open and close symbol are showing here for our

24 calculation in FAVOR. These three are for three different

25 distances away from the inner surface, but this one is very

1 close, this is a little bit away from the inner surface,
2 this is farther away from the inner surface. So there three
3 different solutions.
4 Now, this shows a detailed fluents map and fluents
5 in the mid-core area through the circumference, very
6 significantly, and to match that, we need to divide the
7 beltline area into a number of segments, called sub-regions.
8 Here is the axial weld, the plate area, then the
9 circumferential welds, and the lower axial weld and the
10 lower plate area.
11 So we are dividing into a number of sub-regions to
12 as closely as possible see the distribution through the
13 vessel beltline area, both axially as well as
14 circumferentially.
15 This is a sample calculation. It shows that
16 application of this methodology in the FAVOR code can
17 improve the or extend the life of an operating plant. It
18 was done for Calvert Cliffs, NUREG report CR-4022. We have
19 taken the same PRA, as well as the same thermal hydraulic
20 results, but only the fracture mechanics part has been
21 varied. There are four different codes showing over here.
22 The effect of full power year or the RTNDT values
23 versus what is the probability of failure per reactor year.
24 The first -- the top curve is for surface flaw distribution.
25 That was the flaw distribution available before we have our

1 own distribution, we are just working on that.

2 So there were just surface breaking flaws and Reg

3 Guide 1.99 Rev. 2, the correlation. The top curve. Here is

4 the acceptance criteria for the risk, five times 10E-6, and

5 it shows up like 32 effective power year.

6 Whereas if we take the surface flaw distribution

7 and improve the correlation, it's one -- the embedded

8 correlation has been used, not the one that you're going to

9 be using.

10 DR. SHACK: A revised.

11 MR. MALIK: A revised, yes. And you see a

12 significant improvement, as you can see. At this point,

13 it's almost like it doubled the life in the plant.

14 The next step, what happens if you just use the

15 PVD -- a distribution in the process. It has only embedded

16 flaws. There were no surface breaking flaws in it. But

17 using Reg Guide 1.99 Rev. 2, earlier correlation, you see

18 this curve here. A significant improvement compared with

19 the top one.

20 Now, what happens if you combine the two together?

21 Here is the last one in which you have used embedded flaw

22 distribution from PDF and the revised correlation gives at

23 least an order of magnitude on the curve.

24 DR. SHACK: Now, these are presumably done with

25 the old K-1-c and K-1-a distributions.

1 MR. MALIK: Yes. There will be some more benefit
2 derived from that as well, yes.
3 DR. SHACK: I thought they got worse when they did the
4 statistical analysis.
5 MR. MALIK: You cannot say that it has to -- there
6 are three different transients considered here and in some
7 cases, it goes up. So this is all three transients
8 considered together.
9 In summary, work in the PFM area is coming along very
10 vigorously, actively, and some of the major technical
11 activities are in the correlation of fracture toughness.
12 We'll be completing in the April to May timeframe. The
13 plant release the FAVOR code with those in May to June
14 timeframe.
15 We are implementing those technical enhancements
16 as they become available. We don't want to wait around for
17 them.
18 And we come to new coordination and interaction
19 with PRA and thermal hydraulics sub-group to bring their
20 ideas into especially the uncertainty analysis part of the
21 program.
22 And there are some delays, as you can see, one of
23 the plants moving out and replacing it with another plant
24 means we have to go do fluents calculations and some of it
25 is materials related, as well as frequency and all those

1 things, systems, it needs to be done again.
2 At least for the PFM part, we see about two month
3 lag on that.
4 This is my part of the presentation, if there are
5 any questions.
6 DR. SHACK: I don't see any further questions, so
7 we can move on to the flaw distribution, I guess.
8 MR. MALIK: All right.
9 DR. SHACK: From rocket science to expert opinion.
10 MR. MALIK: Debbie Jackson will be the one who
11 will tell us about that.
12 MS. JACKSON: I am going to give you updated
13 information on what's going on with the development of the
14 flaw distribution. That's part of this PFM work. This is
15 just a quick list of some of the topics that I'm going to
16 discuss today.
17 I'm going to go over the background, which I think
18 Shah has touched on today; the approach that we're using; a
19 little bit of information about the reactor vessel
20 fabricators; the material that we're using for developing
21 the flaw distributions; the expert elicitation process and
22 some concluding remarks.
23 DR. POWERS: When you say flaw distribution, are
24 you speaking strictly of density and size or do you include
25 orientation and location?

1 MS. JACKSON: Density, size, location,
2 orientation. I'm going to get all that information.
3 DR. APOSTOLAKIS: Is it really expert opinion
4 elicitation process rather than expert elicitation process?
5 MS. JACKSON: Expert, yeah, expert judgment
6 process. We kind of -- I was using that interchangeably,
7 but actually, yeah, it's expert judgment and elicitation is
8 one section of it.
9 These are the objectives of the presentation.
10 I'll discuss the need for the generalized flaw distribution,
11 talk about the process, and then discuss the status.
12 This is the background, which was discussed a
13 little earlier today, as to why we're doing all this work
14 we're doing with the PTS and the flaw distribution is an
15 important input to the fracture mechanics calculation, so
16 that's why we're going through this effort.
17 And we believe that the fabrication process
18 presents a number of variables that we need to review for
19 the flaw distribution; specifically, the fabrication process
20 and the different welding processes that are used.
21 We're going to go over a little bit about the
22 expert judgment, why we're doing it. It's needed to review,
23 interpret and supplement available information on the
24 reactor vessel fabrication process. A lot of the people who
25 are involved in the actual fabrication processes for reactor

1 vessels are getting up in age and we don't have a lot of the
2 information here. So that's why we decided put together
3 this expert panel, so we could get people who are actually
4 involved in the fabrication process.
5 This is a list of some of the reference documents
6 that I've used. The NRC has done some expert judgment
7 processes in the past for other subjects and these were some
8 of the documents that I used just for reference in terms of
9 determining how you go through the expert judgment process.
10 In addition, Lee Abramson, who is going to do a part of this
11 presentation, he has been involved with the majority of
12 these elicitations or expert judgment processes.
13 This is a list of the domestic reactor vessel
14 fabricators, Combustion Engineers fabricated a majority of
15 the vessels. Babcock & Wilcox, Chicago Bridge & Iron,
16 Rotterdam, and New York Ship Building, and this data was
17 obtained from the reactor vessel integrity database, the
18 RVID, which NRR is responsible for putting together.
19 Those numbers were just the operating reactors,
20 the ones that are presently on line.
21 This slide shows the material that we're using.
22 Midland was done some time ago and PVRUF, Shoreham, River
23 Bend and Hope Creek, which were being examined by Pacific
24 Northwest National Lab, they are all done using an upgraded
25 SAFT UT system. So this is the current pieces that we're

1 using.

2 The PVRUF, Shah mentioned this briefly, this was
3 completed. One issue came up in one of the meetings that we
4 had with industry sometime late last year. They asked a
5 question, they said a lot of the -- the majority of the
6 material that we have was weld material, so what are you
7 going to do with the base metal, because there's so much
8 more base metal, and the numbers that are presently being
9 used for the base metal were just kind of developed through
10 discussions with some of the experts.

11 So what we have decided to do, we have started
12 actually inspecting some of the base metal so that we can
13 get a valid distribution for that.

14 DR. SHACK: Now, EPRI is also doing some
15 evaluation of the flaws in these weldments, right?

16 MS. JACKSON: Right. The Shoreham material
17 specifically is what we're working on with EPRI. PNL has
18 done some exams of the Shoreham vessel material and then
19 we've sent the material to EPRI so that they can use the
20 methods that are currently used in the plant, because the
21 SAFT UT method isn't presently used in the plants. So
22 that's what EPRI is doing.

23 DR. SHACK: So their goal is not to characterize
24 the flaw distribution, then. It's to benchmark the current
25 techniques through the SAFT.

1 MS. JACKSON: And also to verify some of the data
2 that we have, just kind of like a backup of the information
3 we have.
4 I just have a very old photograph that I have that
5 I found going through some paperwork that I had. This shows
6 one of the vessels being fabricated at Combustion
7 Engineering.
8 This is one of the methods where they -- you can
9 see the weldment here. There are two methods that they used
10 to make the rings. One of them, they actually did the
11 forgings, and another one, they used three plates and they
12 weld them together to form a shell.
13 As you can see by the by this picture, it's very
14 old. This was taken in the early '60s.
15 The data that PNL is gathering from the PVRUF,
16 this is how it was determined that they were going to
17 categorize the flaws just for ease of classification and
18 determining what we would use, because there is a different
19 flaw distribution -- well, a different number of flaws in
20 the welds versus the base metal.
21 And a lot of the flaws so far from the PVRUF were
22 found in the fusion lines or they were found in repairs,
23 weld repairs. The largest flaw in the PVRUF was found in a
24 weld repair and that was 17 millimeters.
25 This graph shows the comparison between the

1 Marshall distribution, which was the existing flaw
2 distribution that was used for many years, and this is the
3 PVRUF data that we have. There are approximately 2,500
4 indications that were found in PVRUF.
5 DR. SHACK: These are combined flaws, right?
6 You're not discriminating here between this is the planer
7 flaw, this is --
8 MS. JACKSON: Right. These are just all the --
9 DR. SHACK: All the indications.
10 MS. JACKSON: Yes. These are just all the flaws.
11 All of the different flaws. And we have some data from the
12 Shoreham vessel. They've just finished doing the UT exams
13 of the Shoreham vessel and this compares the Shoreham to the
14 PVRUF. They found a lot more flaws in the Shoreham vessel
15 than they did the PVRUF. Both of those vessels were
16 fabricated by Combustion Engineering, but they were
17 fabricated in different timeframes.
18 There were no surface breaking flaws located in
19 either of the vessels so far to date, and they just started
20 doing the UT exam on River Bend.
21 Now, I'm going to go through some of the steps
22 that were involved with the expert judgment process to
23 determine the generalized flaw distribution. First of all,
24 the staff and the contractors, we discussed some different
25 issues that we felt needed to be addressed and information

1 that we wanted out of this expert panel.

2 We determined the level of complexity and what we

3 had decided, we had wanted information specifically on the

4 weldments, the base metal. We broke the base metal up into

5 two groups, the forgings and the plate material, and the

6 cladding. We identified an expert panel. We developed the

7 issues and we sent them to the panel for their review, to

8 see if they had any comments, if there were anything that we

9 were overlooking.

10 We had a panel meeting. This was our first --

11 I'll go over this more in detail a little later. And we had

12 elicitation training. Elicitation training is important

13 because during the individual elicitation sessions, you want

14 to eliminate as much bias as you can from each individual

15 expert. So we spent a day and a half going through

16 elicitation training with each of the experts.

17 DR. SHACK: You were looking at Prodigal for a

18 while, which is another expert judgment approach to the

19 characterizing flaws in weldments.

20 MS. JACKSON: Yes. Prodigal is actually a

21 simulation. They don't have -- we did put the PVRUF data

22 into a Prodigal simulation code and it came out, the results

23 were pretty similar to what we actually got from the data

24 from PVRUF. But the -- two of the people who are actually

25 on the expert panel for the Prodigal are on this expert

1 panel that we have for the flaw distribution.

2 And so far, we've elicited one of the experts so

3 far who was on Prodigal and we -- he had some interesting

4 comments, so we just need to talk with him a little more to

5 verify some of the issues that he stated during his

6 elicitation session.

7 DR. SHACK: What is the expert judgment supposed

8 to -- I mean, are they supposed to come up with a

9 hypothesized distribution? Prodigal sort of constructs a

10 distribution based on judgment. Are these guys supposed to

11 -- a beauty contest or what, five flaw distributions?

12 MS. JACKSON: What we've done, initially, we gave

13 them a list of issues to try to get them thinking along the

14 lines. We presented them the PVRUF data that PNL did and we

15 made a presentation on the Prodigal work that was done to

16 date.

17 What we want them to do is from their own expert

18 -- well, from their experience, each expert has individual

19 experience. Some of them were actually involved in the

20 fabrication process. Some of them did the NDE inspections

21 of the individual vessels. One particular expert provided

22 some of the welding material to the vessel fabricators.

23 So we want their own individual opinion from their

24 area of expertise on what we've done so far to date, if they

25 feel that's the correct path to go through to get the

1 generalized flaw distribution, and also if they think a
2 generalized flaw distribution can be developed, one flaw
3 distribution.
4 DR. APOSTOLAKIS: What is flaw distribution,
5 again?
6 MS. JACKSON: Excuse me?
7 DR. APOSTOLAKIS: A flaw distribution, what is it?
8 MS. JACKSON: It's the --
9 DR. APOSTOLAKIS: Probability distribution of
10 what?
11 MS. JACKSON: It's the measurement of the number
12 of flaws per cubic meter in the vessel material.
13 DR. APOSTOLAKIS: Independent of length or just
14 flaws?
15 MS. JACKSON: Just flaws, but the flaws have been
16 broken down into the different sizes. Some of them in the
17 inner 25 millimeters of the vessel and then the outer
18 vessel, those flaws that are in the weldment.
19 DR. APOSTOLAKIS: Now, the experts are going to
20 give you the whole distribution? I think that's what --
21 MS. JACKSON: No, they're not going to give us a
22 distribution. That's -- they're going to -- well, Lee will
23 go into a little bit more detail about that, because he's
24 going to go through as to how we go through the statistical
25 process to actually develop the flaw distribution.

1 DR. APOSTOLAKIS: Okay.

2 MS. JACKSON: Through these experts.

3 MR. HACKETT: Let me make a quick comment on that,
4 too, again, because Debbie touched on it. This is Ed
5 Hackett. One of the things, the key things that we're
6 looking for from the expert elicitation process is, is there
7 a generalized flaw distribution or is that some kind of
8 fantasy construct. Just speaking as a metallurgist myself,
9 I could say that there would be good reason to expert a
10 standard or generalized distribution for CE vessels that
11 were fabricated with submerged arc welding over some time
12 period.

13 Whether or not you can extrapolate that kind of
14 thing to cover all vessels that were manufactured in the
15 United States over the last 20 years and is there a
16 generalized flaw distribution, I think we know there are
17 some exceptions to that already, just based on the fact that
18 we know B&W used electroslag as a process.

19 It's not a multi-pass process. It's very, very
20 different from the other populations.

21 So there is a big question just in terms of is
22 there a generalized flaw distribution or do we have to get
23 more specific about it.

24 MS. JACKSON: Thanks. Yes, because of the varying
25 processes that they used for the different vessels, it may

1 -- we hope that we can get one distribution.

2 DR. APOSTOLAKIS: Who is your technical

3 facilitator in the group?

4 MS. JACKSON: The technical, Lee Abramson. The

5 TFI?

6 DR. APOSTOLAKIS: Yes.

7 MS. JACKSON: Lee Abramson is heading it, but it's

8 going to be a group of us who are going to be doing --

9 actually analyzing the results. There will be three to four

10 of us who will be doing that.

11 DR. APOSTOLAKIS: What kind of expertise will be

12 represented there?

13 MS. JACKSON: What type of expertise do this --

14 DR. APOSTOLAKIS: I know Lee's expertise.

15 MS. JACKSON: Lee's -- we're going to have

16 metallurgists, NDE experts, fracture mechanics, and the --

17 Lee, being the statistics expert.

18 DR. APOSTOLAKIS: The three NUREGs that you cited

19 earlier, are they using this concept of TFI? I know

20 NUREG-1150 did not.

21 MS. JACKSON: They didn't actually use the TFI,

22 because they have -- what I was looking for was what the

23 process they used in terms of getting their experts and how

24 they analyzed the data. There is another document that was

25 put out by ASME that -- this is more of a formal process

1 using the technical facilitator integrator and developing
2 the panel. It's a document that ASME has put out. I can't
3 think of the exact number right now.
4 DR. APOSTOLAKIS: A standard? Are you referring
5 to the PRA standard?
6 MS. JACKSON: No. I don't -- I'll have to get
7 back with you, but I used that document to get the format
8 for going through this process and discussions with Lee.
9 DR. POWERS: I had thought you did use the
10 technical facilitator. They didn't use the terminology.
11 DR. APOSTOLAKIS: They didn't really use the TFI.
12 The TFI -- I think NUREG-1150 tried to be more neutral. The
13 TFI, according to the original definition, to, in fact, put
14 things together if the experts disagree, according to his
15 judgment.
16 MS. JACKSON: Different documents --
17 DR. APOSTOLAKIS: Is this what you intend? 1150
18 didn't do that. 1150 elicited rates and processed them.
19 DR. POWERS: They made a decision on how they were
20 going to run things, but in those cases where they had
21 difficulties, and there were a couple that did have
22 difficulties, the equivalent of TFI --
23 DR. APOSTOLAKIS: It comes close.
24 DR. POWERS: -- made a judgment and they went with
25 it.

1 MS. JACKSON: Right. Some documents use different
2 terminology, but it's basically the point of the process
3 where you aggregate all the results from the experts.
4 DR. APOSTOLAKIS: That's a technical integrator.
5 MR. ABRAMSON: This is Lee Abramson. Perhaps I
6 could clarify that. Here, the TFI we're just referring to
7 is the team of people. I guess the NRC and maybe some of
8 our contractors who are going to pull everything together
9 and come up with the -- I guess, in effect, the input which
10 can be used for this generalized flaw distribution, based on
11 the expert panel elicitation, on the rationales and so on.
12 DR. APOSTOLAKIS: I understand that. Well, there
13 is a NUREG on the probabilistic seismic hazard analysis
14 which defines this thing and makes a distinction between a
15 technical integrator and a technical facilitator. So that's
16 why I'm pressing the point, because there is a difference.
17 MS. JACKSON: What was the number that you said,
18 again, please?
19 DR. APOSTOLAKIS: It's in NUREG report on
20 probabilistic seismic hazard.
21 MR. ABRAMSON: That's the Shack report, right?
22 MS. JACKSON: Okay.
23 MR. ABRAMSON: The Shack report.
24 DR. APOSTOLAKIS: Yes. And there is a distinction
25 between a TFI and a TI. And from what you are saying now,

1 you are really going to be technical integrators, more like
2 1150, with maybe some --
3 MR. ABRAMSON: That's probably correct. We may be
4 a little lose in the language here.
5 DR. APOSTOLAKIS: If you put the word facilitator
6 there, it means something specific.
7 MS. JACKSON: Okay. We'll remember that, because
8 that's something we've been using. Okay. The expert panel
9 that we put together, there are a total of 17 people on the
10 expert panel. We have people from the U.S. Navy, from
11 academia, EPRI, independent consultants, and retirees from
12 different organizations.
13 DR. APOSTOLAKIS: How many you have total?
14 MS. JACKSON: Seventeen.
15 DR. APOSTOLAKIS: Seventeen.
16 MS. JACKSON: This is areas of expertise of the
17 various experts. The construction code failure analysis,
18 fracture mechanics, metallurgy, NDE, reactor vessel
19 fabrication, reliability of flawed welding structures, and
20 actually welding.
21 We also have people who are involved with the
22 steel fabrication process for the vessels.
23 This is the schedule. These next two slides, I'm
24 going to go over the schedule. The items that have checks
25 on them are items that have been completed to date. These

1 two group -- these three items actually happened when we had
2 the Atlanta meeting. We had the first meeting of all of the
3 experts and Lee performed the elicitation training and we
4 discussed issues and we also have the elicitation team
5 identified.
6 We're going through the elicitation of the experts
7 right now. We've already completed the elicitation of four.
8 We're doing one elicitation tomorrow, one of the experts.
9 This process, where we're going to take all of the
10 elicitation data from the experts and integrate, that's
11 going to happen late this month and sometime in April.
12 We're going to have another meeting of the expert
13 panel, so that all of their responses and their rationales
14 can be reviewed. That will be done the first part of May.
15 The final responses and rationales will be put together in
16 the end of May and then we're going to have a workshop at
17 the end of June where we're going to present all of the
18 information from this expert judgment process, and that will
19 be the 27th and 28th of June here at the NRC.
20 The next two slides are going to have a list of
21 the issues that were presented to the experts to develop
22 conversation and so that they could get a general idea as to
23 what type of information we wanted from them.
24 From the PVRUF data, we haven't found any surface
25 breaking flaws, so we wanted to find particularly if anyone

1 knew of any existence of any surface breaking flaws and we
2 also have the two experts, one from -- who has information
3 from the UK Navy and the US Navy. So we have people outside
4 of the nuclear industry also.
5 This particular issue with Hatch, there is a flaw
6 that was fond in a nozzle region in the Hatch vessel and
7 after that was found, they had changed the inspection
8 methods for vessels at CE. They increased the inspection
9 process, so that resulted in additional weld repairs and
10 from the PVRUF data, we found out that a lot of the flaws
11 were found in the weld repairs.
12 And this particular event happened in the early
13 '70s and in the mid '70s, they said that maybe they were a
14 little bit too reactive and they were doing too many weld
15 repairs, so they back and changed the inspection process,
16 not to what it was before the Hatch incident, but it was so
17 that they wouldn't have to do so many weld repairs, because
18 the weld repairs were just increasing at an alarming rate.
19 This is just a brief summary of what went on
20 during the first expert panel meeting. The definition that
21 we came up with for flaw was an unintentional discontinuity
22 that had the potential to compromise vessel integrity.
23 That's what the definition of the flaw that's going to be
24 used through this process when we're eliciting the
25 individual experts.

1 DR. POWERS: Can I ask a couple questions? You
2 chose distributions which consist of density versus --
3 MS. JACKSON: The through wall extant.
4 DR. POWERS: And extant, right. Do you have
5 anything that you can show us on how you're handling
6 orientation?
7 MS. JACKSON: I don't have a backup slide with
8 that information, but I can give that to you. That is one
9 of the other presentations, the location and orientation of
10 the various flaws.
11 DR. POWERS: The other question is, in the
12 densities, is there any likelihood that the flaws are not
13 uniformly distributed within the local volume, but are, in
14 fact, clustered? And if you do, how do you handle that?
15 MS. JACKSON: Some of the flaws were clustered.
16 They used the ASME proximity rules to separate them, because
17 when we initially went through the NDE exam, some of them
18 did appear to be clustered.
19 DR. POWERS: They can separate them for the
20 measurement purposes, but now how do they transmit into the
21 rest of the process to say what's the probability that you
22 have a cluster of flaws in this particular piece of metal?
23 MR. HACKETT: I think I'll comment on that, also.
24 Ed Hackett. Dr. Powers raised this question earlier in the
25 day and it's a good question. The answer does basically

1 relate back to the ASME proximity rules, which are going to
2 take a series of flaws that are grouped together, as you
3 say, in some kind of cluster and then look at the dimensions
4 and the orientation and decide if those should be counted as
5 a single bounding flaw, which is then what you would feed
6 into the fracture mechanics.
7 So the short answer to it is that the ASME
8 proximity rules would be applied to any clusters and then
9 are there clusters, I think the answer is absolutely yes.
10 You certainly see a very large cluster of discontinuities,
11 as Debbie put it, at the clad-base metal interface with the
12 heat affected zone for the cladding, basically, which is an
13 expectation you would have from the metallurgy in this
14 situation.
15 So that's the short answer. The good news is
16 that, as Debbie pointed out, we're not seeing surface
17 breaking flaws and these discontinuities that we do see that
18 are clustered are generally inconsequential when it comes to
19 the single dominant flaw fracture mechanics type driving
20 force.
21 The ones that the clad-base metal interface, I
22 believe, in PVRUF, for instance, were largely of the two
23 millimeter type extent. A lot of them were also volumetric.
24 So a lot of those are just not participating in the -- in
25 contributing to the failure frequency of the vessel and the

1 probabilistic assessment.

2 DR. SHACK: But is that saying, in that size

3 distribution we're looking at, then some of those are

4 actually clustered, that they've decided to build together

5 based on the ASME rules?

6 MR. HACKETT: I'd have to go back and check that,

7 Bill. I'm not entirely sure. It should be. The answer to

8 that, if that's the case, they are clustered and they're

9 close enough, like you have this grouping of flaws that are

10 nominally two millimeters, but they're only a half a

11 millimeter apart, well, then, I think the ASME rules would

12 say, no, you better add those all up and count them and make

13 the -- they're close enough to the surface, you're also

14 going to have to count that as a surface breaking flaw.

15 So those things should be addressed as part of the

16 flaw distribution.

17 MS. JACKSON: Right.

18 MR. DIXON: I've got a couple of comments to try

19 to address your question. The question with regard to

20 orientation, flaws that reside in circumferential welds are

21 considered to be circumferential flaws. Flaws that reside

22 on axial welds and plate are assumed to be axial flaws.

23 So in the axis of the principal stress, to answer

24 your question, there is no sampling.

25 DR. POWERS: Okay. That's really the question.

1 MR. DIXON: There is no sampling with regard to
2 orientation.
3 DR. POWERS: Whatever the axis of the stress is.
4 MR. DIXON: Right. However, with regard to the
5 second question, Ed addressed the fact that putting together
6 the flaw size distributions, proximity rules are used, but
7 in the sampling, there is no proximity. The way the flaw
8 distributions are, it's something like this. The first 15
9 percent are postulated to reside in maybe the first
10 one-eighth of the wall thickness. The next 25 percent are
11 between one-eighth and three-eighths.
12 So the wall thickness are partitioned. So when
13 you are in the loop, if you want to call it a loop, of
14 placing flaws, you're going to first decide is it a category
15 one, two, in other words, in with partition does it exist.
16 Then the other assumption is that it has equal
17 probability of being at any location in that partition.
18 Does that address your question?
19 DR. POWERS: Maybe. Maybe I have to see exactly
20 -- go through the mechanics exactly. Let me see if I've got
21 it.
22 MR. DIXON: Okay.
23 DR. POWERS: You end up with a flaw distribution.
24 That has some big flaws in it.
25 MR. DIXON: Yes.

1 DR. POWERS: Okay. There is as fair probability
2 that the big flaws are in -- were, in fact, stemmed from
3 identifying a cluster of flaws that you added all together.
4 MR. DIXON: Yes.
5 DR. POWERS: You may not have ever seen a flaw
6 that big, but just saw a cluster of them that was
7 effectively that big. So now when you apply the
8 distribution in your analysis, you sample, as statistics
9 would dictate, from the whole distribution.
10 Sometimes you're putting in a big flaw which
11 corresponds to that part of the distribution that came from
12 both big flaws and from clusters that were effectively big
13 flaws.
14 So you don't actually say there's -- okay, there's
15 flaw, flaw, flaw, cluster of flaws, then flaw, flaw, flaw,
16 cluster of flaws.
17 MR. DIXON: No.
18 DR. POWERS: I think I understand what you're
19 doing.
20 MR. DIXON: Every flaw is treated independently.
21 DR. POWERS: Okay. It would, incidentally, be
22 useful for the benefit of mankind and possible future people
23 that want to go in and further improve in your work if you
24 did, in the documentation, keep track of clusters and their
25 distributions. Maybe not be part of your work, but the next

1 guy that comes along might be interested in what you found
2 there.
3 MR. ABRAMSON: I would like to describe how we're
4 going through the elicitation sessions. First, we're doing
5 this individually with each experts, each of the 17 experts.
6 And we have a team there and normative expert, I'm serving
7 as that, and then we have various subject matter experts
8 available, and also the recorder, and Debbie has generally
9 been doing that.
10 Then we present a list of characteristics to each expert,
11 and I'll have a detailed list of that in a moment, and then
12 we ask the experts to identify and discuss the pair-wise
13 interaction between the characteristics, and let me explain
14 what I mean by that.
15 We generally -- we start off the session by just
16 giving each expert a copy of this interaction matrix. Now,
17 here are the -- we have identified 14 what we call
18 characteristics, the product form, forgings, plate,
19 cladding, weldment, weld processes, form mechanisms, and so
20 on.
21 And these are just the headings. We have a very
22 detailed discussion of each one of these. Like for the form
23 mechanisms, there are any number of them, for example and so
24 on.
25 We say, all right, each flaw can be characterized

1 by each of these characteristics. Each flaw can be
2 characterized like in 14 ways or 14 dimensional flaw and it
3 has a particular product form and has a weld process that it
4 was formed by and it has -- the flaw has a particular
5 mechanism, et cetera, et cetera, et cetera. So each flaw is
6 unique in this point of view.
7 Now, what we ask them to do is we know that these
8 aren't necessarily -- that -- what we're going to be asking
9 them, in effect, is the likelihood that each one of these
10 will lead to a flaw of a particular size and we know that
11 there can be interactions between these.
12 For example, the welder skill could be very
13 important as to whether or not you have a flaw and that
14 could interact with the flaw mechanism, for example and so
15 on. The experts are going to tell us all this.
16 So we ask -- we go through this one by one,
17 basically each one of these characteristics and we ask them
18 to discuss any possible interactions with all of the others.
19 And, of course, we're recording all of this.
20 DR. APOSTOLAKIS: But, Lee, just to know that the
21 welder skill is important gives you half the picture. Don't
22 you have to know how skilled the actual welders were? I
23 mean, you're talking about the significance of each one of
24 these. How do you know that?
25 MR. ABRAMSON: Yes. Well, this is what we ask the

1 experts, whether they consider welder skill. I mean, all
2 the welders are qualified and so on. And so we talk about
3 the effect of the particular skill of a welder and whether
4 that might make a difference or not.
5 DR. APOSTOLAKIS: But, I mean, let's say that they
6 tell you yes it makes a difference. Now what do you do?
7 Wouldn't you have to decide --
8 MR. ABRAMSON: We're going to ask them -- I'm
9 going to tell -- I'm going to come to that in just a moment
10 as to how we're going to use this.
11 DR. APOSTOLAKIS: Okay.
12 MR. ABRAMSON: In effect, we're doing this --
13 there are no numbers. Eventually, we're going to have to
14 elicit some numbers in order to be able to get a
15 distribution, but here, this is all qualitative and what it
16 does is assess the stage, as I see it, it gives the experts
17 a chance to discuss how they view each one of these
18 characteristics and, in particular, they're going to focus
19 generally on their own areas of expertise.
20 And I ask them to talk about interactions. Again,
21 I think very useful material as far as the rationales for
22 everything like that. It kind of sets the stage. We don't
23 ask for any numbers at this point.
24 So this discussion goes on for maybe a half an
25 hour or longer, going through this matrix. And I think it

1 serves that useful purpose, also to get the experts oriented
2 into the mode of thinking that as to how each of these
3 characteristics might possibly affect the likelihood of a
4 flaw.
5 DR. APOSTOLAKIS: And that's a scale from one to
6 14?
7 MR. ABRAMSON: I'll come to that in just a moment.
8 DR. APOSTOLAKIS: So what are the columns?
9 MR. ABRAMSON: Pardon me? On, the columns. When
10 I say interactions, you have 14 characteristics and here are
11 14 columns.
12 DR. APOSTOLAKIS: You just put X's.
13 MR. ABRAMSON: You just put X's, that's right.
14 They put X's there. So that this -- as I said, this gives
15 the experts an opportunity to give us a benefit of their
16 experience, how they see these particular characteristics,
17 and to ring in how they see it affecting, in a qualitative
18 way, the various likelihood of a flaw.
19 All right. And then we get to, I guess literally
20 it will be the bottom line that we're going to need in order
21 to get the distribution, although we consider -- this is an
22 essential part of the process of getting these rationales
23 out in the open and we're going to report these back, as
24 Debbie indicated, to the experts and, of course, in the
25 final report.

1 So after we've gone through this discussion, we go
2 through the characteristics one at a time. For each one, we
3 ask the experts to identify that alternative with the
4 largest likelihood of leading to a flaw. Now, for each of
5 the characteristics, we have a number of alternatives, and
6 Debbie is going to talk about those.
7 For example, the weld processes, there's automatic
8 and unautomatic, we have a number of them, versus manual.
9 So these are the alternatives for the characteristics. So
10 we have these sub-categories. We have a number of these for
11 each one of them and we say, all right, which is the most
12 important, in your opinion, that's going to be number one.
13 And then what we do is we don't ask them for any
14 absolute numbers. We ask them for only relative numbers.
15 And we say compare each alternative with the highest ranked
16 alternative, how much less likely is it to create a flaw.
17 We get a factor, a factor of two, a factor of three,
18 whatever, ten percent less, 15 percent less and so on.
19 And we ask them for that number and, also, in
20 addition, we ask them for three numbers. First of all, I
21 ask them for high, mid and low value. The mid value is one
22 that's where they say their best guess, if you like, a 50/50
23 chance. And we went over all of this in detail when we did
24 the expert elicitation, what a mid value and a high value
25 are.

1 A high value is supposed to be a subjective 90
2 percentile -- excuse me -- 95 percent. So we say a high
3 value is such that you're almost sure that it's not going to
4 be higher than this. You've got about a five percent chance
5 roughly. And a low value, you're pretty sure it's not going
6 to be lower, it will be less than five percent.
7 So you've got the high value, which is 90 percent,
8 mid value is about the median, all subjective, of course,
9 low value is five percent, so the difference between the
10 high value and the low value is like a 90 percent confidence
11 level. So we ask all of this.
12 DR. APOSTOLAKIS: I don't understand that bullet,
13 frankly.
14 MR. ABRAMSON: Pardon me?
15 DR. APOSTOLAKIS: I understand the first two. So
16 you're comparing each alternative with the highest ranked
17 alternative.
18 MR. ABRAMSON: That's right.
19 DR. APOSTOLAKIS: What is the relative change in
20 likelihood? I don't understand that. What do you mean by
21 that?
22 MR. ABRAMSON: Okay.
23 DR. APOSTOLAKIS: Let's take the example on slide
24 25, the processes, you have automatic --
25 MR. ABRAMSON: Okay.

1 DR. APOSTOLAKIS: -- and then manual.
2 MR. ABRAMSON: Right.
3 DR. APOSTOLAKIS: So now somebody says the highest
4 ranked alternative is manual.
5 MR. ABRAMSON: Manual, right.
6 DR. APOSTOLAKIS: So now I compare the three
7 automatic alternatives to the manual.
8 MR. ABRAMSON: Exactly.
9 DR. APOSTOLAKIS: As you say, somebody says SMAW
10 is a factor of two less likely and so on. We've done all
11 that.
12 MR. ABRAMSON: Right.
13 DR. APOSTOLAKIS: What is the relative change in
14 likelihood of a flaw and how that plays into this?
15 MR. ABRAMSON: Okay. Let me say how we're going
16 to use this. You have no question about we're making the
17 relative -- you get the relative values. The question -- I
18 think what you're asking is, and that's, of course,
19 essential for this process, is how is all this going to be
20 used in order to get what we call a generalized flaw
21 distribution.
22 DR. APOSTOLAKIS: Because that's where we're
23 headed.
24 MR. ABRAMSON: That's where we're headed. Okay.
25 Let me tell you how this is going to be done.

1 DR. APOSTOLAKIS: It's not clear. I really don't
2 understand what you mean by assess relative change in
3 likelihood.
4 MR. ABRAMSON: All right. We're going to start
5 with the PVRUF distribution, because that's based on data.
6 That's the only thing we have, and we've got some hard --
7 we've got some numbers out of that and Debbie has gone over
8 that and you've heard presentations on that.
9 Now, the PVRUF flaws all have their
10 characteristics. It was a CE vessel, some of them are
11 automatic, some are manual, some are repaired and so on and
12 so forth.
13 Therefore, for every kind of flaw, for every kind
14 of flaw there, we can characterize it -- flaw size, and we
15 have the distribution, for every flaw size, we can
16 characterize the PVRUF data according to this 14
17 characteristics in the matrix.
18 And we have -- we know what the flaw distribution
19 is. We know what the likelihood, what the probability of a
20 getting a flaw of a particular size is. That's the data --
21 that's what the data gave us.
22 Now, we have another pressure vessel, with other
23 characteristics. Let's, for example, say one of the PVRUF
24 flaws was a manual weld. All right. Another pressure
25 vessel had an automatic weld. Now, the experts are telling

1 us that, say, an automatic weld is half as likely to have a
2 flaw of a particular size. So what we do then is we're
3 going to take that distribution and we're going to divide by
4 two.
5 DR. APOSTOLAKIS: So you are, in essence, adopting
6 the original distribution to the new vessel with the new
7 characteristics using input from the experts.
8 MR. ABRAMSON: Precisely, that's right. We have
9 this benchmarked distribution, it's a PVRUF, and then we
10 have all the relative comparisons.
11 DR. APOSTOLAKIS: So the experts never give you
12 absolute results.
13 MR. ABRAMSON: No.
14 DR. APOSTOLAKIS: It's always relative to the
15 original distribution.
16 MR. ABRAMSON: That's right. Frankly, I think
17 that this is -- it's fortunate that we have the PVRUF data,
18 because it's much harder to give absolute numbers than it is
19 to give relative numbers, especially when they have no basis
20 for it. They have no basis.
21 We're fortunate -- I mean, obviously, that's what
22 we did in the project to get this PVRUF data and we intend
23 to use this as an anchor in order to be able to get the
24 generalized distribution, with, of course, the uncertainties
25 and so on and so forth.

1 So that's the program and that's how we intend to
2 use this information.
3 DR. APOSTOLAKIS: Again, I don't understand the
4 inspector skill or the welder skill. How does that enter?
5 I understand the materials, the procedure, the weld
6 processes we just discussed, because they're more or less
7 objective. But when you come to welder skill, what does
8 that mean?
9 MR. ABRAMSON: Well, the experts have told us, of
10 course, that the particular skill of the welder can matter.
11 The problem is, of course, I think many of these welds are
12 -- well, I don't know if any records exist as to which
13 welders did which welds and what their skill level was and
14 so on and so forth.
15 Of course, we assume they're all qualified
16 welders. Recognizing that there could be some variability,
17 one way this could enter into it is to say, well, we may
18 want to try to put some kind of a fudge factor or an
19 uncertainty factor based -- let me back up a minute.
20 Let's say that the experts tell us that for a
21 particular kind of weld characteristics, welder skill is
22 important. Maybe it isn't, maybe it is, but let's say it
23 does. The particular kind of weld, the manual welds, it's a
24 very complex weld for repairs, for example, repairs. It's a
25 repaired weld and welder skill is important, but we don't

1 know what the welder skill is.

2 So what this tells us then is since we don't know,
3 that maybe what we should do is we should add some factor
4 for increasing the uncertainty in the effect, because
5 they're telling us that welder skill is important. We don't
6 know what a welder skill is, so this, in effect, would add
7 to the uncertainty on to the flaw distribution.

8 So that would be how we could use it, and, again,
9 we're going to be guided, of course, to a great extent by
10 what the experts are telling us and our own judgment of how
11 to incorporate this.

12 DR. APOSTOLAKIS: The last question has to do with
13 your 14 by 14 matrix. So you've explained now what the
14 third bullet meant, but you had the original distribution as
15 the reference point.

16 Now, if you had these correlations, how do you
17 handle adjusting the values?

18 MR. ABRAMSON: Again, we're going to do what the
19 experts tell us and we're asking them for a particular
20 product form, for example, what are the answers. What we're
21 doing is where it does matter with these interactions, we
22 elicit different values for these relative changes.

23 DR. APOSTOLAKIS: So is it possible then that you
24 say, well, look, welders kill is important and it's strongly
25 correlated with inspector skill?

1 MR. ABRAMSON: Yes.

2 DR. APOSTOLAKIS: So we're not going to count

3 inspector skill because we have already done the other one.

4 MR. ABRAMSON: That's right.

5 DR. APOSTOLAKIS: These are the kind of judgments.

6 MR. ABRAMSON: Exactly.

7 DR. APOSTOLAKIS: That I would have to make.

8 MR. ABRAMSON: That's right. Exactly. Now, we

9 recognize that some of these, like welder skill and

10 inspector skill, you're really not going to be able to get

11 any numbers for, but, again, what we're trying to do is to

12 identify all -- as Debbie said, all of the issues which

13 could be important and listen to what the experts are

14 telling us and to try to incorporate as much as possible.

15 DR. APOSTOLAKIS: The 14 by 14 matrix then

16 protects you against double-counting. That's really what it

17 does.

18 MR. ABRAMSON: Yes, that's right, I mean, assuming

19 that things are -- inspector skill and welder skill, that's

20 right, we're not doing it together, of course.

21 DR. APOSTOLAKIS: That's a clever idea.

22 MR. ABRAMSON: Yes.

23 DR. POWERS: I guess I didn't understand how you

24 handle the correlation.

25 MR. ABRAMSON: What we do is where there is a

1 significant correlation, we'll elicit different values from
2 the experts for each of those. For example, they tell us
3 that the difference between weldments and plate, so we'll
4 do, all right, first for weldments, what are your values for
5 this, then for plate, what are your values for this, and so
6 on.
7 So when we do this initial discussion with the
8 experts on the interactions with the 14 by 14 matrix, we
9 make a note of what's important and, of course, we don't
10 forget to come back to it and ask the experts say, yeah,
11 this is really important, we'll come back and we'll just
12 re-elicit it.
13 In effect, we're getting it conditional on what
14 they say are the important values.
15 DR. POWERS: I mean, I understand that you might
16 do plates and welds differently.
17 MR. ABRAMSON: Right.
18 DR. POWERS: But suppose you come back and you
19 say, gee, inspection procedure and inspector skill are
20 highly correlated. You use the worst possible procedure
21 with the worst possible inspector. They combine.
22 MR. ABRAMSON: Right.
23 DR. POWERS: Whereas by the time you get down the
24 best possible inspector, it's pretty much independent of
25 procedure. He does a good job no matter what procedure is

1 there.

2 MR. ABRAMSON: Right.

3 DR. POWERS: How do you recognize this?

4 MR. ABRAMSON: Well, we ask them about it. They
5 tell us this. We'll say, all right, what would it be for
6 this particular kind of -- assume, say, you've got a good
7 inspector and we're dealing with -- what was the
8 characteristic you were dealing with, with the procedure,
9 say, so say you've got a good inspector and you have a
10 procedure.

11 By the way, I should emphasize one thing which we
12 tell the experts right away going in. What we are
13 interested in is the flaw distribution as -- a pressure
14 vessel, as installed and ready to operate. This is after
15 it's gone through all the pre-service inspection. So this
16 isn't the flaw distribution that may have existed and then
17 was caught by inspectors and so on and so forth. So then
18 the question with inspector skill has to do with, well, are
19 there some things which might have escaped the inspector
20 because there weren't the skills.

21 DR. POWERS: You're going to clip this
22 distribution somehow?

23 MR. ABRAMSON: You mean truncate it?

24 DR. POWERS: Yes, because you're going to say
25 certain kinds of flaws get caught.

1 MR. ABRAMSON: Yes, absolutely. Absolutely.
2 DR. POWERS: And you're going to get some
3 assessment of the inspector's skill and that's going to
4 cause you -- for poor inspectors, you will clip less than
5 you will for good inspectors, and some procedures are better
6 than others.
7 What I'm asking is how do you decide when you've
8 got correlation between them? That is, you have a bad
9 inspector and a bad procedure. Does that -- how does that
10 change where you clip this distribution, truncate the
11 distribution?
12 MR. ABRAMSON: Well, let's say, all right, well,
13 you see, we would have to -- in order to be able to actually
14 apply this information about the quality of the inspections,
15 we would have to know for a particular pressure vessel
16 whether the inspector was good or bad.
17 DR. POWERS: We don't know that.
18 MR. ABRAMSON: We don't know, so we've got a
19 random sample of inspectors. So I think a way we would
20 handle that, and I mentioned it previously, is to increase
21 the variability and increase the uncertainty on what the
22 distribution is, because we don't know whether the inspector
23 was good, bad or indifferent. However, we do know that
24 depending upon his skill, you might have a different
25 distribution.

1 Well, the way to handle that would be you'd have
2 to have an uncertainty bound range of some sort on the
3 distribution.
4 DR. POWERS: I can see how you'd handle the
5 individual. Now what I'm asking is you've got both, you've
6 got to account for both the inspector and the procedure that
7 was adopted.
8 MR. ABRAMSON: I think we would know the procedure
9 from the records.
10 DR. POWERS: Go back to the records.
11 MR. ABRAMSON: Go back to the records when you try
12 to do that.
13 DR. POWERS: And if it turned out, lo and behold,
14 that you used the worst possible procedure you could, the
15 worst one you've ever heard of, you've already corrected the
16 distribution for the fact that you know that the inspectors
17 are of a random sample, some of them were bad and some of
18 them were good, whatnot. Now, what do you do with the
19 procedure? Is it just completely independent of the
20 inspector or do you add another fudge factor on top of it or
21 do you say no, bad inspectors, I've already added enough
22 fudge factor, I'll add no more, but for the good one, I
23 haven't added enough, so I have to add some.
24 MR. ABRAMSON: I think it will have to be a matter
25 of our judgment based on what the experts are telling us how

1 to interpret this. That's the best I can tell you. Each
2 one, in effect, each distribution is going to be custom
3 made.
4 DR. KRESS: You would have to ask the experts, if
5 I had a high-high or a high-medium or a high-low, you would
6 have six different things, you would have to ask them what
7 factor goes in to those. I don't see any other way you do
8 it. Wouldn't you have to -- you would have to have them
9 define the correlation for you.
10 DR. POWERS: You're going to have to know. It
11 could well be that good inspectors are doing a fantastic job
12 and it doesn't matter what procedure you use.
13 DR. KRESS: Absolutely.
14 DR. POWERS: And then bad inspectors do a bad job,
15 but it's a little bit better with a good procedure, but not
16 a lost worse with a really bad procedure. You've got to
17 know that information, somebody has got to tell you that.
18 DR. KRESS: And then they have to extrapolate this
19 to suppose you have a three-way correlation. You've got a
20 three-dimensional matrix you have to deal with.
21 DR. APOSTOLAKIS: The uncertainty is in the
22 result. That's probably overkill.
23 DR. POWERS: I don't know that it's overkill,
24 George. The problem is if you just go through and do it
25 randomly, you are going to put a tail on this distribution,

1 that when you're talking about things at
2 six-times-ten-to-the-minus-fifth amounts to a bunch. But
3 because it's correlated, you shouldn't have that tail.
4 It's the classic problem of dealing with the tails
5 of distributions, correlations count out there.
6 DR. APOSTOLAKIS: Sure.
7 DR. POWERS: They don't affect the means very much
8 at all, but they sure affect those tails
9 MR. ABRAMSON: Recognizing that, is that -- that's
10 why we emphasize these interactions when we're going to try
11 to -- not to double count or triple count or whatever we're
12 going to do, we recognize that.
13 DR. POWERS: Good.
14 MR. ABRAMSON: If there are no more questions, I
15 Debbie has a few final remarks to make.
16 DR. POWERS: It gets up to about 16,000 different
17 ways that you have to handle things.
18 DR. KRESS: Yes, I think so. That's asking a
19 little too much of the experts.
20 DR. POWERS: We've got really good experts. They
21 all come from Oak Ridge. They're great experts. We don't
22 want any of the Argonne guys coming to the expert
23 elicitation.
24 MS. JACKSON: These are from the discussion,
25 you've gone through these. One point I want to make in

1 terms of the inspection procedure, the inspection procedure
2 is a final inspection procedure after the vessel is fully
3 assembled, because the welding procedures themselves have
4 individual inspection procedures for different points.
5 So the inspection procedure that's listed in the
6 list of characteristics is the final inspection procedure.
7 So I'll just go to the --
8 DR. POWERS: This is after the cladding?
9 MS. JACKSON: Yes, after the cladding. After it's
10 ready to be --
11 DR. POWERS: Then we can throw that one away.
12 MS. JACKSON: So these are just some concluding
13 remarks that we've put together so far. The expert
14 elicitation process is complex, as well as the expert
15 judgment process, and we want to identify some significant
16 issues in the development of flaw distribution. We want to
17 address the combination of the relative effects of the
18 characteristics in the PVRUF distribution and that the flaw
19 distribution may vary by vessel fabricator.
20 Are there any other questions?
21 DR. SHACK: We'll know the answer by June.
22 MS. JACKSON: Yes.
23 DR. APOSTOLAKIS: Are we writing a letter this
24 time?
25 DR. POWERS: Can they ask 16,000 questions by

1 June?

2 MS. JACKSON: I'd like to get the title of that

3 NUREG that you mentioned, that you mentioned before, the

4 title of that NUREG.

5 DR. APOSTOLAKIS: Abramson knows. The Shack

6 report, she would like to have it.

7 MS. JACKSON: Are you familiar with that?

8 MR. ABRAMSON: Yes, I've got it.

9 DR. SHACK: What we'd like to propose is to come

10 back into session at quarter to one, since we're likely to

11 be a little pressed for time this afternoon.

12 [Whereupon, at 12:02 p.m., the meeting was

13 recessed, to reconvene at 2:45 p.m., this same day.]

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1 A F T E R N O O N S E S S I O N

2 [12:45 p.m.]

3 DR. SHACK: I'd like to come back into session and
4 I guess we're going to have Mark Cunningham who is going to
5 give us the big picture.

6 MR. CUNNINGHAM: My nickel?

7 DR. SHACK: Your nickel.

8 MR. CUNNINGHAM: Good afternoon. My name is Mark
9 Cunningham. I'm in the PRA Branch in the Office of Nuclear
10 Regulatory Research.
11 I'm here this afternoon to give you kind of an overview of
12 where we're at and where we may be going in terms of
13 re-looking at the acceptance criterion that's established
14 for the PTS rule.

15 Basically, just as an overview, we have a deadline
16 in May of this year to provide a Commission paper describing
17 what changes or recommending potential changes the
18 acceptance criteria that are used in the PTS rule or a
19 recommendation maybe to leave it the way it is or whatever.

20 We wanted to take on this issue early on, because
21 if the policy decision took us in a certain direction, we
22 wanted to know that early enough in the process so that we
23 could adjust the rest of the program to accommodate it.

24 So basically what we'll have is that what I'm
25 going to do today is walk you through a number of items that

1 will be in that Commission paper or kind of the structure of
2 the Commission paper, talk about the acceptance criterion
3 itself as it currently is, talk about two issues of things
4 that have arisen since 1983 or whatever when the rule was
5 established in terms of guidance on use of PRA, and then
6 information on severe accident phenomenology, and then talk
7 about, at least introduce some potential revisions or ways
8 that we could change the acceptance criterion, talk a little
9 bit then about how we plan to finish up the paper over the
10 next couple of months, including coming back to the
11 committee perhaps in late April or May or something like
12 that.
13 At this point, we're not looking for a letter or
14 anything, but we may at the -- in the May timeframe.
15 You probably heard a great deal about this the
16 last couple of days, but the rule was established in 1983 as
17 an adequate protection rule, on contrast to some of the
18 other rules that we'll talk about later, like the station
19 blackout rule that were cost-beneficial safety enhancements.
20 So it was developed under different provisions of the
21 backfit rule.
22 The rule itself established an embrittlement
23 screening criterion that licensees had to evaluate their
24 plants against to determine whether or not they had adequate
25 safety margins in their vessel.

1 The acceptance criterion is in the form of a
2 frequency of a through wall crack. Basically, if you could
3 demonstrate that the frequency of that through wall crack
4 was less than five-times-ten-to-the-minus-six per year, then
5 you could continue to operate that plant.
6 If you went above that, then you had to
7 demonstrate that, through additional analyses or changes to
8 the vessel design or changes to how you're operating the
9 plant, to reduce the frequency down to acceptable level.
10 There's a couple of key underlying assumptions in
11 that five-times-ten-to-the-minus-six. Basically, you may
12 have heard about this today, but it's a
13 five-times-ten-to-the-minus-six of basically having a
14 certain no ductility temperature or whatever you call it,
15 the RTNDT or RTPTS.
16 From a risk standpoint, there's a couple of key
17 aspects to it. One is that if you talk about a through wall
18 crack, we made the presumption that the through wall cracks
19 equivalent to a large opening in the vessel and it's
20 equivalent to core damage, that you're not going to have a
21 capability once you start one of these through wall cracks
22 in a PTS accident to mitigate it in erms of preventing core
23 damage.
24 When the rule was established, there was an
25 argument made that the containment performance was not

1 particularly an issue in these accidents.

2 DR. KRESS: Is that assumption going to be

3 revisited there?

4 MR. CUNNINGHAM: Yes. I'll come back to that, but

5 that's one of the things that we need to think about. The

6 argument at the time was that the types of accidents that

7 get you into a PTS are accidents where there is a great deal

8 of water around, that you're over-pressurizing or

9 over-cooling the vessel. So you've got a lot of water in

10 the core, in the vessel.

11 You also have availability and presumably

12 operability of containment sprays. So the effects of that

13 was even if you opened up the vessel and weren't able to

14 cool the core, that you're not threatening the containment

15 itself, and depending on where we go in some of the

16 discussions of how we might re-look at the rule, what the

17 acceptance criterion that may or may not be an issue, but

18 we'll come back to that or I'll come back to that.

19 There's at least four key pieces of Commission

20 guidance that have been established since the rule was

21 established in the early '80s. You're well familiar with

22 these. We've got the safety goal policy statement. We

23 established two other rules that are similar in some

24 respects, the station blackout rule and ATWS rule dealing

25 with accidents that were identified in PRAs as being very

1 important to risk or core damage frequency at least.

2 The backfit rule became a little more codified and

3 well established and we -- in these timeframes and the

4 regulatory analysis guidelines that went with the backfit

5 rule that introduced risk information into the backfit rule

6 process in a particular way was also established.

7 Then just in the last couple of years, we've come

8 up with Reg Guide 1.174. So I'm going to talk about each of

9 these in a little more detail. As you know, the safety goal

10 policy statement defined qualitative and quantitative goals

11 for acceptable risk. That was in the 1986 statement.

12 Later on, in 1990, the Commission approved having

13 a ten-to-the-minus-four subsidiary core damage frequency

14 goal. That has an impact on defining what's an acceptable

15 overall core damage frequency and then that starts to impact

16 decisions on what could be an acceptable frequency of

17 particular initiators, and as we'll get to in a little bit,

18 it kind of reflects our thinking in the station blackout

19 rules and the ATWS rules in terms of what was an acceptable

20 frequency of having core damage accidents from those

21 initiators.

22 Again, it was intended for generic decisions using

23 industry average information, I think. So in one respect,

24 it's very relevant to the PTS rule in the sense that this is

25 a rule that -- it's a generic rule and that sort of thing.

1 So let's come back to some of the options that
2 deal with do we have the potential for using -- how do we
3 use the safety goal information in re-thinking the
4 acceptance criterion.
5 In the late '80s, we had two new rules
6 established, as I said, with the station blackout and the
7 ATWS rules were established as cost-beneficial safety
8 enhancements. So the staff had to argue why the benefit of
9 achieving these rules and what core damage frequency or risk
10 reduction we achieved was wroth the cost of implementation.
11 In both cases, there was a goal established of
12 ten-to-the-minus-five per reactor year. So in the sense,
13 this starts to lay out and says that we want to have -- even
14 if we have an overall core damage frequency goal of
15 ten-to-the-minus-four, we don't want to have any particular
16 initiator or group of accidents contributing more than about
17 ten percent.
18 DR. KRESS: That's a real significant item.
19 MR. CUNNINGHAM: Yes, and it comes back and when
20 we come back to some of the options, it kind of precludes, I
21 think, some options that we might have in terms of how you
22 would re-established or re-think the acceptable criterion
23 for the PTS rule.
24 DR. APOSTOLAKIS: How are these groups of
25 accidents defined?

1 MR. CUNNINGHAM: Not very precisely,
2 unfortunately.
3 DR. APOSTOLAKIS: I mean, the LOCAs, how do you
4 treat the LOCAs? As a group or small LOCA and the medium
5 LOCA?
6 MR. CUNNINGHAM: In this case, most of the station
7 blackout issue was a transient-initiated. So it could be --
8 it was basically any transient that would get you into a
9 situation of loss of off-site power and on-site power.
10 DR. APOSTOLAKIS: So it's specific for this.
11 MR. CUNNINGHAM: Yes, very specific for this, with
12 --
13 DR. BONACA: Would the LOCA in design basis, you
14 consider core damage?
15 MR. CUNNINGHAM: I'm sorry.
16 DR. BONACA: You can see the core damage also from
17 a LOCA that meets design basis, which is a limited amount of
18 fuel oxidation.
19 MR. CUNNINGHAM: In the context of these, those
20 would not be station blackouts that would have to meet the
21 goal of ten-to-the-minus-five.
22 DR. APOSTOLAKIS: But it is apportionment of risk
23 to certain categories of accidents.
24 MR. CUNNINGHAM: Okay.
25 DR. APOSTOLAKIS: I'm trying to understand what

1 you meant by core damage.

2 MR. CUNNINGHAM: Really core melt, if you will.

3 DR. APOSTOLAKIS: Core melt. Okay.

4 MR. CUNNINGHAM: Core melting.

5 DR. APOSTOLAKIS: If you add them all together,

6 you get where you want to be. All right.

7 MR. CUNNINGHAM: Yes. And just to be clear, there

8 is no Commission guidance that really says we're going to

9 allocate ten percent, there is not that -- we had talked at

10 one time ten or 15 years ago about the idea of reliability

11 allocation or risk allocation, but it wasn't formally

12 established for this. It was more general guidelines.

13 In fact, these rules were established a little

14 before the Commission formally approved the

15 ten-to-the-minus-four as an overall goal for acceptable

16 frequency, but it was always in people's minds of having

17 roughly those numbers, if you will.

18 The rules themselves, these two rules, were

19 justified basically on an off-site risk analysis. So at

20 this time and using -- when they were justified, you didn't

21 -- there was no specific guidance on containment

22 performance. So it was basically you've got this initiators

23 and the final decision metric, if you will, was averted

24 off-site population dose. So it was, to some degree,

25 irrelevant what specific containment performance -- how

1 containment performed in these accidents.

2 It could have been good or bad or whatever. It

3 was kind of -- the analysis was indifferent to that.

4 Then came up with the backfit rule and the

5 regulatory analysis guidelines. It has two parts to it, one

6 of which -- the first part is an initial screening on

7 potential reductions in CDF and conditional probability of

8 early containment failure. So at this point, we introduced

9 containment performance as a particular issue into the

10 backfit rule process.

11 One of the things we'll talk about a little bit

12 later is the idea of using the same type of information in a

13 reverse sort of way to justify potential increases. This is

14 focusing on what is the potential benefit of a proposed

15 change in terms of a reduction in core damage frequency and

16 a reduction in -- and an analysis and evaluation of

17 containment performance.

18 So if a proposed change did not gain you much in

19 terms of core damage frequency, then very often they were

20 just excluded and said you can't pursue the backfit with

21 those. If they passed that test and said, yeah, it might

22 have this substantial benefit, then you went on to look at

23 the off-site risk averted associated with the accident, but

24 this is the place where the backfit rule and the safety

25 goals started to come together in terms of using the safety

1 goals to define that initial screening.

2 Last, but not least, of course, is Reg Guide

3 1.174. It goes off and it has a little bit different flavor

4 to it. One is that it introduces a set of general

5 principals, as you know. We discussed them for many, many

6 times here. But the five principals that we talk about in

7 Reg Guide 1.174 are not explicitly laid out in some of this

8 other earlier guidance, like the backfit rule.

9 So when we come back to it, it has some advantages

10 in terms of how we would use -- might use some of this

11 guidance to look at the PTS rule. It introduces

12 probabilistic guidelines in terms of CDF goals and delta CDF

13 and LERF, so, again, it's a little different than what was

14 in the reg guide analysis guidelines.

15 It was conditional probabilities of containment

16 performance. Again, I think we're basically consistent in

17 terms of the numerics of it to show how changes in risk, in

18 this case, going up, might be consistent with the backfit

19 rule, which is intended to look at changes in the risk going

20 down.

21 As you may recall, when we talked about 1.174, one

22 of the goals was that we would allow increases in core

23 damage frequency, fairly small increases in core damage

24 frequency. One of the goals was that we don't, on the one

25 hand, allow core damage frequency to go up to a magnitude

1 where if we applied the backfit rule, we'd take them back to
2 where they were to begin with. So we wanted to avoid that
3 situation.
4 So that's some of the more recent guidance type
5 information. The other part of it is more recent work
6 that's been going on in accident phenomenology. As I said,
7 the rule itself was -- at the time of the rule, the staff
8 opinion or judgment was that there was not a strong
9 correlation between having a PTS event and containment
10 performance, that you were likely to keep the containment in
11 place.
12 Needless to say, in the last 15 years, there's
13 been a lot of work going on in trying to better understand
14 severe accident phenomena, not the least of which is
15 described, if you will, in 1150, and then a lot of work
16 that's been done since 1150 in trying to understand the
17 impacts of direct containment heating. There's probably a
18 lot of other things.
19 So part of what we're going to have to address is
20 depending on how we go on establishing the -- re-thinking
21 the acceptable criterion, we may have to bring -- re-think
22 the issue of containment performance. The question is, is
23 there anything that we have not learned in the last 15 years
24 that would run counter to what we decided 15 years ago, that
25 the containment performance was not much of an issue.

1 We've got -- the issues I've got at the bottom of
2 the slide here, we're going to think about what about the
3 dynamic loadings on the core and in the internals and the
4 vessel and the piping. Can you --
5 DR. KRESS: Is this the rocket ship?
6 MR. CUNNINGHAM: The rocket is part of it, but
7 it's also a question of tilting and that sort of thing, just
8 general motions of the vessel that -- one possibility is
9 that that can pull penetrations, that you move the piping
10 enough that you pull a penetration out.
11 DR. KRESS: Fail containment.
12 MR. CUNNINGHAM: Fail containment and then you've
13 got to decide is that a large -- could you have a large
14 release under those circumstances. Combined with some of
15 these other things.
16 DR. KRESS: Is it implicit in there the thinking
17 that at the bottom of the vessel, that you have no way to
18 get a lot of ECCS through the core? So that what you have
19 is a passageway for natural convection for air and you may
20 have air combustion to the team, which changes your hydrogen
21 thinking and your energy thinking and what goes into
22 containment. Is that part of this?
23 MR. CUNNINGHAM: I hadn't thought about that, but
24 yes, that belongs.
25 DR. KRESS: It's part of the thinking.

1 MR. CUNNINGHAM: Yes, that's right. That's a good
2 point. So the dynamics aspects at the time of the PTS
3 event. You're going to have some pressure loadings at that
4 point from the steam escaping and that sort of thing, but
5 again, it's a little different in the sense that you're --
6 the reason you're breaking this vessel is because you've got
7 a lot of water inside.
8 So that's a little different scenario.
9 DR. KRESS: When we use a large break LOCA, we
10 have this low-down calculation to get the loads, steam going
11 in. If you just suddenly break off the bottom --
12 MR. CUNNINGHAM: Yes.
13 DR. KRESS: -- of the primary vessel, I don't know
14 how you would redo the choke flow equation. You're going to
15 get a definition loading.
16 MR. CUNNINGHAM: That's right.
17 DR. KRESS: Versus timing.
18 MR. CUNNINGHAM: That's right and it would be
19 different, too, if you were to take the bottom head off or
20 having one of the axial welds go.
21 DR. KRESS: Yes.
22 MR. CUNNINGHAM: And open up that way. That's
23 right. So related to that is the -- are the loadings such
24 that you might tend to disperse the core. One possibility
25 is -- especially with a core that's kind of old, you might

1 be breaking it apart and things like that and what impacts
2 does that have. You're doing this before you would melt,
3 before you would expose it to air or anything like that.
4 So you have those sorts of things, and then you
5 come back to the question of what's the availability of your
6 containment sprays and things. This is not a scenario where
7 --
8 DR. KRESS: In the risk basis, you generally have
9 to assume some frequency or probability that they will be
10 failed.
11 MR. CUNNINGHAM: Yes, that's correct, but it's
12 different in character than, say, a station blackout, where
13 conditional probability of containment ESF failure is
14 essentially one. Here you've probably got them operational
15 and that is going to impact the phenomenology somehow.
16 DR. KRESS: The failure probability.
17 MR. CUNNINGHAM: Yes. That's right, if it's one
18 percent or something like that. You've got to bring all
19 these things together in some sort of way to sort out what
20 is -- how close -- what's our real estimation of the
21 containment performance and is it really any different than
22 what we thought about 15 years ago.
23 So we're trying to bring those two sets of new
24 information together into several potential revisions, if
25 you will.

1 One potential re-thinking of the acceptance
2 criteria is to focus more on the core damage frequency, and
3 that, in a sense, what we're talking about is bringing the
4 PTS rule into line with the blackout and the ATWS rules.
5 I'll come back to that in a minute.
6 Others are more focused, bring in the concept of
7 containment performance, as well. So they're a little more
8 modern in terms of our thinking about how you understand
9 accidents. One I have kind of alluded to earlier is you
10 might develop some sort of a reverse backfit process.
11 The second is you basically work from the Reg
12 Guide 1.174 guidelines, which are really oriented towards
13 changes, burden reduction changes, if you will, associated
14 with license amendments. Now, in effect, you're going to
15 apply that same set of principals and guidelines to a rule
16 change. So it has that difference in flavor, but it has the
17 same general concepts underlying it.
18 I am going to talk about all of those potential
19 revisions a little bit. And one idea is that you could
20 apply the goals for the ATWS rule and the station blackout
21 rule.
22 So one possibility is that you deal with and say
23 that the acceptable frequency in PTS is
24 ten-to-the-minus-five. So it's a little bit of a relaxation
25 of where we are today.

1 You would justify, if you will, and looked at the
2 rule in terms of off-site consequence risk instead of
3 containment performance, because that was the basis for
4 justifying the rules to the SBO and ATWS rules to begin
5 with.
6 So in one hand, it does establish some consistency
7 among these three rules. It would allow some increase, but
8 it doesn't introduce any particular -- no explicit
9 consideration of containment performance into it, and so, in
10 a sense, it's a little dated relative to our policies of
11 today.
12 So another option is to develop a reverse backfit
13 process, if you will. What we mean is basically you take
14 the reg analysis guidelines, which are used to justify
15 potential reductions in core damage frequency, and turn it
16 around and say, well, how can I develop some sort of mirror
17 to that which would allow me to justify increases in core
18 damage frequency.
19 DR. KRESS: Is it one over 2000?
20 MR. CUNNINGHAM: Something like one over 2000 or
21 some such thing. So you would have to do some sort of
22 cost-benefit analysis to say how much can we agree to allow
23 this to increase. There are several issues associated with
24 that, problems with that. One is that this is an adequate
25 protection rule.

1 So you're exploring very --

2 DR. KRESS: It's apples and oranges.

3 MR. CUNNINGHAM: That's right, and how you would
4 turn that into fruit salad or whatever is a little unclear
5 at this point as to what you would do in those areas.

6 So clearly there is a policy implication and
7 there's a lot of work that has to be done to sort that all
8 out.

9 Another approach then is to basically take the
10 principals from 1.174, which, again, were designed for
11 license amendment, changes, and apply it to a rule change.
12 It has the advantage that it ensures consistency, what we
13 think is the right -- is the most current, anyway, and the
14 best way of thinking about using -- making risk-informed
15 decisions.

16 DR. KRESS: How do you go from a backfit -- 1.174
17 was supposed to be tied to specific individual plants. You
18 now go to a rule which is supposed to cover all the
19 population. Do you divide those things by a hundred, those
20 CDFs and LERF?

21 MR. CUNNINGHAM: That's a good question. I think
22 what will happen is that the rule -- the application of the
23 rule is going to be a plant-specific basis. There are only
24 going to be a few plants --

25 DR. KRESS: You may just treat it with --

1 MR. CUNNINGHAM: Yes. And that's the way --
2 DR. KRESS: You're right, it would be
3 plant-specific.
4 MR. CUNNINGHAM: You set up the rule in some sort
5 of generic way, but it has to be applied on a plant-specific
6 basis. In reality, that's the way it's happening today with
7 the present rule, is that each plant has to evaluate their
8 vulnerability to the PTS and you'd have to have the same
9 thing here.
10 This has implications. If you're starting now
11 with a goal of five-times-ten-to-the-minus-six, the Reg
12 Guide 1.174 process would basically say you're probably not
13 going to let it get any bigger, much bigger than
14 five-times-ten-to-the-minus-six, but you bring in the LERG
15 consideration and if LERF is -- if containment performance
16 is not an issue, then you can end up with something like
17 five-times-ten-to-the-minus-six.
18 If containment performance is an issue, then you
19 could -- you may have to ratchet the
20 five-times-ten-to-the-minus-six down a little bit to deal --
21 to make it more in line with our LERF criterion in 1.174.
22 So in this one, one of the disadvantages of going
23 this way is that it introduces more explicitly the
24 consideration of LERF and that means we've got to nail down
25 some of these phenomenological issues a little bit better

1 than where we were, than where we are today.

2 So that kind of gives you an idea of where we are

3 on this paper right now. What we're doing is developing a

4 Commission paper. We'll be trying to have a draft the end

5 of this month that's basically going to look a lot like what

6 you've just seen here, with -- we want to go through and say

7 what was the basis for the original acceptance criterion,

8 what have we learned since then in terms of the Commission

9 guidance on PRA, and on accident phenomenology, look at some

10 potions for potential revisions, including this issue of

11 containment performance, and the one thing that would -- the

12 paper would have is it would have a recommendation on where

13 -- how to go on this.

14 What we would like to do is get the paper to you

15 sometime in the next month probably, with the idea -- let me

16 back up. We owe it to the Commission in early May. We

17 think some of these issues would be worthwhile talking to

18 the committee about. So maybe in late April or early May,

19 we would get the draft paper to you, or I guess it would

20 have to be late -- sometime mid to late April.

21 DR. KRESS: Sounds like a joint PRA and Severe

22 Accident subcommittee meeting.

23 MR. CUNNINGHAM: So that would be the idea.

24 DR. BONACA: Would you run something like this

25 through the generic issue program?

1 MR. CUNNINGHAM: I'm sorry?

2 DR. BONACA: Would you run something like this
3 through the generic issue program? This is a situation
4 where you have -- I mean --

5 MR. CUNNINGHAM: If the issue of PTS came up today
6 as a new issue and not be -- have a rule already and that
7 sort of thing, then you would -- one way to deal with it
8 would be to put it through the generic issue process and say
9 what's the value of pursuing a rule or some other regulatory
10 mechanism to deal with this.

11 DR. BONACA: You have a burden reduction issue
12 here, to some degree.

13 MR. CUNNINGHAM: It's a burden reduction issue,
14 yes, that's right. So the generic issue process is,
15 strictly speaking, not applicable here because we've got an
16 existing rule and we're talking about modifying it, because
17 we have a different set of processes for changing rules like
18 that.

19 The flavor of this one is a little different
20 because the rule itself started out as being probabilistic,
21 basically. So we have to re-think some of those aspects of
22 it, as well.

23 DR. APOSTOLAKIS: So you're proposing to have
24 another subcommittee meeting to discuss this or bring it
25 back before the committee?

1 DR. SHACK: We would have to have a full committee
2 meeting to write a letter.
3 DR. APOSTOLAKIS: Sure.
4 MR. CUNNINGHAM: Yes.
5 DR. KRESS: It's the sort of thing you might be
6 able to put it before the full committee. That is all we're
7 talking about.
8 MR. CUNNINGHAM: This is basically all we're
9 talking about and the key element --
10 DR. KRESS: We didn't have all the other parts of
11 the PTS in there, we're just talking about this right here.
12 MR. CUNNINGHAM: Yes. I think -- and we wouldn't
13 -- in the March-April paper, we wouldn't be proposing to
14 resolve the issues on the phenomenology. We just kind of
15 acknowledge them and say they have to be worked. The
16 principal difference between what we've seen here and the
17 paper would be some sort of recommendation on what's the
18 right fit of PRA guidance, if you will, for this and you may
19 have gotten some sense of where I'm coming from anyway on
20 this.
21 So it may be that a full committee meeting is all
22 that's needed.
23 DR. KRESS: That's a meaty issue, allocation of
24 risk among sequences.
25 DR. APOSTOLAKIS: The problem with a full

1 committee meeting is if we don't like it.

2 DR. KRESS: It might be better to --

3 DR. APOSTOLAKIS: It might be better to have --

4 DR. KRESS: -- subcommittee and a full committee.

5 DR. BONACA: I think so, too.

6 DR. APOSTOLAKIS: Yes, because --

7 DR. BONACA: One of the potential revisions you
8 mentioned is driven by consistency with -- among the three
9 principal risk-informed rules. This particular case, you
10 really have lost a vessel. You still have an ability of
11 cooling it through, I guess, injecting into the vessel and
12 draining and then -- or through the spray system.

13 MR. CUNNINGHAM: Yes.

14 DR. BONACA: How different is this kind of
15 scenario from what you had for the station blackout and ATWS
16 rules? In those cases, we have some fraction of scenarios
17 where you end up with a failed vessel, but others you don't
18 and you're able to cool long term. I just don't see this as
19 a -- I mean, if this is driven by consistency, I would say I
20 don't care about consistency there.

21 I have a situation here where I have to rely on
22 containment. So it seems to me that that would be driving
23 some. I guess this is all preliminary, so you don't have
24 any thoughts.

25 MR. CUNNINGHAM: The value of the consistency is

1 if somebody is looking out -- if somebody is looking in from
2 the outside to try to understand, well, what are you really
3 talking about in terms of trying to have acceptable core
4 damage frequency from your major rules, there is an
5 advantage to having them all kind of line up.
6 There are disadvantages. The nature of this rule
7 is different and I think part of the reason that the present
8 acceptance criterion is more restrictive than that for the
9 ATWS rule and the station blackout rule is the recognition
10 of the different character of this accident. Again, right
11 off the bat, you've compromised one of your barriers, but
12 you also seem to have -- at least relative to a blackout
13 rule, you have perhaps more confidence in the containment
14 performance than you would have had.
15 So it is a different beast. So I guess I would be
16 surprised if we go the route of saying, well, just for the
17 purpose of consistency, we're going to set up the rule to be
18 like the blackout and ATWS rules.
19 DR. BONACA: One other question I had was it seems
20 the main consequence of applying these new insights to --
21 it's really license renewal, allows a vessel to probably be
22 operable for a much longer period of time. By much, I mean
23 some longer period of time, but the question then becomes
24 are there other effects that are not really within just the
25 rule that now come together to -- I haven't thought about

1 this enough, but I'm saying that as you age these plants and
2 you allow the vessel to continue to be operable for a long
3 period of time, doesn't it open up other issues, other
4 questions regarding --
5 MR. CUNNINGHAM: I'm not sure offhand whether that
6 comes up or not. I haven't thought much about that aspect
7 of it.
8 DR. BONACA: I haven't either, but I just --
9 DR. KRESS: Another thought on your consistency
10 question. You talk about, say, the
11 one-times-ten-to-the-minus-five versus the
12 five-times-ten-to-the-minus-six. Both of those, I presume
13 it is some sort of representation of a mean value.
14 MR. CUNNINGHAM: Yes.
15 DR. KRESS: The ATWS rule -- the ATWS sequence has
16 certain sequence-specific uncertainty associated with it.
17 That's a lot different in the uncertainty associated with --
18 and that ought to fit into the system somewhere.
19 MR. CUNNINGHAM: That's right.
20 DR. KRESS: And that either means you lower the
21 mean value you're dealing with or you put some sort of
22 confidence level on it that's different than just the mean.
23 MR. CUNNINGHAM: Yes.
24 DR. KRESS: So somehow I wanted to get across that
25 that thinking needs to be into this acceptance criterion.

1 The sequence-specific uncertainties are different and should
2 be accounted for when you go to this acceptance criterion
3 some way.
4 DR. BONACA: Especially, and I completely agree
5 with you, Tom, especially in the case where you have burden
6 reduction. And so that becomes a very important issue to
7 understand what this ten-to-the-minus-five means.
8 *Mr. Foley. And the
9 five-times-ten-to-the-minus-six, maybe this has been gone
10 through in the last couple of days somehow, but there is a
11 -- one of the things the paper needs to do is explain the --
12 what's the -- it's five-times-ten-to-the-minus-six of what
13 and that's a through wall crack frequency, but it's also
14 tied to a particular RTPTS or RTNDT and that value was set
15 based on some conservative assessments of what was really
16 going to happen and that sort of thing, and all of that
17 needs to be laid out a little more carefully in the paper
18 and, in a sense, re-thought of how we would do -- how we
19 would address the uncertainties in the acceptance criterion
20 as we go forward.
21 So it's another piece that belongs in this paper.
22 DR. BONACA: And also just one last comment. We
23 talked about rigor this morning.
24 MR. CUNNINGHAM: I'm sorry?
25 DR. BONACA: WE talked about rigor in the

1 calculations. I think that because of what's happening
2 here, I mean, rigor is not any more a desirable thing and is
3 an expectation. We understand how this is derived and there
4 is rigor.
5 MR. CUNNINGHAM: Okay. If there's nothing else on
6 that.
7 DR. SHACK: Comments from the committee? Perhaps
8 we can then start with Nathan's presentation.
9 MR. CUNNINGHAM: Yes. We can move into a
10 discussion of how we're going to do some of the PRA
11 calculations that assess the performance of the plants.
12 DR. KRESS: I did want to say I think it's crucial
13 that you look very carefully at this question and whether
14 changes to containment failure probability impacts it.
15 MR. CUNNINGHAM: Yes. Okay. I'm going to stay
16 here. We've got three other folks who are going to join me
17 and do most of the work. Nathan Siu and Roy Woods from PRA
18 staff in the Office of Research and then Bill Galyean, who
19 is a contractor to us from Idaho National Engineering and
20 Environmental Laboratory.
21 MR. WOODS: As mark said, I'm Roy Woods. I'm from
22 Mark's branch, he's my branch chief, the Probabilistic Risk
23 Analysis Branch in our Office of Research.
24 With me at the table is Nathan Siu, on the far
25 side there, who is senior technical advisor in the PRA and

1 human reliability analysis parts of this PTS effort. Nathan
2 is also one of the driving forces behind the uncertainty
3 analysis for the entire PTS effort, including the thermal
4 hydraulics and the probabilistic fracture mechanics and the
5 PRA and HRA.
6 DR. POWERS: I can't help but say it's better to
7 have him back working on the fire risk assessment.
8 MR. WOODS: I'm pointed out he has several hats
9 and I've mentioned three or four of them right there.
10 DR. POWERS: He's got an important hat on most of
11 the time.
12 MR. WOODS: And I think Ali Mosleh, Professor
13 Mosleh, from University of Maryland, Materials and Nuclear
14 Engineering Department is here, back there somewhere. He is
15 heavily involved in the uncertainty analysis, also.
16 Also with me here is Bill Galyean from Idaho
17 National Engineering and Environmental Laboratory. He is
18 Research's contractor for the PRA and the PRA now includes
19 HRA. He doesn't have those contractors, but they're working
20 very closely together, as I will get to in a minute here.
21 Anyway, that's the work that his doing for us.
22 The objective of the PRA part of this, of the
23 whole project actually, is to support development of a
24 technical basis for revised pressurized thermal shock rule.
25 In doing that, we want to ensure that the overall process is

1 coherent and risk-informed and that there is a good
2 integration of the different aspects.
3 As I pointed out, I'm the leader of the PRA team
4 which now includes HRA. That, of course, identifies the
5 sequences and various errors that you would be worried about
6 and failures that you would be worried about.
7 That determines the sequences that we need to do,
8 the thermal hydraulics analyses for which I think David
9 Bessette talked about. He's the leader of that team. And
10 then the output of the thermal hydraulics analyses tells you
11 the input conditions for the probabilistic fracture
12 mechanics, which Shah Malik is the head of that team. So
13 those are basically the three teams.
14 Throughout all of these efforts, we are doing a
15 unified effort to take into account the uncertainties and we
16 are dividing them into aliatory and epistemic uncertainties,
17 which George wants, and it's a very good idea. That's what
18 we are trying to do here.
19 All of this is in support of the development of a
20 screening criteria which will probably be very much like the
21 type of screening criteria we have now at least, which is
22 based on the reference temperature for the nil ductility
23 transition, which is an embrittlement parameter, really.
24 In developing this, we will be looking at trying
25 to relate whatever criteria we have to risk figures of

1 merit; that is, through wall crack frequency or one of the
2 others that Mark referred to a few minutes ago.
3 Right now we are aiming it mostly toward through
4 wall crack frequency, which we are hoping to be able to
5 equate to a core damage and if that comes out acceptably,
6 then what might go after that wouldn't make any difference
7 in the conclusion, then we can stop there. That's where we
8 are kind of hoping we will at moment.
9 Also, as I mentioned, we are definitely doing
10 treatment of uncertainty, which will be related to the
11 qualitative issues; in other words, where you have a great
12 uncertainty is where you might want to maintain your
13 defense-in-depth to attempt to compensate for the
14 uncertainty that you have.
15 The way we're approaching this while thing is to
16 update the early 1980 PRA studies that we did. Those were
17 for Oconee, Calvert Cliffs, and H.B. Robinson. What we are
18 doing in updating these studies is reflecting changes to the
19 operation of the plant and changes to the hardware of the
20 plant. For example, emergency operating procedures have
21 changed a great deal since the early '80s.
22 They are now symptom oriented instead of event
23 oriented. An example of the changes to the plants
24 themselves, we are currently working on Oconee and they've
25 made significant changes to their integrated control system.

1 So we have to take those changes into account.

2 Those are just examples. We're looking at the

3 whole plant.

4 We also are reflecting changes to the PRA

5 state-of-the-art and the example I would use there is HRA,

6 human reliability analysis. We're using basically the

7 ATHENA team in this effort and the ATHENA team is meeting

8 with the PRA people. They are indistinguishable now, in my

9 mind. We sit down and we meet together and we talk about

10 what sequences are going to be modeled and what's going to

11 be in the sequences, both hardware and people oriented

12 things in those sequences.

13 DR. POWERS: What is it that you are looking for

14 to get from ATHENA that you wouldn't get from something like

15 THERP?

16 MR. WOODS: One of the things is errors of

17 commission, plainly. What might the operator -- when might

18 the operator be misled and think that he should do one

19 thing, when actually that's not what he should do in the

20 particular situation. He thinks he's in one place, but he's

21 actually in another place and he takes the right action for

22 where he thinks he is, but it's the wrong action for it,

23 that type of thing.

24 That can be very important. It can be a

25 significant contributor to the risk and that's not in there

1 now and we're trying to put that in there.

2 MR. SIU: The other thing I think they can say is

3 that we're going to have a more causally beast description

4 of why the error occurs, whether it's an omission or a

5 commission error, and it's going to reflect what's happening

6 during the sequence.

7 That's something that you can include in the THERP

8 analysis, but it's not tied in quite as explicitly, I would

9 say, as in what we're going to be doing.

10 MR. WOODS: And on the other side of the coin,

11 also, they're better able to look at recovery actions.

12 DR. POWERS: Both those things that you mentioned

13 there, the causality and the recovery, aren't those going to

14 get terribly plant-specific?

15 MR. WOODS: Yes. As are some of the other issues,

16 some of the hardware issues. We're finding -- in fact, I'll

17 get to that in a minute, where we talk about wrapping their

18 arms around the total population of plants from basically

19 four analyses.

20 That's a difficult issue because all of these

21 things are -- I mean, it's not unexpected, but it's turning

22 out the more we look at it, the more we realize how

23 plant-specific they are. That is a problem.

24 In fact, when I get to that, if you guys have any

25 good ideas on how to handle that, that's one place we'd

1 really appreciate input.

2 DR. POWERS: It raises the issue of how

3 representative are the plants that are being run through

4 this thing. How big of a sample set does it take. Have you

5 wrestled with that issue?

6 MR. WOODS: That's exactly the next point at the

7 bottom of this slide, address other plants. Let me get to

8 that now.

9 What we need to do is make sure that within the

10 scope of the analyses we do, we somehow include all plants

11 that have a significant PTS risk at the end of their

12 license, and we need to do this in a defendable manner. We

13 want to -- I guess what I'm trying to say is we end up with

14 four analyses and we might find that some plant that's not

15 among those four has a higher safety injection pressure or

16 safety injection flow capability or something.

17 So we need to somehow take that into account.

18 Now, this is assuming that that high capability exists in

19 the plant where there will be a significant embrittlement at

20 the end of the license. If there isn't, then for this

21 purpose, it's not of concern.

22 If you find such a plant, then we would have to

23 somehow also, in all fairness, take a look and see if there

24 is some other feature of that plant that might tend to

25 counter that. Maybe they have better whatever capability

1 somewhere else and take all that into account, but we have
2 to somehow do that without doing a full-blown PRA, because
3 we don't have the budget or the time to do a PRA for each
4 and every plant.
5 We're struggling with that. If there are any
6 constructive ideas, we'd welcome them.
7 DR. POWERS: They're mostly desperation ideas. I
8 can see how you can screen out based on embrittlement, there
9 are data that you could go to. You might even be able to
10 screen that out in the hardware because you can certainly
11 look at the FSAR.
12 But if indeed errors of commission are important,
13 screening based on procedures is a very tough thing to do,
14 because you have to read the procedures.
15 MR. WOODS: Right.
16 DR. POWERS: You have to get them, and that's an
17 enormous task.
18 MR. WOODS: That's exactly what we're in the
19 process of doing at Oconee right now. We were down there --
20 these three, Mark wasn't with us, but we were there
21 yesterday and the day before talking in some detail, well,
22 great detail actually, with everybody we wanted to talk to
23 at Oconee. They were cooperating quite well with us.
24 But the more we got into it, the more we realized,
25 hey, they have certain procedures, they approach these

1 problems in a certain way, and you can't assume that someone
2 else will. It's different and we're struggling with how to
3 handle that. You've hit on a very significant problem we're
4 facing.
5 MR. SIU: If I could add, Roy. I think there are
6 two parts of this screening which Mark pointed out in the
7 previous presentation. One is this initial screening
8 criteria, which is based on embrittlement, and what we need
9 to do is to be able to pick the embrittlement screening
10 criteria that gives us confidence that if the plant passes
11 that, there's just no problem, period.
12 Once you get past that point, then there will be a
13 plant-specific analysis that will demonstrate that the
14 particular risk criteria are satisfied. So at that point, I
15 imagine that's where your procedure issues are going to come
16 in and that's not something that we're going to perform.
17 Our main task is to set the embrittlement
18 criterion appropriately and to set the right level for the
19 second step.
20 MR. GALYEAN: Also, if I could add. We are
21 engaged in an effort right now to try and categorize plant
22 to plant differences that we feel are relevant to the PTS
23 issue, things like turbine bypass capacity, high pressure
24 injection capacity.
25 DR. POWERS: Things you can read about the plant.

1 MR. GALYEAN: Right. And our expectation is that
2 -- and, in fact, it is in the program plan that towards the
3 end, we are going to do sensitivity studies on the PRA
4 models to quantify what impact these plant to plant
5 differences could have on at least the frequency of these
6 PTS sequences.
7 DR. POWERS: Do you want to give me the risk
8 achievement worth of the operator? Nobody wants to do that
9 for me.
10 MR. WOODS: That leads right into this. We've
11 already covered a good deal of this slide, but basically
12 we're trying to calculate through all correct frequencies
13 from four plants, including uncertainties, that we're doing
14 PTS and PRA models for Oconee and Beaver Valley. The NRC is
15 -- or Bill Galyean, at INEL, with our sponsorship, are
16 developing those models.
17 Two other plants already include PTS sequences in
18 their PRA models and that's Calvert Cliffs and Palisades,
19 and we are planning on obtaining those models. Bill is
20 putting them in the SAPPHIRE code, so we can manipulate it
21 and change it and massage it and do sensitivity studies and
22 that sort of thing and use all four of those.
23 And what we'll end up -- then there's a
24 significant time at the end of this last point here, a
25 significant time after we develop those things and use them,

1 we realize we'll have four different models with four
2 different sets of assumptions and we're going to have to
3 somehow come to grips with how to put it all together in a
4 coherent way.
5 But what we'll end up with is four or more points
6 which each point from that graph behind me represents one
7 plant and what you do is you evaluate that -- you evaluate
8 that plant for its through wall crack frequency assuming
9 that the material condition is at an RTNDT which is
10 evaluated in a certain way as required by the PTS rule at
11 the end of that plant's license.
12 And by definition, that RTNDT is RTPTS, that's
13 just what we mean by that. And once we come up with an
14 acceptable through wall crack frequency, based on safety
15 goals or whatever, as Mark discussed, then that determines
16 the through wall crack frequency star on the vertical axis
17 and you could read across to some representation of those
18 points that you have and determine what the correlated RTPTS
19 is.
20 That would then be your screening limit. The
21 problem is, as you pointed out, Dr. Powers, that you've got
22 four points at most and you need to somehow come to grips
23 with how to handle the other plants.
24 That's the point of this slide, really. I'm
25 pressing the end here at this part.

1 Open questions, in addition to the ones that we've
2 talked about, at the moment, we're not treating internal
3 fires, floods, external events in these analyses. We
4 realize that the resulting failures, for example, for
5 internal fire that causes cables to burn and causes hot
6 shorts and causes various equipment to fail, which might
7 confuse the operator, this could involve the whole process,
8 that could cause PTS events to initiate or it could make
9 ones that have initiated for some other reason worse or
10 both.
11 DR. POWERS: Maybe we should stop all this and
12 just get into that fire problem right away.
13 MR. WOODS: Put Nathan's fire hat back on and keep
14 it on. I understand.
15 DR. POWERS: Take the resources from this, devote
16 them all to the risk assessment and validated models, sounds
17 good to me.
18 MR. WOODS: So you have several hats. You
19 probably understand why it's necessary to have several hats.
20 Anyway, we've already mentioned the problem with
21 coming to grips with the relationship between through wall
22 crack frequency. Well, maybe we haven't, but the problem is
23 when you go beyond through wall crack frequency and you're
24 trying to say that's not equal to core damage frequency,
25 what you're looking at is something that's very, very

1 uncertain and we're not sure that we can predict how big the
2 hole is and whether or not the core would actually be
3 damaged with enough certainty to actually take credit for
4 it, and that's the problem with going beyond through wall
5 crack frequency and just assuming that's equal to CDF.
6 Also, if you go from CDF to LERF, it's a similar
7 uncertainty. So as I said, really all we're doing at the
8 moment is we have a task in place to identify the various
9 issues that would be involved if we had to or wanted to, for
10 whatever reason, go beyond through wall crack frequency and
11 we're sort of keeping track of those, but we aren't spending
12 a lot of our resources on that at the moment.
13 DR. KRESS: On your previous slide, would you put
14 it back up?
15 MR. WOODS: Certainly.
16 DR. KRESS: I had a question. You implied that
17 the three points were three different plants.
18 MR. WOODS: That's correct, yes.
19 DR. KRESS: But the PTS, RTPTS is extrapolated out
20 to the end of current life.
21 MR. WOODS: The RTPTS for each plant would be the
22 RTPTS for that plant at its end of license, either extended
23 license or license now, if it hasn't applied for an
24 extension, or whatever problem you --
25 DR. KRESS: My point is there is a time involved

1 in there and you have to extrapolate something about the
2 fluences and so forth.
3 MR. WOODS: Yes.
4 DR. KRESS: Why can't you just continue that
5 extrapolation and have more than one point per plant and
6 define what this curve looks like for each plant? And isn't
7 it like having more data points to fit this curve?
8 MR. WOODS: No, it's not.
9 DR. KRESS: It's not.
10 MR. SIU: Again, don't take the graph too
11 seriously. This is just an example. One of the things
12 we're showing, for example, is a monotype relationship
13 between RTPTS and through wall crack frequency, and that may
14 not exist just because of the system differences or the
15 procedure definitions.
16 DR. KRESS: It would be monotonic for a plant.
17 MR. SIU: For a plant, that's right, and you could
18 plot --
19 DR. KRESS: That's why I was suggesting it.
20 MR. SIU: That's right. You could do that,
21 certainly. I think Mark Kirk had a comment.
22 MR. KIRK: The only thing I wanted to point out is
23 that RTPTS is, by definition, fluence, it is at end of
24 license fluence.
25 DR. KRESS: But maybe you could plot it versus

1 effect of full power year or something.

2 MR. WOODS: I was going to turn this over to Bill

3 Galyean now to give you some more details on the PRA and

4 with the incorporated HRA model that we're developing.

5 DR. POWERS: Having convinced us that the problem

6 is impossible.

7 MR. WOODS: That was not my intent.

8 MR. GALYEAN: I'm going to just -- I have these

9 three slides that I'm going to talk about just to give you a

10 feel for the general philosophy of the PRA analysis.

11 Afterwards, I will turn it over to Nathan and he

12 will get into more details on the uncertainty and the

13 integration aspects of the process.

14 As has been mentioned before, our intention and

15 our approach is to build on the original PTS PRA analyses.

16 We have the benefit of their results that we can allow us to

17 more cleverly develop the PRA models and develop the

18 accident sequence, the PTS accident sequences and evaluate

19 the importance of the various initiating events.

20 Again, as has been mentioned, we intend to update

21 these models in the analyses based on the current plant

22 designs, operating procedures, operating practices, and also

23 update on our current understanding of reliability for the

24 various systems, components, and also, in particular, the

25 initiating event frequencies.

1 So basically it's just an update both on the
2 state-of-the-art of PRA and -- and when I say PRA, I also
3 mean HRA. And also to update them based on the current
4 designs and operations of the plants we're looking at.
5 DR. POWERS: I'm just curious. In setting up and
6 deciding how you're going to update the PRAs and what not,
7 you had some basis for deciding you were going to do these
8 things, but you were going to leave out fire.
9 MR. GALYEAN: As was pointed out, external events
10 is still an open issue, and so the decision to leave out
11 fire has not yet been made. It's still being talked about.
12 We're still trying to understand what the implications are.
13 There was one event that occurred at Oconee, in fact, that
14 did result in some over-cooling. When I say one event, I
15 mean a fire in a switch gear.
16 And so we are certainly aware of that and aware of
17 the potential, but as far as how significant a contributor
18 external events are in comparison to all the other
19 initiating events, that's still something we're wrestling
20 with and still trying to decide what the -- whether it's
21 worthwhile to pursue that.
22 Again, that decision has not yet been made.
23 DR. POWERS: Are we ever going to get the IPEEE
24 insights document, report?
25 MR. CUNNINGHAM: Yes. The insights report is, on

1 the present schedule, I believe we're supposed to have a
2 draft this summer. That will not happen because we've had
3 -- we want to develop the insights report after we got the
4 reviews done and the reviews won't be done this summer, for
5 a variety of reasons, some of which are resource
6 limitations, some of which are related to fire issues that
7 we're dealing with with a number of utilities.
8 So I believe that realistically it will be early
9 next year -- late this year or early next year.
10 DR. KRESS: Couldn't you ask yourself whether any
11 fire events will activate the ECCS and sort of estimate the
12 effect on the frequency, initiating frequency?
13 MR. GALYEAN: Well, we do, in fact, the -- an
14 obvious area where we can improve on the original is the
15 initiating event frequency. We do have quite a bit of
16 operating experience data that we have collected and
17 analyzed through another program sponsored by the NRC and in
18 there we do have a frequency of inadvertent SI actuation,
19 for example. So theoretically, any contribution --
20 DR. KRESS: Due to fire.
21 MR. GALYEAN: Due to fire would be in there.
22 MR. SIU: I think it's fair to say that the tools
23 and techniques that we have now can be applied with the same
24 degree of certainty that we have with other core damage
25 scenarios associated with fire.

1 The problem is in the data-gathering, because the
2 concern actually with Oconee, this was non-safety switch
3 gear that was affected and you're talking about affecting
4 control systems on the balance of plant side. We don't
5 trace those cables.
6 MR. GALYEAN: This slide is intended to be more
7 illustrative of kind of the approach we're taking. It lists
8 the initiating events that we're looking at. It compares
9 the frequency from the original Oconee IPTS analysis and the
10 -- to the frequency that we anticipate using in the current
11 analysis.
12 The initiating event frequencies come from NUREG
13 CR-5750 initiating event frequency report, came out
14 recently. Also, in the last column, we just have some
15 comments or observations that we've concluded based on our
16 look at these various initiating events.
17 An obvious point of comparison are the top -- is
18 the top event, the reactor trip, turbine trip event, where,
19 in the original analysis, they assumed six events per year
20 and the current industry performance is less than one a
21 year.
22 Some of the others are not so different. But we
23 are also looking at a number of initiating events that were
24 not included in the original IPTS analysis. Also note that
25 we are looking at both at power events and events that occur

1 at essentially hot zero power, which because of the thermal
2 hydraulics response of the plant, could be more severe than
3 at power events.
4 The other obvious area for improvement over the
5 original analysis is in the HRA portion, which we've already
6 touched on. In the original analysis, it took a very
7 conservative and a very crude type of approach toward
8 quantifying human errors and we -- the state-of-the-art, I
9 think, the current state-of-the-art will allow us to
10 significantly improve over that application of -- that was
11 done in the original.
12 In particular, and, again, as mentioned, we will
13 be utilizing the ATHENA folks in the development of the
14 human reliability analysis and they will be looking at,
15 again, kind of a broader range of human interactions in the
16 response to a PTS type of transient.
17 That pretty much concludes my prepared comments.
18 If there are no questions on the PRA portion of this
19 analysis, I will turn it over to Nathan and he can talk
20 about the uncertainty and integration issues.
21 MR. SIU: Thanks. The issue of uncertainty has
22 come up a number of times in discussion here, so we just
23 wanted to talk briefly about what we're planning to do, what
24 we are doing, and I guess I will start off by saying that a
25 lot of this is discussed in the white paper, which I believe

1 was distributed to the committee, and I know it's a lot to
2 read there. But if you have any comments on it, by all
3 means, we'd appreciate them.
4 I think one of the main points to raise is this
5 framework diagram. It's kind of hard to see on the screen
6 there, but, again, it's in the paper and it's in the
7 handout. Basically, that shows how we go from the PRA event
8 sequence analysis, which identifies sequences at a certain
9 level of detail, such as you have an initiating event and
10 subsequent successes and failures of your safety systems.
11 Obviously each PRA sequence can represent a bundle
12 of thermal hydraulic sequences, actual realizations, because
13 of, for example, different timings of events within the
14 definition of the PRA sequence, CF sub-scenarios that have
15 to be analyzed.
16 One of our problems, of course, is deciding which
17 sub-scenarios to analyze to represent the PRA sequence.
18 Once we have identified those sequences and they
19 have associated frequencies, then you pass them on to the
20 probabilistic fracture mechanics analysis, which is
21 basically all the material embedded in the FAVOR code. In
22 fact, the FAVOR code takes a lot of this information and
23 does the integration. So we're talking on a conceptual
24 level rather than the level of what actually is going to be
25 done.

1 And if you're interested in the mechanics, we can
2 talk a bit about that a little bit later.
3 What I did want to point out here is that the PRA
4 analysis does identify sequence frequencies. There will be
5 sub-scenario frequencies associated with the thermal
6 hydraulics analysis and each of these frequencies, of
7 course, are uncertain. There will be uncertainty
8 quantified.
9 How we do that in PRA space is it's the standard
10 procedure, it's well known, and we can talk about that, if
11 you wish, but I was going to touch briefly on what we're
12 doing in thermal hydraulics and TFM, because that's
13 something I think that's certainly a little bit unusual for
14 the kinds of analysis that we usually perform.
15 I did want to point out also that in the PFM
16 analysis, you see this little -- these two distributions
17 overlapping. That's supposed to be a representation of
18 stress and strength. So basically what we're saying is that
19 some fraction of times that the vessel is hit with a
20 particular thermal hydraulic sub-scenario, some pressure or
21 temperature characteristic curves, it will fail.
22 But it's some fraction of time, it's not
23 necessarily one, it's not necessarily a zero.
24 Of course, we're uncertain about a lot of the
25 parameters that go in here, so there's a layer of

1 uncertainty that's not explicitly represented in this
2 diagram. That's what the note at the bottom of the diagram
3 indicates.
4 Regarding the probabilistic fracture mechanics
5 parameter and our treatment of uncertainty, the white paper
6 talked about what are the sources of uncertainty in the key
7 model parameters, the ones that we have been told are the
8 ones that seem to drive the results, and based on some
9 guiding principals as to how we're doing this modeling,
10 those uncertainties were characterized as being either
11 aliatory or epistemic.
12 DR. KRESS: I gather that wasn't as
13 straightforward as you might think.
14 MR. SIU: It's not -- neither -- well, I don't
15 know if it's straightforward. It is something that -- there
16 are modeling decisions being made as you go through this.
17 You have to decide what's your model of the world.
18 Professor Apostolakis' papers talk about this.
19 Once you fix on that model, then you can derive
20 what is -- how you would categorize each of these, but I
21 would say at this point, the paper is still being digested
22 by lots of folks and I'm sure we're going to get some ideas
23 as to maybe whether the categorization that's in the paper
24 is correct or not.
25 I think it's a pretty good stab at it, I'd like to

1 think that.

2 The aliatory uncertainties in this -- again, I'm
3 talking about the probabilistic fracture mechanics part, so
4 that's that third box in that diagram. I'm not talking
5 about the whole spectrum. But certainly you have
6 uncertainties there arising because of the uncertainties in
7 the thermal hydraulics scenario. So the frequency with
8 which you get hit with a particular scenario trace or at
9 least a scenario trace that represents a bin of thermal
10 hydraulics sub-scenarios.

11 And then there is this issue of conditional
12 failure of the vessel given a thermal hydraulic scenario,
13 and that's the point I was trying to raise through that
14 stress-strength diagram.

15 We are -- so that's -- we're addressing aliatory
16 uncertainties through those two mechanisms, through the
17 scenario frequencies and through the stress-strength model.

18 The epistemic uncertainties, we're just using
19 standard estimation techniques. You heard some discussion
20 this morning about such things as the copper, nickel content
21 at, let's say, a particular position in the reactor vessel.
22 The point about the correlation of parameters is obviously
23 an important one, and I don't know that we've looked into it
24 as carefully as we should yet.

25 But once we have characterized the uncertainties

1 and the propagation of these uncertainties through the
2 model, it is done in the FAVOR code, it's a standard Monte
3 Carlo propagation approach and I don't know that we need to
4 talk about that very much.
5 Again, FAVOR is the tool being used to assemble
6 all these results.
7 I'd say that we're a little further behind in our treatment
8 of thermal hydraulic uncertainties. The white paper, as you
9 have seen, is focused primarily on the issue of the
10 probabilistic fracture mechanics issues. But certainly we
11 have the same objective. We need to characterize and
12 quantify the uncertainties, in this case, in the thermal
13 hydraulics analyses.
14 Right now, we expect that whatever we do, that
15 characterization will be compatible with the current version
16 of FAVOR, which means basically we're talking about
17 deterministic pressure and temperature traces over time,
18 also the heat transfer coefficient of the downcomer, and
19 that the uncertainties in the thermal hydraulics scenarios
20 will be represented through uncertainties in the frequencies
21 of those scenarios, but we won't have bands of scenarios to
22 propagate through the code, because of just computational
23 limitations. We don't think we can do that.
24 The University of Maryland has the lead with this
25 work. Professor Ali Mosleh is sitting back there. He and

1 Professor Modarres are our PIs, and we've initiated planning
2 on how to actually do this work. This is, as many of you
3 know, not an easy task to look at the thermal hydraulic
4 uncertainties.
5 We have a cooperative research program with the
6 University of Maryland, and so they will address this issue
7 under that task.
8 The first part of that task will be to look
9 specifically at PTS issues and later on we expect that they
10 will broaden out and look at non-PTS applications and maybe
11 broaden the approach to go beyond just the assessment of
12 uncertainties in the thermal hydraulics scenario
13 frequencies.
14 We do believe right now that the approach will
15 involve a considerable amount of screening because of,
16 again, the computational resources that are required. We
17 have to get down pretty quickly to scenarios where it
18 appears that a detailed analysis is needed.
19 We hope to use both thermal hydraulic models and
20 probabilistic fracture mechanics models in that screening
21 process.
22 That's all I have to say about uncertainty
23 analysis. Again, we have some backup slides, we'd be
24 willing to chat with you about that, if you have any
25 questions.

1 DR. POWERS: The thing on that last slide that's
2 most striking is this rapid screening and if you're going to
3 use Monte Carlo methods, why do you care about screening
4 things out?
5 MR. SIU: Well, as you know, you can do Monte
6 Carlo in the crudest fashion. You would end up simulating
7 things that you really don't care about. So you could use
8 screening in the sense of important sampling, where you
9 focus your Monte Carlo analysis on those parts where it
10 really makes a difference.
11 What we're talking about is trying to eliminate
12 scenarios where there just doesn't look like there's going
13 to be any PTS challenge whatsoever. That's obviously the
14 first screen. Then you can, from a PRA standpoint, say,
15 well, this is possible, but it just is highly improbable and
16 because of the systems failures that you require and you
17 throw those out, as well, and the hope is, and obviously we
18 don't know that this hope will be realized until we do it,
19 is that we really can narrow down to a smaller number of
20 scenarios that are reasonably tractable.
21 We might have to develop some sort of simplified
22 thermal hydraulic representation to address uncertainties,
23 propagation of uncertainties, but, again, that's open to
24 question right now.
25 DR. POWERS: It's just that the screening is going

1 to be based on intuition and judgment.

2 MR. SIU: Yes, that's fair, and I will also say

3 that I think we're way better than where we were back then

4 in the '80s.

5 DR. SHACK: Could you explain a little bit more

6 about the notion that the thermal hydraulic, the

7 uncertainties is all in the frequencies and not in the time

8 traces?

9 MR. SIU: Roy, could you go back this diagram?

10 MR. WOODS: Sure.

11 MR. SIU: As a philosophical matter, I suppose you

12 could say that if you define the scenarios finely enough,

13 let's say that you know exactly when everything occurs and

14 if you're comfortable that you have a very robust model for

15 the system behavior, that most of the uncertainties would be

16 in just the specification of -- I don't know what

17 parameters, I'm certainly not an expert here, maybe Farouk

18 in the back might be able to help me out here.

19 But if you -- there are some parameters that,

20 let's say, your empirical coefficients in the heat transfer

21 correlation, we all know, you know those within plus or

22 minus 20 percent, at best.

23 Okay. But if you've nailed everything else down

24 and all you have to know is that particular coefficient, you

25 could say, well, there could be some uncertainty there, yes,

1 and then I could have a bundle of scenarios rather than a
2 single one.
3 What we're saying right now is hopefully we will
4 carefully define the scenarios such that we can get down to
5 that point where if we really are talking plus or minus 20
6 percent, it's not really a big issue compared to some of the
7 other things that we've got in the other parts of the model.
8 And one of the concerns is that we don't do an
9 overkill here if we have huge uncertainties in other parts
10 of the analysis.
11 But it's clearly an approximation, but doing it
12 this way. We've had some discussions with the thermal
13 hydraulics modelers and have some sense of feeling at this
14 point that a lot of the uncertainties have to do with the
15 input to their models and if that's the case, then I think
16 we know how to handle that.
17 MR. WOODS: As we pointed out, I guess this is
18 just summarizing. The development of the Oconee PTS PRA
19 model is going very well. The integrated PRA team, HRA
20 team, is developing a plant model and has visited the plant.
21 It's 2:00. They're still visiting the plant,
22 aren't they?
23 MR. GALYEAN: That's right.
24 MR. WOODS: We were there Tuesday and Wednesday of
25 this week, the three of us, plus three HRA people and --

1 well, anyway, you get the idea. There was a part of the
2 meeting regarding integrated control systems. The guy that
3 we needed to talk to was only available today. So they
4 stayed and the three of us had another important engagement.
5 So we left and left them there to do it.
6 DR. POWERS: And then you dropped by here, right?
7 MR. WOODS: I'm sorry?
8 DR. POWERS: Then you dropped by here.
9 MR. WOODS: Yes, right, then we dropped by here.
10 I think this is an accurate statement here, screening level
11 results are expected shortly. It depends. You don't want
12 to say shortly as this afternoon, but like toward the end of
13 this month, middle of next month, we expect to have some
14 idea where the through wall crack frequency -- no, no. I'm
15 sorry -- where the frequencies of some of these significant
16 sequences are. We will not have run it through the thermal
17 hydraulic analysis and we will not have run it through the
18 PFM calculations.
19 But we will begin to have PRA results, PRA/HRA
20 results at that point.
21 And that's the one we're working on now. We have
22 made some initial contacts with Beaver Valley. I think we
23 pointed out they are the ones that are going to step in for
24 the Westinghouse three-loop plant. We wanted a three-loop
25 plant because H.B. Robinson is a three-loop plant. We had

1 the previous analyses back in the mid '80s for H.B.
2 Robinson, so if you choose a similar plant, you know some of
3 that's applicable. The thermal hydraulics models are
4 applicable more so than they would be for a four-loop plant
5 or something.
6 So anyway, that's been initiated. We're getting
7 some requests to them. I guess I have to back up and say
8 for the Oconee people, that the cooperation has just been
9 excellent. If they had it or could imagine where it might
10 be or could dredge it out or call somebody in, then we had
11 it just as quickly as they could provide it.
12 So that really is going very well.
13 And the last item on this slide, uncertainty
14 analysis, I guess we just talked about that. There's not
15 much else to add. That's the presentation. Do you have
16 questions?
17 There can be several reasons for no questions.
18 Some of them are not complimentary and some of them are.
19 DR. POWERS: I know this committee pretty well.
20 They're all being complimentary right now. That was a very
21 nice presentation.
22 DR. KRESS: If we had criticisms that were severe,
23 we wouldn't be reluctant to say them.
24 MR. WOODS: I've seen that over the years maybe.
25 DR. KRESS: Actually, I think this looks pretty

1 good.

2 DR. POWERS: You can get back to some good fire

3 analysis.

4 DR. SHACK: I guess there is sort of one comment.

5 I look at that embedded analysis and it sort of looks like

6 it makes the whole problem go away. If I live with embedded

7 flaws, everything else goes away. Is this overkill? Have

8 you seen anything that indicates that you're unconservative

9 somewhere else?

10 So that if they produce the new flaw analysis, you

11 could declare victory. Dana wants it done completely, but

12 he wants it done quickly so you can get back to the fire

13 analysis.

14 DR. POWERS: But you have to do fire analysis to

15 do it completely.

16 MR. CUNNINGHAM: There could be a couple of places

17 where we're under-estimating, if you will, the frequencies.

18 One is the human element of it, the human performance

19 element of it. We're adding some different wrinkles to that

20 that we haven't done before. So that could change our

21 perspective on the frequencies to some of these challenges.

22 The other part comes back to the acceptance

23 criterion that I talked about, is that I wouldn't imagine

24 that it gets any less conservative, if you will, or higher

25 value of an acceptance criterion today.

1 Under some scenarios that I don't think are
2 probable, but under some scenarios, that could become
3 tighter. So it offsets, to some degree, some of the
4 benefits we get in the materials area.
5 I don't think that's a likely scenario, but I
6 think we need to nail that down. So there are at least a
7 couple of places where it could come into play, where other
8 features of the analysis could come into play to counteract
9 some of the benefits we're getting out of the materials
10 research.
11 MR. SIU: There are some other places, like
12 treatment of support systems, where, like Bill pointed out,
13 some new initiators that were not in the old studies and
14 might raise the numbers. Again, the hope is that it doesn't
15 raise them tremendously, but you don't know until you do it.
16 MR. DIXON: Also, Terry Dixon, from Oak Ridge. I
17 assume you're referring to the plants that Shah put up this
18 morning. Those analyses were done in 1998 based on the
19 PVRUF data and it's my understanding that the Shoreham data
20 is coming in with higher flaw densities than PVRUF. So
21 that's one thing that could be negative relative to the
22 analysis results that Shah put up this morning.
23 Also, the statistical distribution of the K-1-c
24 database, it was discussed this morning that the effect is
25 transient dependent, so who knows. So those are two

1 possibilities that could go counter to what you saw this
2 morning.
3 DR. SHACK: Just to finish up, does anybody have
4 any -- go around the table, if anybody wants to add any
5 comments.
6 DR. POWERS: Well, the probabilistic is going to
7 be looked at and we'll see what we get and the plan seems to
8 be fine. My biggest concern is that when people start
9 telling screening, I think of babies and bath water and
10 things like that, because the intuition just doesn't work.
11 We wouldn't go to PRA if our intuition was so good
12 on these things. But these are cautious people that have a
13 lot of expertise in doing this and so I have a great deal of
14 confidence in them.
15 We talked this morning about rigor in the
16 statistical analysis and whatnot and quite frankly, I really
17 didn't understand the rigor there. I think what they really
18 mean is they're doing a pretty careful job and to an
19 engineering detail and they don't really mean they're going
20 to go through a rigorous statistical analysis on this stuff
21 that would leave us all confused and befuddled. They're
22 doing things that are pretty obvious, is what I think
23 actually, and it looks very promising.
24 This is one of the really nifty research programs,
25 because it brings together three disciplines and a focused

1 attack that probably is a lot of fun to work on, actually,
2 because you probably learn a heck of a lot in the project
3 meetings.
4 So I guess I'm pretty positive on this, except for
5 the fact that it deters a really good fire safety analyst,
6 so he's not available to work on one of the really important
7 problems.
8 DR. BONACA: I can only say that I am favorably
9 impressed by the effort, by the comprehensiveness of all the
10 elements coming together. This is a very good example of a
11 lot of deterministic and probabilistic analysis coming
12 together.
13 The area where I have still questions, in my mind,
14 is regarding criteria that will be used to modify the rule.
15 That's really a much more, I guess, sensitive issue, because
16 of all the things we discussed before.
17 I'm sure that I recognize that you recognize that
18 it is a sensitive issue and I'll be very alert to how it's
19 being modified, because there is a lot of information coming
20 together here, but, again, this is a quite unique scenario
21 we're talking about, more different than most.
22 So that's where I have more questions.
23 DR. SHACK: George?
24 DR. APOSTOLAKIS: The presentation this afternoon
25 was fairly high level. I think the implementation is really

1 where difficulties will be. So I guess I'll form an opinion
2 then.
3 DR. POWERS: One aspect of it that was not pursued
4 other than just to bring it up that will be really
5 interesting to see what they do is the hot standby analyses
6 and how you approach those problems. That will be new and
7 different.
8 DR. KRESS: Yes.
9 DR. SHACK: I just basically thought the
10 presentations were very good. It seemed to me a very
11 comprehensive and interesting program. We're looking
12 forward to sort of seeing how it all plays out.
13 DR. KRESS: I frankly was very impressed. I think
14 this is can serve as a model program on how to risk-inform
15 regulation. I think it's very good. I'm quite glad to see
16 this very nice uncertainty incorporation in the process. I
17 think, as a follow-on to that, I think we need to really
18 think about how are we going to use those uncertainties in
19 the decision-making process, and I didn't really see that
20 come through.
21 Now, I think it has to do with the acceptance
22 criteria and I think acceptance criteria, to me, is a matter
23 of policy and it's something that really could impact this
24 whole thing as much as anything, because moving it just a
25 little bit one way or the other can make a big difference.

1 The other thing is I wasn't -- I had some minor
2 concerns about the expert elicitation process, but that may
3 just be my bit. I don't like expert elicitation. But I
4 recognize that there are some places where that's the only
5 way you can get the uncertainty and so you have to use it.
6 But I agree with Dana that you have to watch out
7 for correlations and there may be better ways to correlate
8 the mean versus -- or the variance versus the mean and what
9 they have, but those are minor issues.
10 I really think you have a good thing going here
11 and I urge you to continue with it. It's a good way to --
12 you've wrapped up all the data, you've got all the models
13 wrapped up, you've done an uncertainty analysis. I think
14 it's a complete package and that's really what I like about
15 it.
16 People can come back ten years from now and look
17 at your report and say, whoa, they'll know exactly what you
18 did and it will all be retrievable. It's good stuff, I
19 think. You guys can be proud of it.
20 DR. BONACA: Just one thing. In addition to that,
21 I would really -- I really enjoyed the documentation you
22 provided. I think the paper on uncertainty analysis was
23 very clear, helpful.
24 MR. SIU: Thank you.
25 DR. SHACK: Tom, are you ready to make a decision

1 on whether we need a subcommittee meeting on the Commission
2 paper topic?
3 DR. KRESS: I think we ought to have a
4 subcommittee meeting and then bring it to the full.
5 DR. SHACK: Rather than just a full committee
6 meeting.
7 DR. KRESS: Yes. And just on this part that Mark
8 talked about.
9 DR. APOSTOLAKIS: Half a day?
10 DR. KRESS: Half a day would be plenty, I think.
11 MR. DUDLEY: And we would be looking at a full
12 committee meeting in May.
13 DR. KRESS: I don't know what the timing was. I
14 think we'll have to --
15 DR. SHACK: Because of the way they plan to do it,
16 it almost has to be.
17 MR. CUNNINGHAM: We owe a Commission paper in May.
18 DR. KRESS: That would be a good time to do it.
19 MR. CUNNINGHAM: It would be good. I'm not
20 expecting that the Commission will have to make an immediate
21 decision on where we go on this, so I don't know that it --
22 if the letter happens in June versus May, that it will make
23 that much difference, quite frankly.
24 DR. SHACK: It sort of has to be in that
25 timeframe.

1 MR. CUNNINGHAM: Yes.

2 DR. POWERS: Do we have it in our future

3 activities list?

4 MR. DUDLEY: No, we don't. So this meeting was to

5 define what future meetings we would have.

6 DR. BONACA: That would mean a subcommittee meeting

7 next month.

8 MR. DUDLEY: That's correct.

9 MR. HACKETT: Just a point of clarification. This

10 is Ed Hackett. The full committee then, Noel, in June,

11 would address the entire project or are we looking at just

12 addressing the acceptance criterion?

13 MR. DUDLEY: Well, there would be one full

14 committee meeting in May to discuss the risk criteria and

15 then the expert elicitation would be heard either in June or

16 July, based on your progress.

17 MR. HACKETT: Okay. Thanks.

18 DR. POWERS: Yes. We don't want to schedule an

19 expert elicitation process until they're ready. I don't

20 want it cascading, June, and then next it's July, and then

21 it's September and October. Give yourselves some padding on

22 your schedule.

23 I assume experts are a little bit like herding

24 cats and you'll not go wrong.

25 MR. HACKETT: It's been tough. I got to say,

1 Debbie probably deserves some kind of award for what she's
2 been able to do so far, Debbie and Lee.
3 MR. CUNNINGHAM: Thank you very much.
4 DR. SHACK: We are adjourned.
5 [Whereupon, at 2:16 p.m., the meeting was
6 concluded.]
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REPORTER'S CERTIFICATE

This is to certify that the attached proceedings before the United States Nuclear Regulatory Commission in the matter of:

NAME OF PROCEEDING: MEETING: MATERIALS AND METALLURGY

CASE NUMBER:

PLACE OF PROCEEDING: 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.

Mark Mahoney

Official Reporter

Ann Riley & Associates, Ltd.

INTRODUCTORY STATEMENT BY THE CHAIRMAN OF THE
MATERIALS AND METALLURGY SUBCOMMITTEE
11545 ROCKVILLE PIKE, ROOM T-2B3
ROCKVILLE, MARYLAND
MARCH 16, 2000

The meeting will now come to order. This is a joint meeting of the ACRS Subcommittees on Materials and Metallurgy and on Reliability and Probabilistic Risk Assessment. I am Dr. William Shack, Chairman of the Materials and Metallurgy Subcommittee. Dr. George Apostolakis is Chairman of the Reliability and Probabilistic Risk Assessment Subcommittee.

The other ACRS Members in attendance are: Mario Bonaca, Thomas Kress, and Dana Powers.

The purpose of this meeting is for the Subcommittees to review the status of activities related to the staff's Pressurized Thermal Shock (PTS) Screening Criterion Reevaluation Project. The Subcommittees will gather information, analyze relevant issues and facts, and formulate proposed positions and actions, as appropriate, for deliberation by the full Committee.

Mr. Noel Dudley is the Cognizant ACRS Staff Engineer for this meeting.

The rules for participation in today's meeting have been announced as part of the notice of this meeting previously published in the *Federal Register* on February 25, 2000.

A transcript of this meeting is being kept, and will be made available as stated in the Federal Register Notice. It is requested that speakers first identify themselves and speak with sufficient clarity and volume so that they can be readily heard.

We have received no written comments or requests for time to make oral statements from members of the Public.

[Chairman's Comments]

We will now proceed with the meeting and I call upon Mr. Edwin Hackett, Acting Chief of the Materials Engineering Branch in the Office of Nuclear Regulatory Research, to begin.

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
JOINT MEETING OF THE MATERIALS AND METALLURGY AND
RELIABILITY AND PROBABILISTIC RISK ASSESSMENT SUBCOMMITTEES
PTS SCREENING CRITERION REEVALUATION

MARCH 16, 2000

ROCKVILLE, MARYLAND

- PROPOSED AGENDA -

	TOPIC	PRESENTER	TIME
I.	Opening Remarks	W. Shack, ACRS	8:30-8:35 a.m.
II.	Pressurized Thermal Shock Analysis Methodology Overview	E. Hackett, RES	8:35-9:00 a.m.
III.	Probabilistic Fracture Mechanics Analysis	S. Malik, RES	9:00-10:00 a.m.
	A. Methods B. Input C. Issues D. Computer Code (FAVOR)		
	- BREAK -		10:00-10:15 a.m.
IV.	Probabilistic Fracture Mechanics Analysis (Continued)	S. Malik, RES	10:15-11:00 a.m.
V.	Status of Flaw Distribution Expert Elicitation Process	D. Jackson and L. Abramson, RES	11:00-12:00 noon
	- LUNCH -		12:00-1:00 p.m.
VI.	Introduction	G. Apostolakis ACRS	1:00-1:05 p.m.
VII.	PTS Risk Acceptance Criterion	M. Cunningham, RES	1:05-2:15 p.m.
	- BREAK -		2:15-2:30 p.m.
VIII.	Probabilistic Risk Assessment	H. Woods, RES N. Siu, RES W. Galyean, INEEL	2:30-3:30 p.m.
	A. Identified Scenarios B. PRA Analysis Efforts C. Uncertainty Analysis		

IX.	Discussion	W. Shack, ACRS	3:30-4:30 p.m.
X.	Adjournment	W. Shack, ACRS	4:30 p.m.

NOTE:

Presentation time should not exceed 50 percent of the total time allotted for specific item. The remaining 50 percent of the time is reserved for discussion.

Number of copies of the presentation materials to be provided to the ACRS - 25.

OVERVIEW OF PRESSURIZED THERMAL SHOCK TECHNICAL BASIS RE-EVALUATION PROJECT

E. M. Hackett, Acting Branch Chief
Materials Engineering Branch
Office of Nuclear Regulatory Research

Presentation to the
Advisory Committee on Reactor Safeguards
Materials and Metallurgy Subcommittee

March 16, 2000

PTS RE-EVALUATION PROJECT BACKGROUND

- Recent technical developments indicated the potential for increasing the accuracy (reducing conservatisms) for PTS analyses:
  - Improved estimates for weld flaw density and distribution
  - Improved embrittlement correlations
  - statistical bases for fracture toughness
- The project was initiated in April, 1999 as a fully-participatory effort with the industry (MRP, EPRI, NEI)
- ACRS briefings - 2/99, 7/99, 3/00
- Project organized in three key technical areas:
  - Probabilistic Fracture Mechanics (PFM)
  - Thermal-Hydraulics (T-H)
  - Probabilistic Risk Assessment (PRA)

PTS RE-EVALUATION PROJECT APPROACH

- Overall - Best estimate analyses for individual technical inputs with uncertainty explicitly addressed at each point

- Update technical inputs in PFM, T-H and PRA and Re-do IPTS studies with new information

- In parallel, re-assess the PTS Risk Acceptance Criteria

PTS RE-EVALUATION PROJECT
CURRENT STATUS

- Significant progress in key technical areas:

- PFM
  - Expert elicitation for generic flaw distribution (5/00)
  - Revised embrittlement correlations (4/00)
  - Statistical bases for fracture toughness (4/00)
  - Plant-specific flux maps being developed:
    - * Palisades (1/00)
    - * Oconee (3/00)
    - * Calvert Cliffs (7/00)
    - * Beaver Valley 1 (9/00)

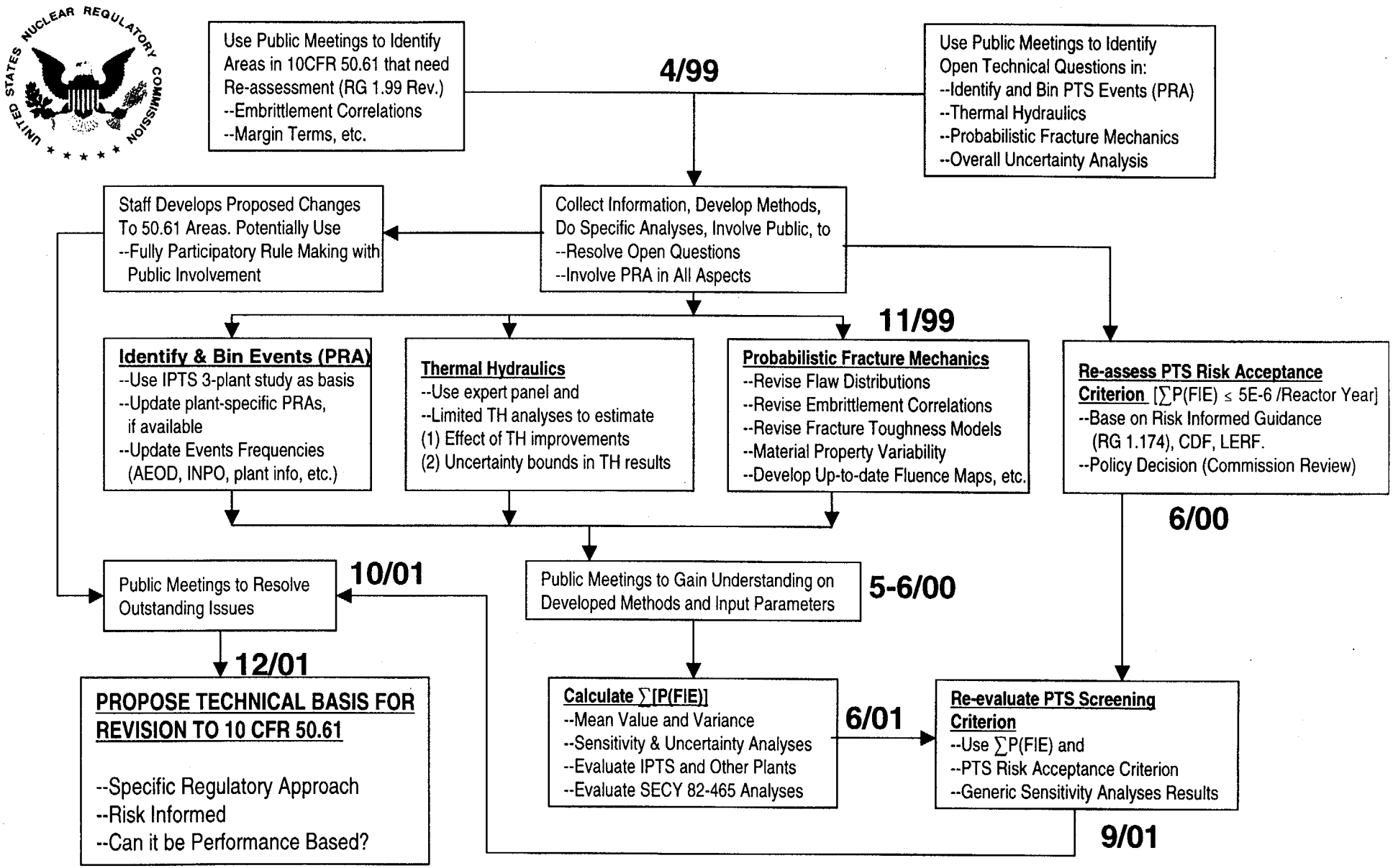
- T-H
  - Determination of key transients to be analyzed (4/00)
  - Verification from testing at Oregon State University APEX facility

- PRA
  - Consistency w/NRC risk-informed guidance
  - RG 1.174, CDF, LERF
  - Options presented for Policy Decision (Commission paper - 5/00)

PTS RE-EVALUATION PROJECT
ISSUES

- H.B. Robinson declines participation (2/00)

- Beaver Valley Unit 1 agrees to participation (3/00)
  - Additional PRA and T-H work
  - 2 month schedule delay?



Development of Technical Basis to Revise PTS Rule 50.61

PTS Re-evaluation Project
Progress in
Probabilistic Fracture Mechanics

Shah Malik, Mark Kirk, Doug Kalinousky, Tanny Santos
Materials Engineering Branch
Office of Nuclear Regulatory Research,
U.S. NRC

Presented to: Advisory Committee on Reactor Safeguards,
Materials and Metallurgy Subcommittee
March 16, 2000

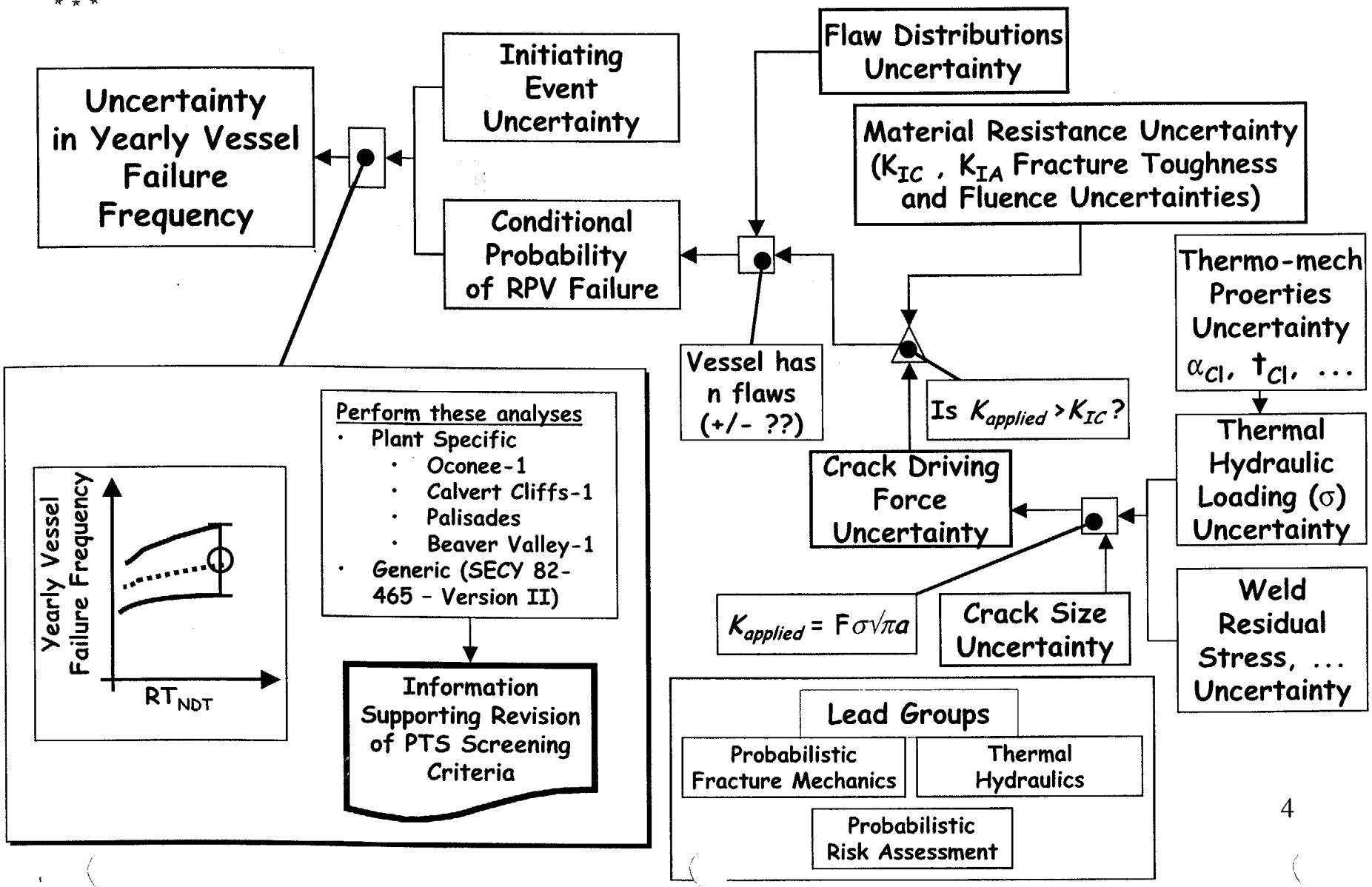
PTS Re-Evaluation Project
Probabilistic Fracture Mechanics
Presentation Outline

- Overall status of PFM activities
- Where it fits into PTS re-evaluation
- Progress in major PFM technical areas
- Concluding remarks

PTS Re-Evaluation Project
Probabilistic Fracture Mechanics
Overall Status

- Held 6 public meetings (staff, contractors, industry representatives, and public)
  - 1999: May, July, Sept., Nov., Dec.
  - 2000: Feb.
- Near and long term action plans developed
  - Tasks assigned to groups and individuals
- Coordinated with PRA and TH activities
- Interim version of PFM code, FAVOR, released in Oct. 1999 for comments and use

Where this Fits into PTS Re-Evaluation



PTS Re-Evaluation Project
Probabilistic Fracture Mechanics
Major Technical Areas

1. Fabrication Flaw Distributions in RPV beltline
2. Rigorous statistical representation of fracture toughness, K1c and K1a, data
3. Improved irradiation embrittlement correlations to predict shift in RT_{NDT} (ΔRT_{NDT})
4. Improved statistical distributions for material chemistry and initial (unirradiated) RT_{NDTo}
5. Beltine neutron fluence maps
6. PFM computer code, FAVOR, revision

PTS Re-Evaluation Project
Probabilistic Fracture Mechanics

Fabrication Flaw Distributions

- Objective: Determine generalized flaw sizes, density (# of flaws/unit volume), and location distributions of fabrication flaws in welds, plates and forgings in RPV beltline region, using:
  - NDE/DE techniques and expert judgement process
- RES Staff: Deborah Jackson
- NRC Contractor: PNNL

Probabilistic Fracture Mechanics Fabrication Flaw Distributions --Contd.

- NDE/DE of welds in one RPV (PVRUF) completed, and continuing for others
  - NRC, Industry/EPRI working in parallel
  - PVRUF, Shoreham, River Bend-2, Hope Creek-2 vessels
- Expert judgement process is continuing
- NDE of limited plate material has begun
  - Data to be collected in March/April '00
- Generalized distributions to be developed by May/June '00

Probabilistic Fracture Mechanics
Fracture Toughness (K_{IC} and K_{IA}) Curves

- <u>Objective</u>: Revise toughness distribution curves based on expanded LEFM-valid (ASTM E 399) available data and rigorous statistical methods
  - Current distributions were based on:
    - ➢ limited 1970's/80's data
      - ◆ 171 data points for K_{IC} (LEFM-valid)
      - ◆ 50 data points for K_{IA} (LEFM-valid)
    - ➢ In SECY-82-465 and IPTS studies, Ad-hoc distributions developed from lower-bound ASME toughness curves

- <u>RES Staff</u>: Mark Kirk, Shah Malik, Nathan Siu
- <u>Contractors</u>: ORNL, Univ. of Maryland

Probabilistic Fracture Mechanics
Fracture Toughness (K_{IC} and K_{IA}) Curves

Assemble All Available Valid K_{IC} and K_{IA} Data → Establish Sources of Uncertainty → New Description of K_{IC} / K_{IA} for FAVOR

ORNL

- Purely statistical assessment
- Interim curves
  - Use in FAVOR
  - Illustrate likely overall changes from current FAVOR model

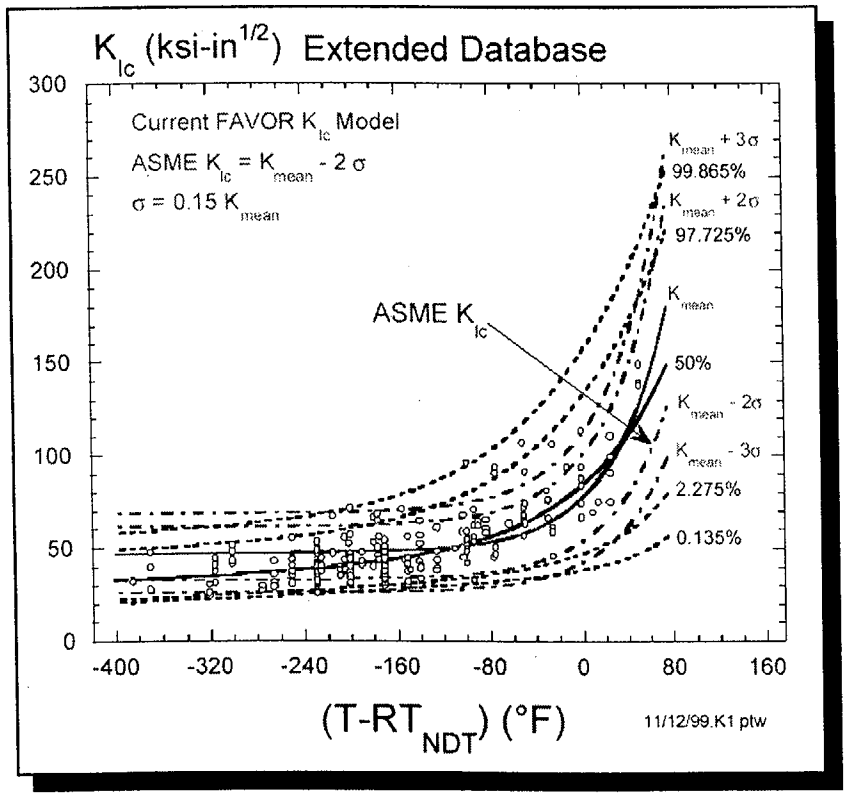
University of Maryland

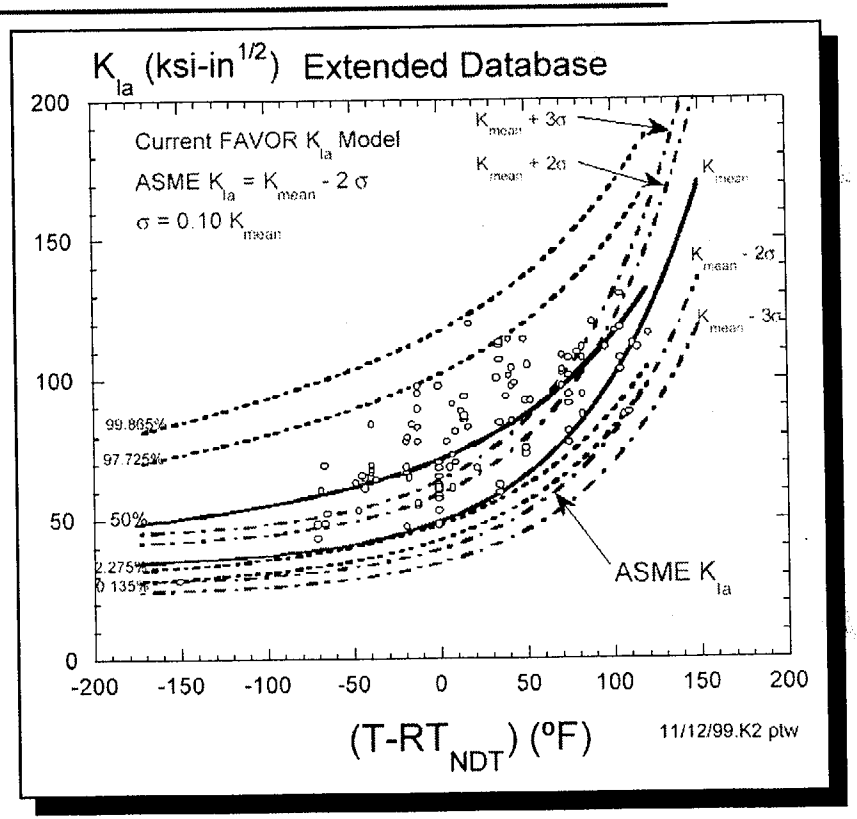
- Root cause analysis
- Physical basis
- Distinguish
  - Aleatory
  - Epistemic
- Procedure to treat parameter and model uncertainty
  - Consistent with PRA methodologies

Probabilistic Fracture Mechanics
Fracture Toughness (K_{IC} and K_{IA}) Curves, Cont.

- ORNL searched and collected additional data (database has now increased considerably)
  - 83 additional LEFM-valid K_{IC} (initiation) data (254 total)
    - Increase of almost 50%
  - 62 additional LEFM-valid K_{IA} (arrest) data (112 total)
    - Increase of over 100%
  - Weibull distributions developed based solely on data
  - Japanese K_{IC} / K_{IA} database was not available, but we may be able to obtain it now

Probabilistic Fracture Mechanics
Fracture Toughness (K_{IC} and K_{IA}) Curves





Old *FAVOR* scatter-bands too narrow

Effect on Probability of Vessel Failure Depends on Transient Considered

Probabilistic Fracture Mechanics
Fracture Toughness (K_{IC} and K_{IA}) Curves

Form of ORNL Equations

$$K_{Ic}(p,\Delta T) = a\Delta T + b\Delta T \cdot \{-\ln(1-p)\}^{1/(c\Delta T)}$$

$$a = 10.8957 + 23.4192 \cdot \exp(0.0023 \cdot \Delta T)$$

$$b = 14.7582 + 42.6312 \cdot \exp(0.0124 \cdot \Delta T)$$

$$c = 2.03025 + 0.4983 \cdot \exp(0.0135 \cdot \Delta T)$$

$p =$ Cumulative probability of failure

$\Delta T =$ Temperature relative to RT_{NDT} (in °F)

Probabilistic Fracture Mechanics
Fracture Toughness (K_{IC} and K_{IA}) Curves

Assemble All Available Valid K_{IC} and K_{IA} Data → Establish Sources of Uncertainty → New Description of K_{IC} / K_{IA} for FAVOR

ORNL DONE

- Purely statistical assessment
- Interim curves
  - Use in FAVOR
  - Illustrate likely overall changes from current FAVOR model

University of Maryland We Are Here

- Root cause analysis
- Physical basis
- Distinguish
  - Aleatory
  - Epistemic
- Procedure to treat parameter and model uncertainty
  - Consistent with PRA methodologies

Probabilistic Fracture Mechanics
Fracture Toughness (K_{IC} and K_{IA}) Curves

University of Maryland

Root Cause Analysis

- Identify sources of uncertainties
- Physically based material's model for the toughness curves in ductile-to-brittle transition temperature range
  - Prof. Natishan (EPRI funding)

PRA Framework

- Distinguish epistemic (state of knowledge) and aleatory (randomness) parts of uncertainties
- Mathematical model to quantify uncertainties

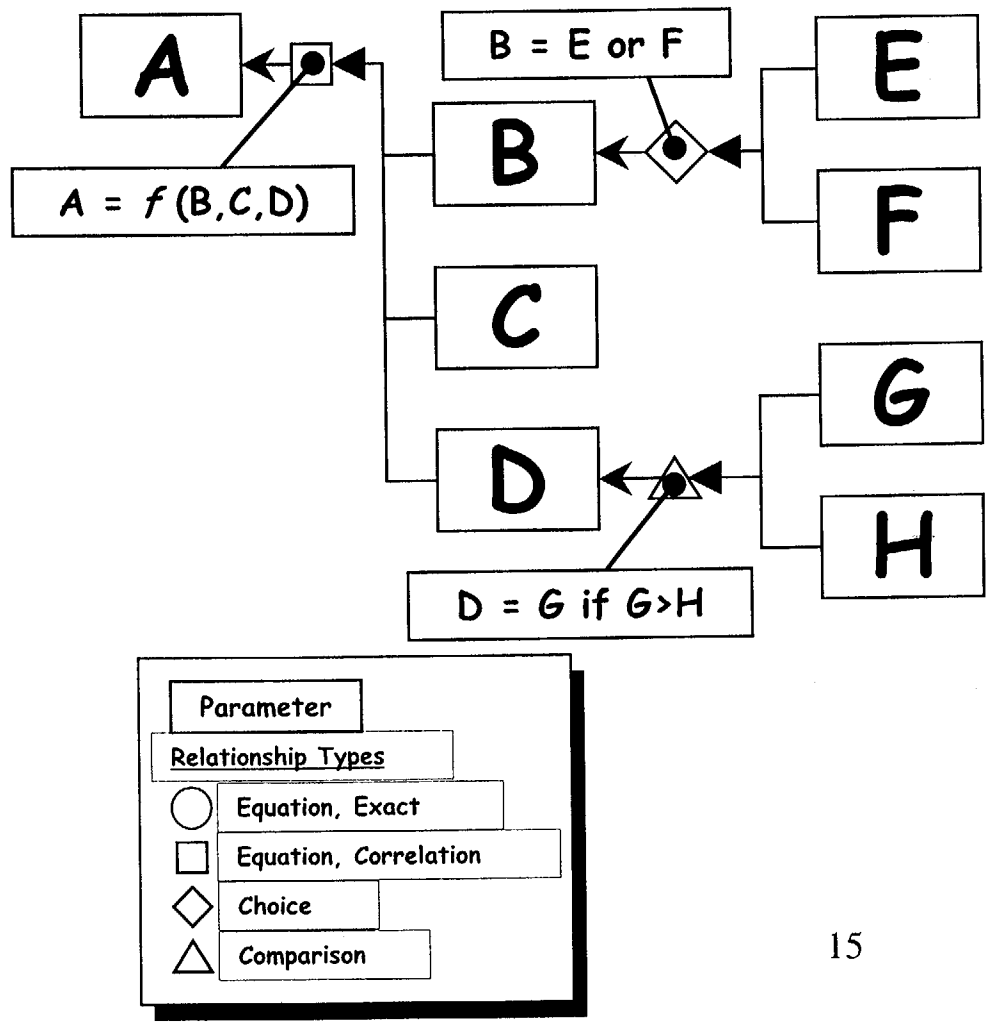
Product:

- Recommended program structure for FAVOR
  - Profs. Modarres and Mosleh (NRC funding)

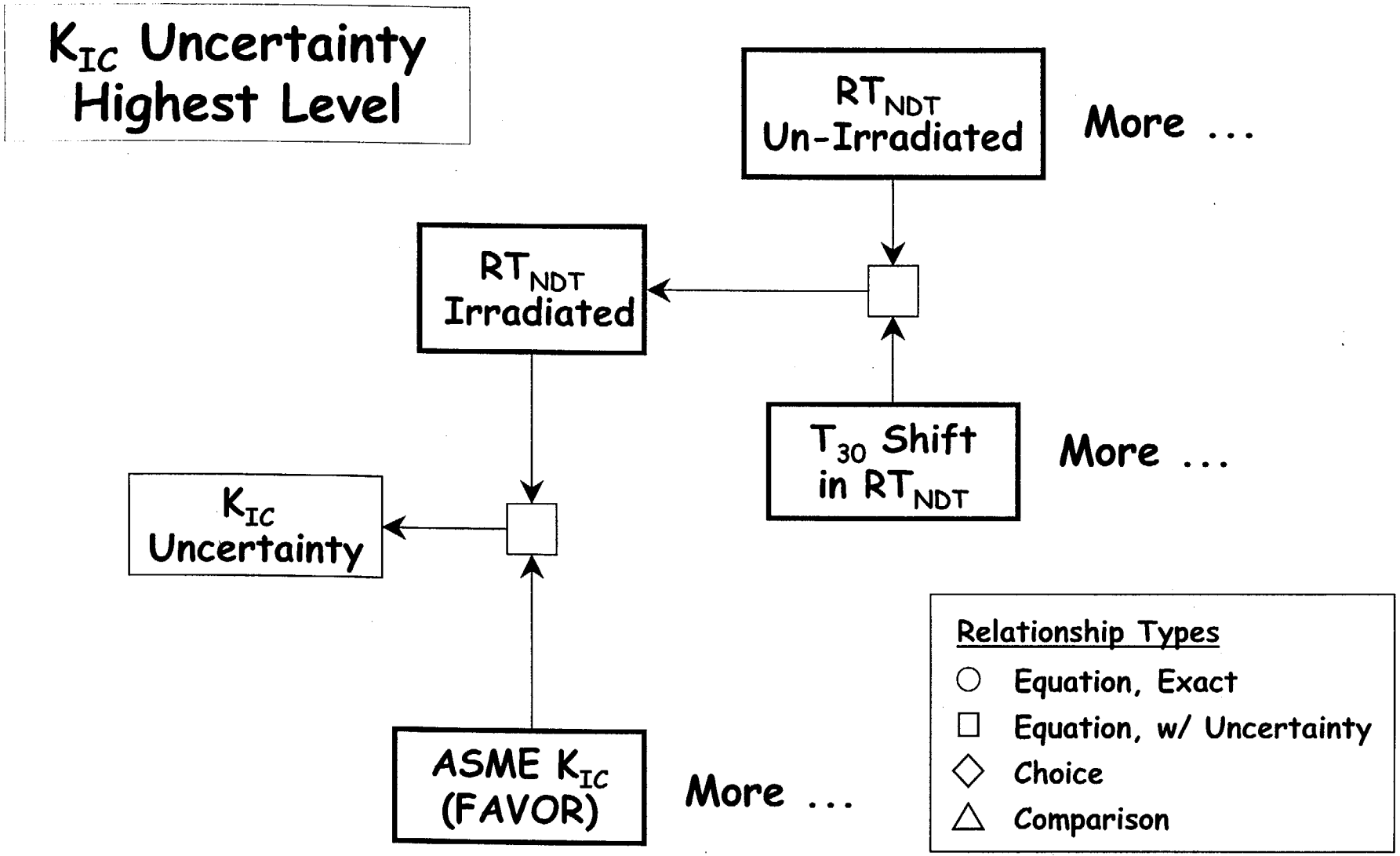
Probabilistic Fracture Mechanics
Fracture Toughness (K_{IC} and K_{IA}) Curves

Root Cause Diagrams

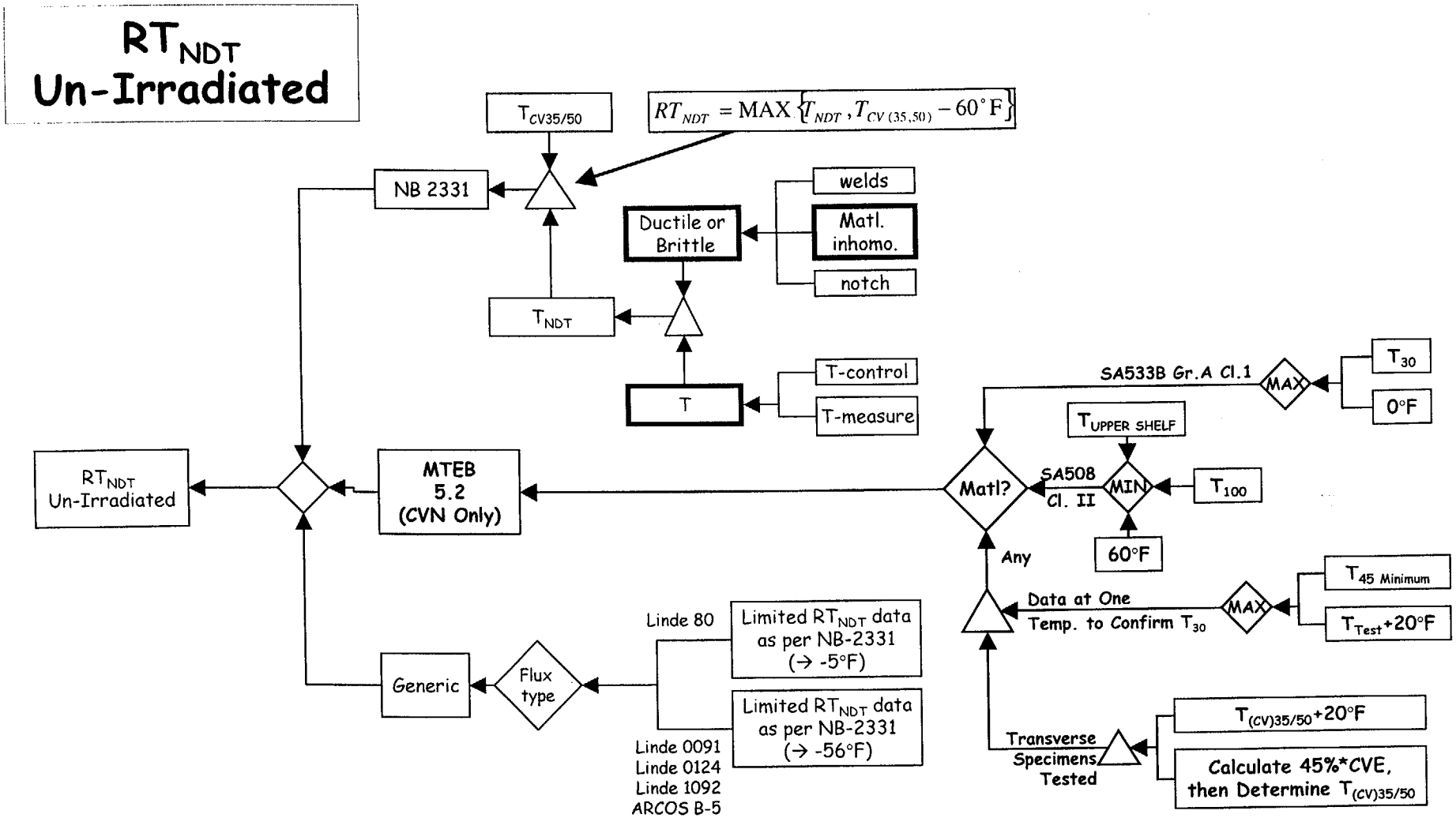
- Displays complex process in a logical format
- Provides big picture view while preserving details
- Builds consensus
  - Provides a common language for discussion
  - Allows participants to "see" their input
- Visual hierarchy
  - Streamlines critique
  - Enables understanding by non-experts
- Both parameter and model uncertainty treated
- Process ensures use of technically correct models



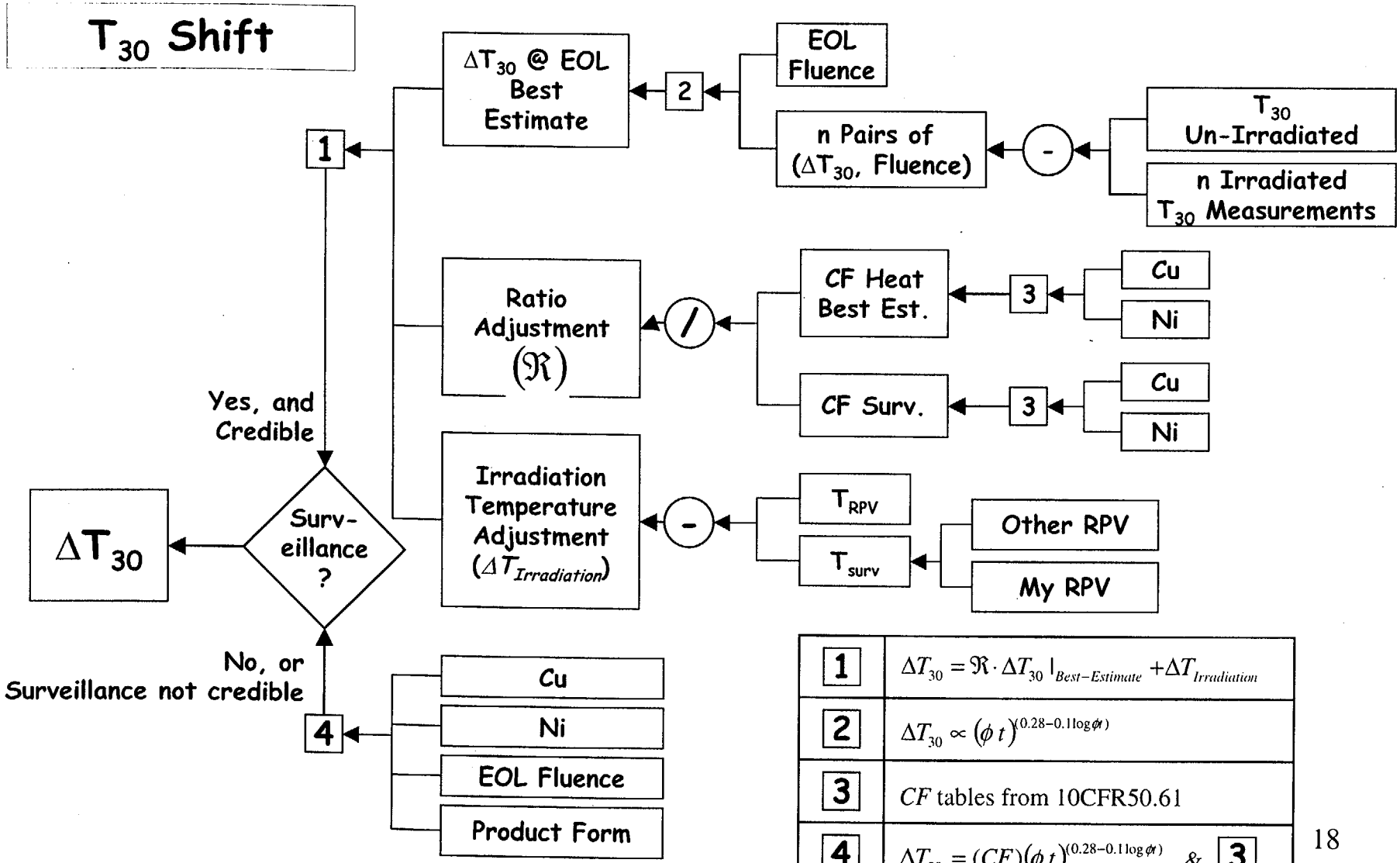
Probabilistic Fracture Mechanics
Fracture Toughness (K_{IC} and K_{IA}) Curves



Probabilistic Fracture Mechanics
Fracture Toughness (K_{IC} and K_{IA}) Curves

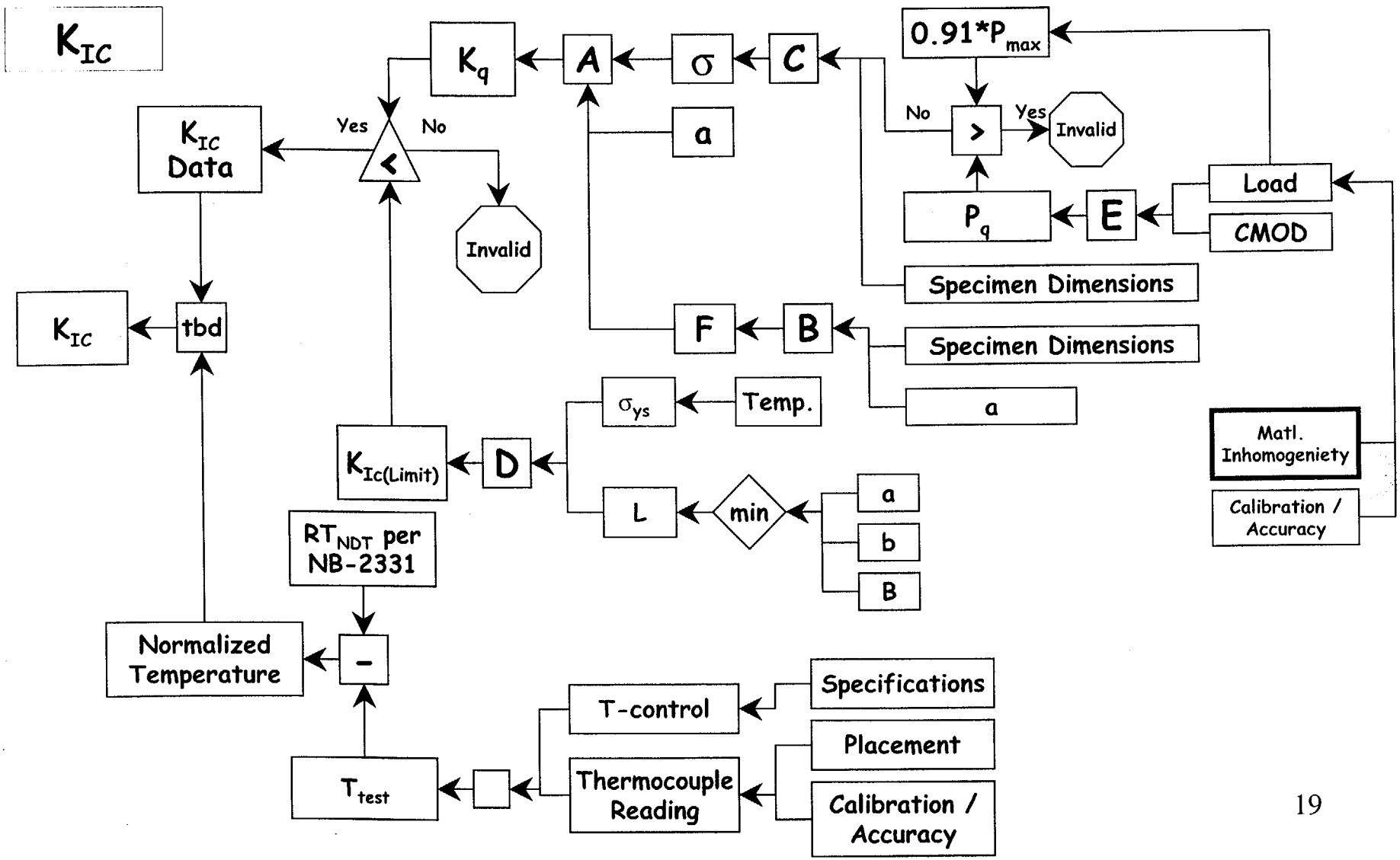


Probabilistic Fracture Mechanics
Fracture Toughness (K_{IC} and K_{IA}) Curves



1	$\Delta T_{30} = \Re \cdot \Delta T_{30}\,\vert_{Best-Estimate} + \Delta T_{Irradiation}$
2	$\Delta T_{30} \propto (\phi\, t)^{(0.28-0.1\log\phi t)}$
3	CF tables from 10CFR50.61
4	$\Delta T_{30} = (CF)(\phi\, t)^{(0.28-0.1\log\phi t)}$ & 3

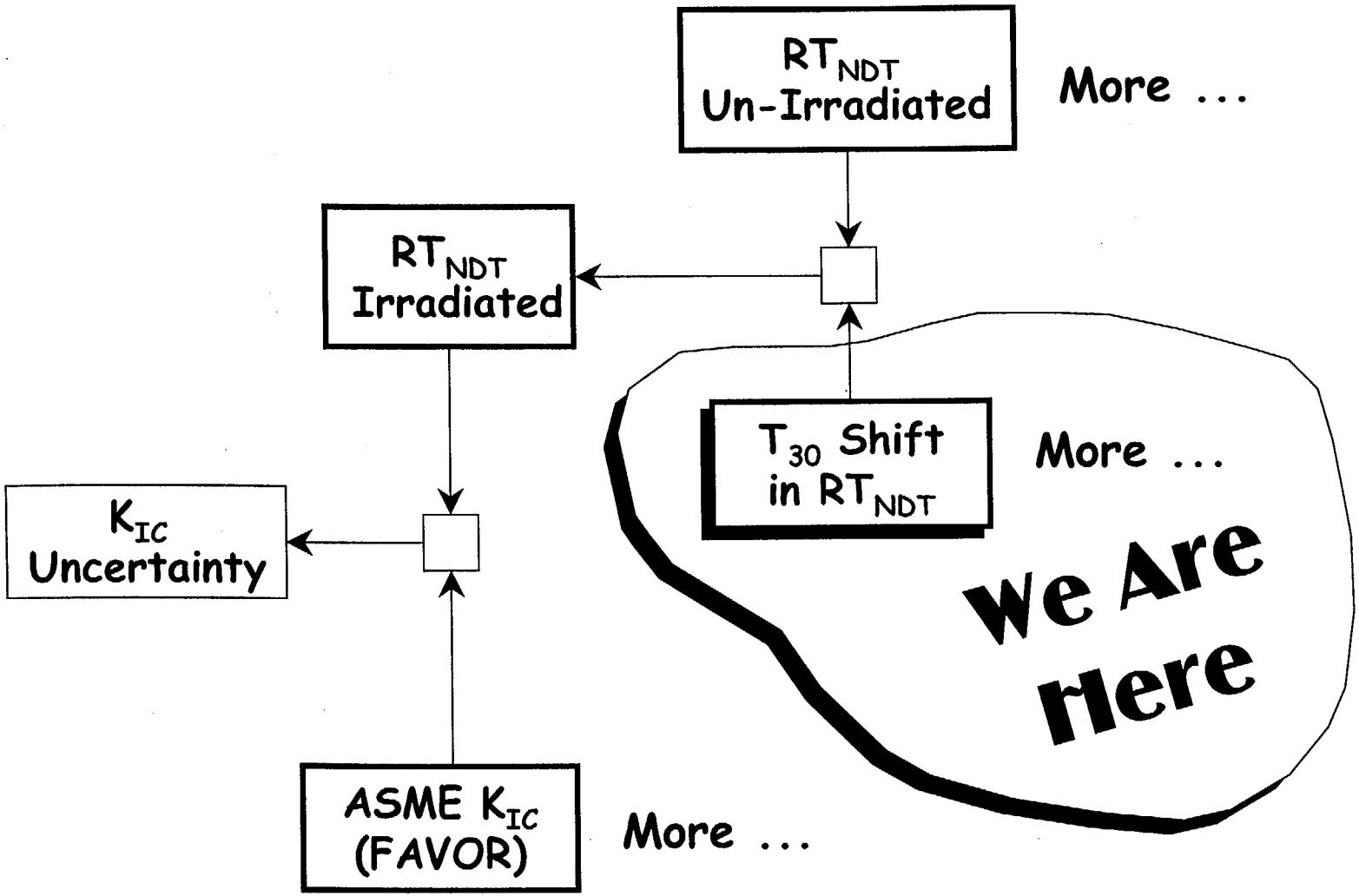
Probabilistic Fracture Mechanics
Fracture Toughness (K_{IC} and K_{IA}) Curves



Root Cause Analysis, Summary

- **Data distributions can be entered at any level of the diagram (not JUST to the far right)**
- **Appropriately incorporates all uncertainty sources**
- **Diagrams more than schematic**
  - Represent a mathematical model
  - Basis for simulation studies
- **Separates uncertainties at "choice" nodes**
  - Eliminates double-counts
  - Impossible in a purely statistical assessment
- **Model uncertainties identified and treated**
  - Eliminates double-counts

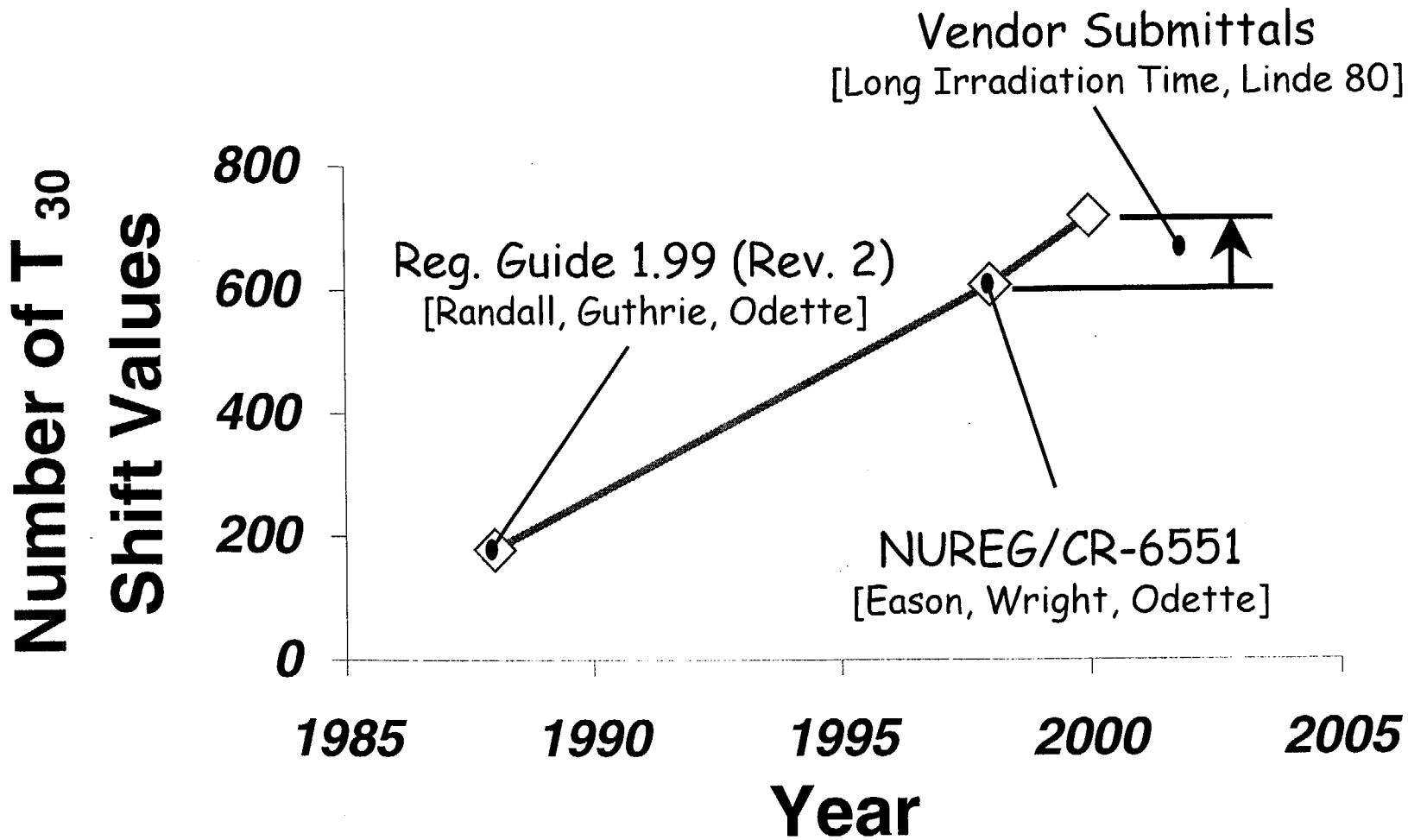
Probabilistic Fracture Mechanics
Irradiation Embrittlement Correlations



Probabilistic Fracture Mechanics
Irradiation Embrittlement Correlations

- **<u>Objective</u>: Develop a model to predict the shift in RT_{NDT} due to irradiation embrittlement**
  - More data
    - Better coverage of primary variables
    - Longer time exposures
    - Higher fluences
  - Rigorous statistical methods
  - Physical understanding
- **Activity provides guidance to**
  - Reg. Guide 1.99, Rev. 3
  - PTS re-evaluation
- **<u>RES Staff</u>: Mark Kirk, Carolyn Fairbanks, Shah Malik**
- **<u>NRC Contractors</u>: ORNL, Modeling & Computing Services, Univ. of California/Santa Barbara**

Probabilistic Fracture Mechanics Irradiation Embrittlement Correlations



Probabilistic Fracture Mechanics
Irradiation Embrittlement Correlations

How Have the Models Changed?

1988 RG 1.99 Rev. 2	$\Delta RT_{NDT} = (CF) f^{(0.28-0.1\log f)}$
1998 NUREG/CR-6551	$\Delta RT_{NDT} = A \exp\left(\frac{2.207\times10^4}{T_c+460}\right)\left(\frac{f}{10^{19}}\right)^{0.4132}$ $+B(Cu-0.072)^{0.682}(1+2.35Ni)^{1.381}\left\{0.5+0.5\tanh\left[\frac{\log_{10}(f)-18.27}{0.849}\right]\right\}$

- Physically motivated fits
- Separate terms for
  - Stable matrix defects (A)
  - Cu rich precipitates (B)
- Cu saturation

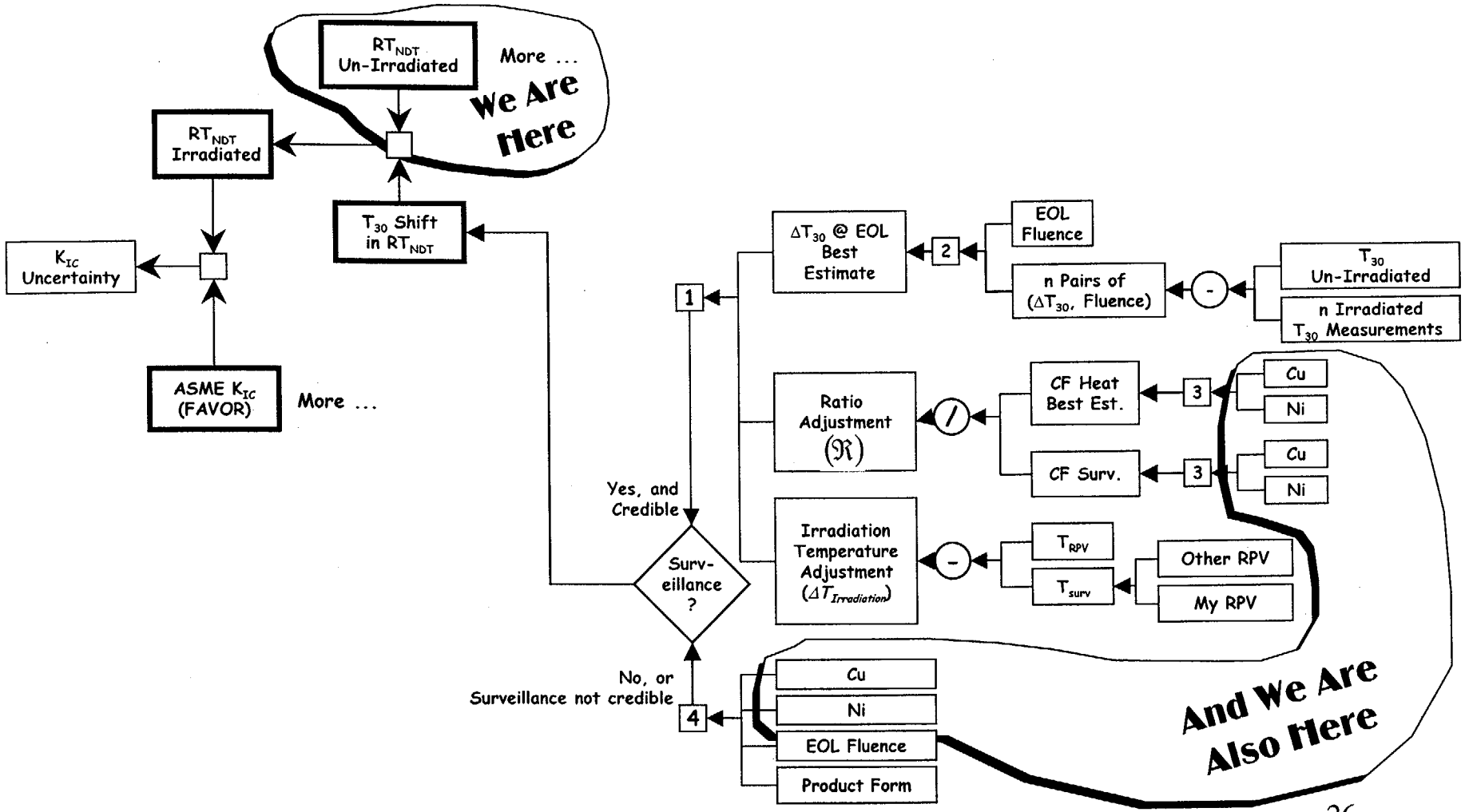
- Under consideration
  - Phosphorus
  - Long time effects
  - Use of surveillance as a check

Probabilistic Fracture Mechanics
Irradiation Embrittlement Correlations

- **Status**
  - Finalizing the model
    - Database frozen
    - Gating criteria for term admission established
    - Mini-basis documents being written
  - Model for PTS re-evaluation
    - Available in April / May
    - Feeds into K_{IC} / K_{IA} uncertainty analysis
  - Regulatory Guide 1.99 Revision 3
    - 12/00: Technical basis document
    - 6/01: Draft for public comment
- **ASTM E-10 evaluating the model for E900 standard**

Physical Basis	Statistical Basis	
	Strong (>95%)	Weak (>70%)
Well Accepted	Include	Include
Plausible	Include	Maybe
Not Established	Probably	Exclude

Probabilistic Fracture Mechanics Chemistry , RT_{NDTo} Distributions



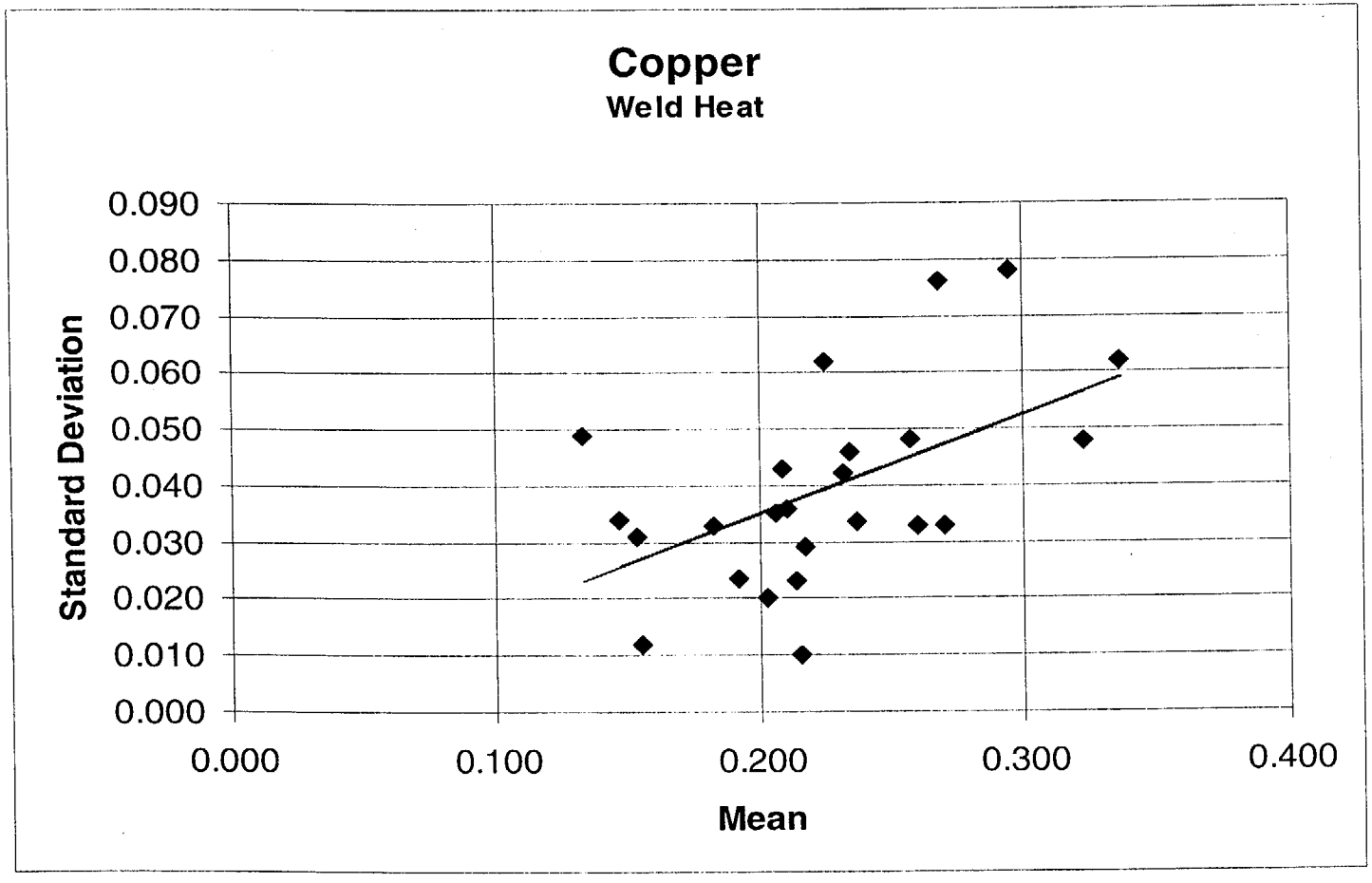
Probabilistic Fracture Mechanics Chemistry , RT_{NDTo} Distributions

- <u>Objective</u>: Using NRC and industry data, determine --
  - Heat specific distributions of:
    - Copper, Nickel, Initial RT_{NDT} (RT_{NDTo}), Phosphorous?
  - Heat to heat variability of the mean
  - Local variability
    - Within sub-region
    - Through wall-thickness (coil-by-coil ?)
- <u>RES Staff</u>: Doug Kalinousky, Tanny Santos, Lee Abramson

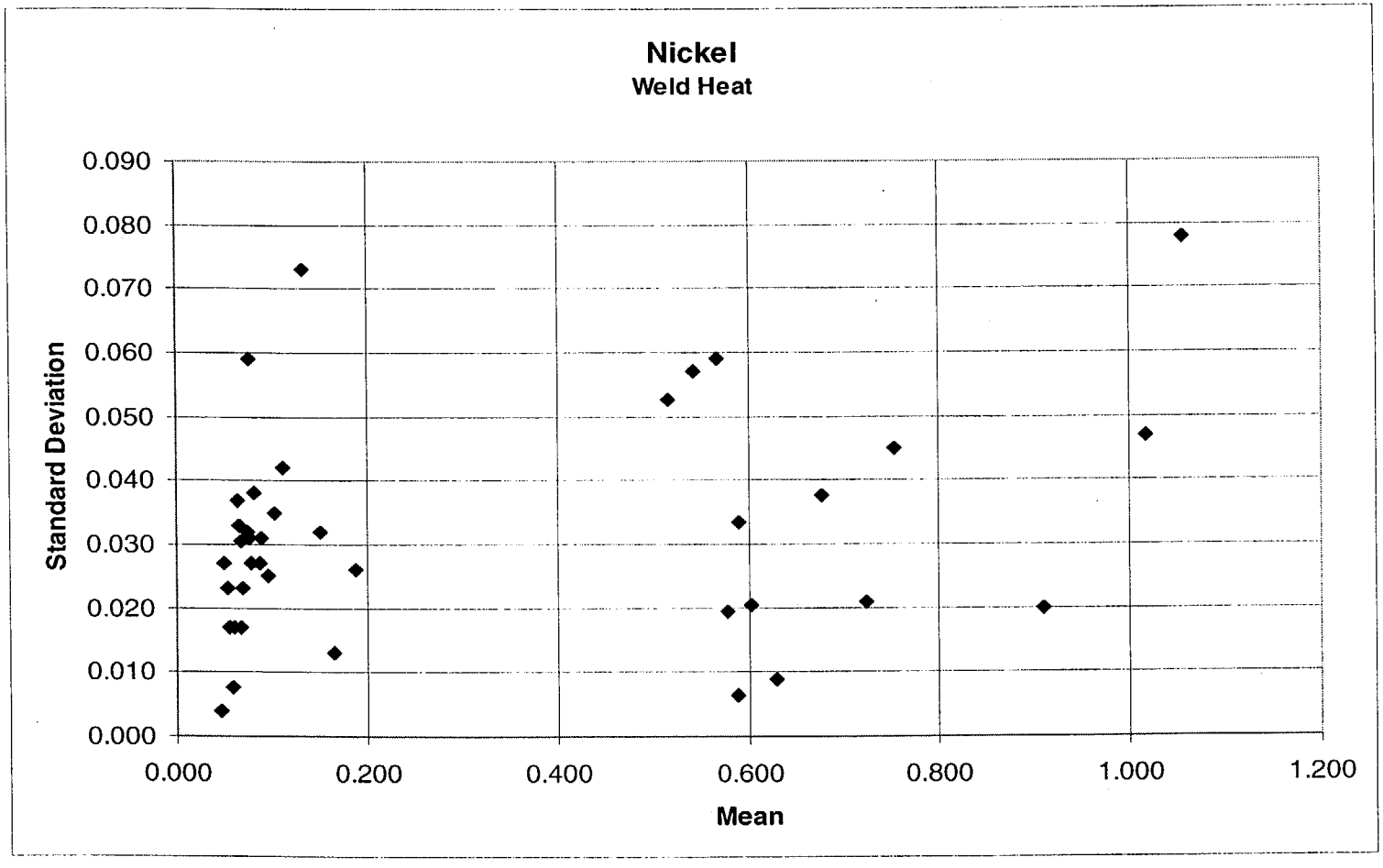
Probabilistic Fracture Mechanics
Weld Chemistry Distributions

- Considered all heats with 5 or more data
  - 24 heats for copper
  - 39 heats for nickel
- Determine heat-specific mean values and standard deviations for Cu and Ni
- Plot mean value vs. standard deviation
- Determine best fit line by linear regression

Weld Chemistry (Cu)



Weld Chemistry (Ni)



Weld Chemistry

- Copper
  - Normal or Lognormal Distribution
  - Best estimate
    - Mean of means from data
  - $Cu_{STD\ DEV} = Cu_{(Mean)} * 0.175$
- Nickel
  - Distinct populations for low and high Ni
  - Treat nickel-addition welds separately
  - Further analysis ongoing

Weld Local Variability

- Local variability determined from a separate CE Report with measurements on 8 blocks of materials
  - 5 measurements at t/4 locations in each block
- Copper & Nickel
  - Standard Deviation of 0.01 for Ni and Cu
  - Type of distribution needs to be determined
- Through-wall variability (coil-by-coil ?)
  - Still to be determined if needed

Plate Chemistry

- Limited Amount of Data
  - 1 or 2 points per heat
- Use heat best estimate from RVID2
  - Cannot justify a distribution
  - Do not sample

Plate Local Variability

- Assumed Normal distribution
  - Limited amount of data (3 groups of 6 data/group)
- Standard deviation
  - Copper: 0.002
  - Nickel: 0.005

Weld RT_{NDTo}

- Data from RPVDATA
- Grouped by heat
  - Used data for all heats with 3 or more measurements
  - 19 heats with 65 data
- Sample Δ_{weld} (deviation from heat mean $\equiv$ $heat_{mean}$ - measured $value_i$)
  - Add Δ_{weld} to $heat_{mean}$ values

Weld RT_{NDT0}

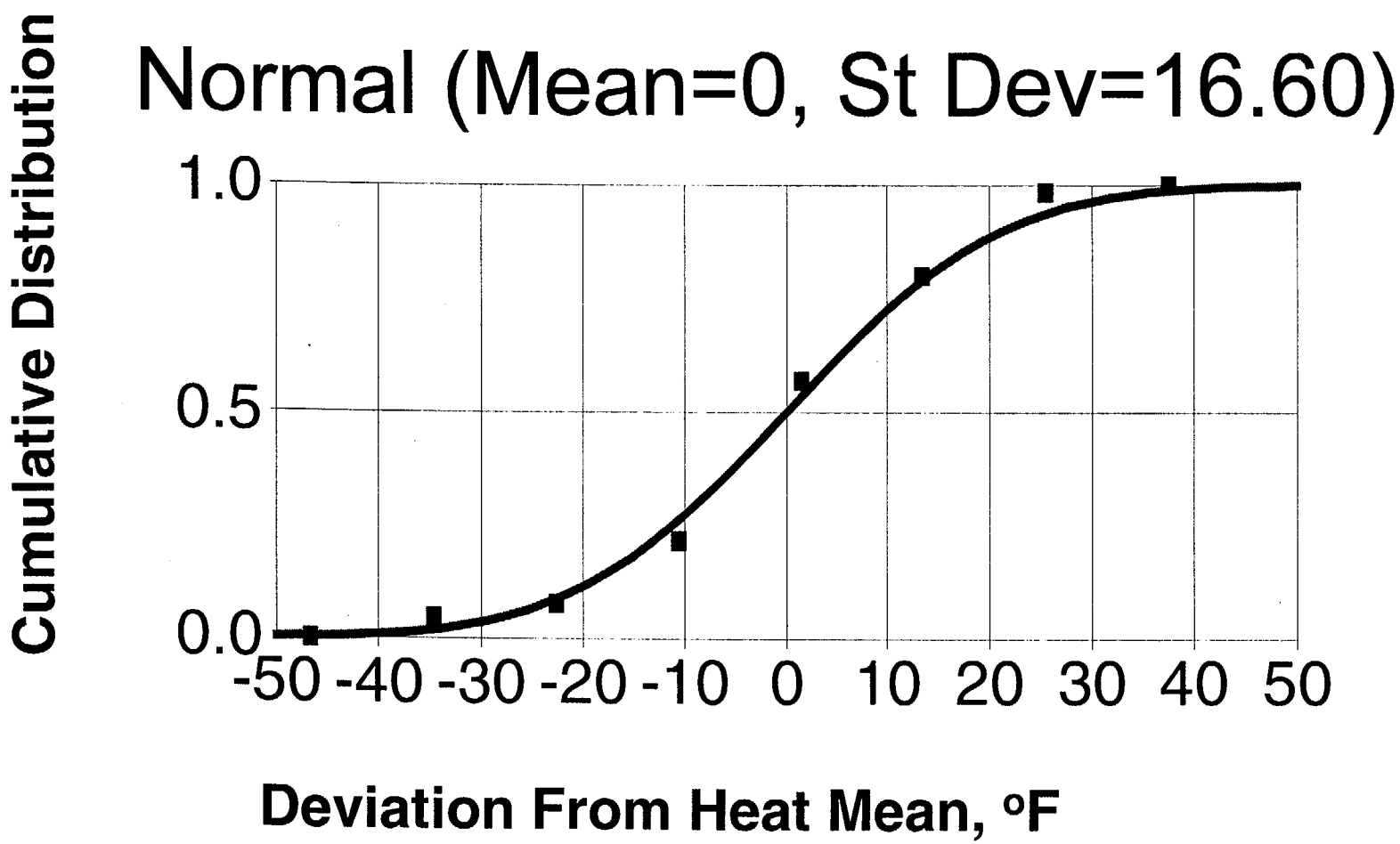
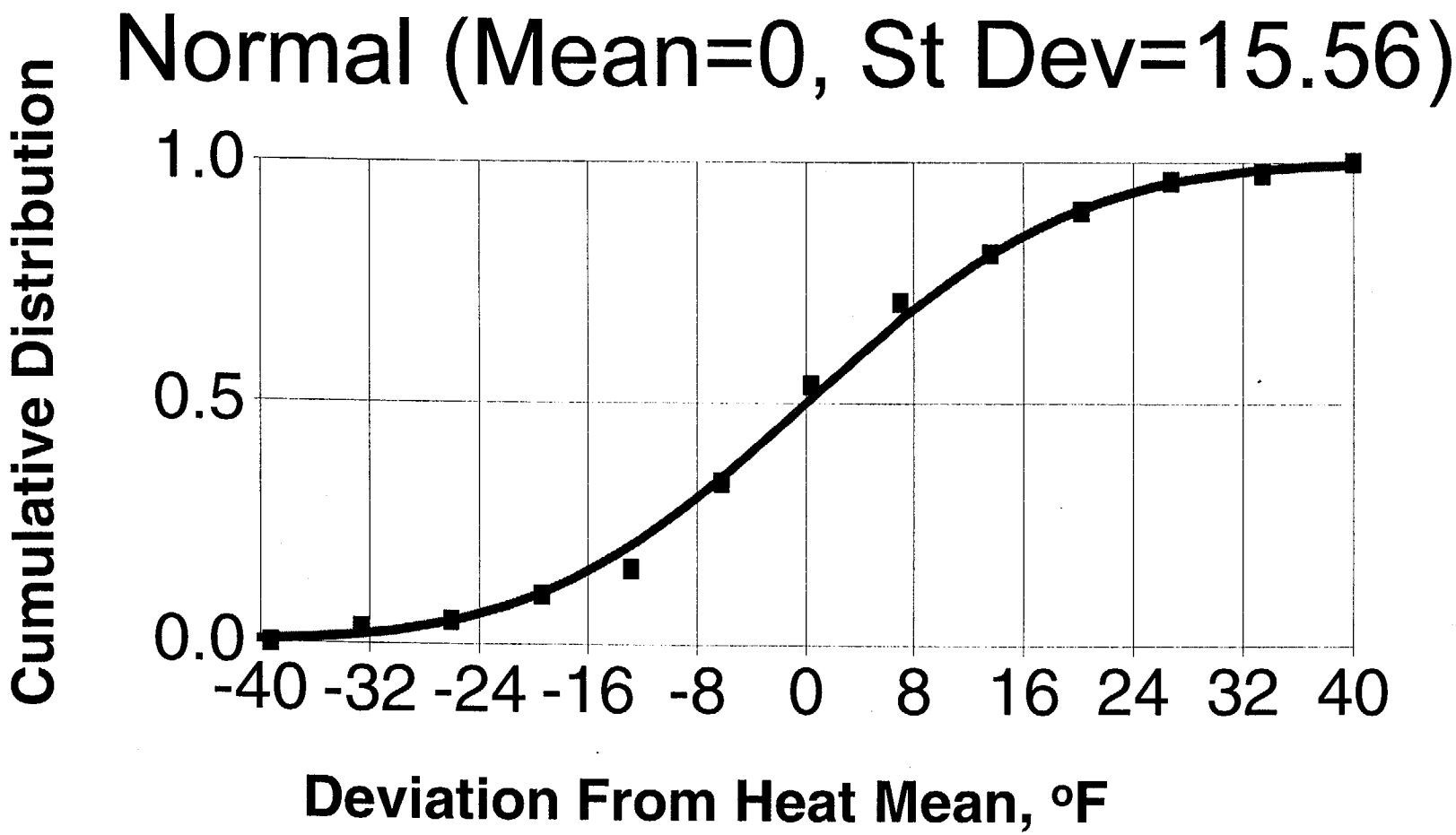

Normal (Mean=0, St Dev=16.60)
Cumulative Distribution
1.0
0.5
0.0
-50 -40 -30 -20 -10 0 10 20 30 40 50
Deviation From Heat Mean, °F

Plate RT_{NDTo}

- **Data from RPVDATA**
- **37 heats (3 or more measurements)**
  - 128 total data points
- **Same approach as Weld RT_{NDTo}**

Plate RT_{NDTo}



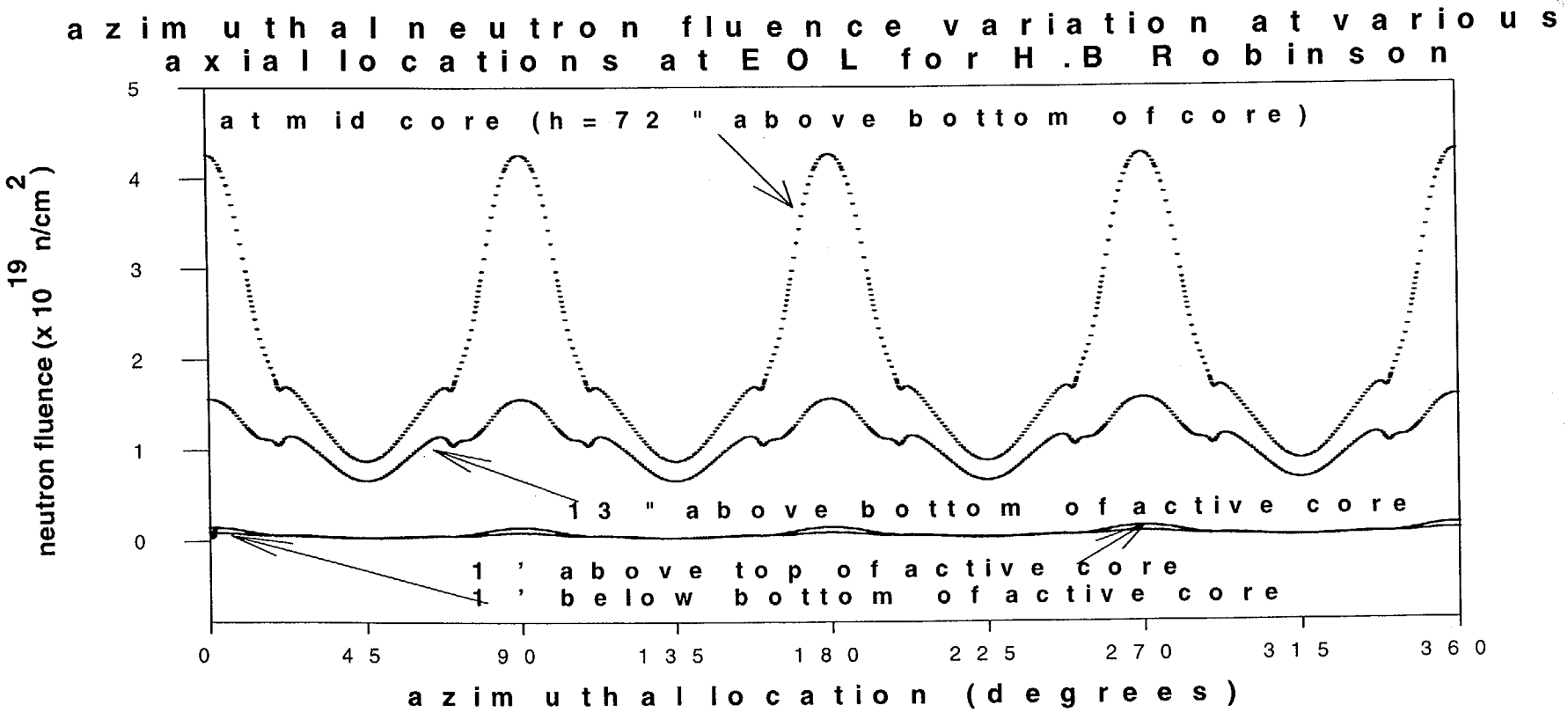
Probabilistic Fracture Mechanics Beltline Neutron Fluence Calcs.

- <u>Objective</u>:
  - Determine up-to-date EOL fluence maps for the plants using currently available cycle-by-cycle fuel loading histories
  - estimate 1σ uncertainty in fluence calculations
    - ➢Initial estimate of 1σ fluence = 15% of the mean
- Dosimetry Draft Guide-1053 (1999), and draft NUREG/CR-6115 methodology used
- <u>RES Staff</u>: Wiliam R. Jones
- <u>NRC Contractor</u>: Brookhaven National Lab.

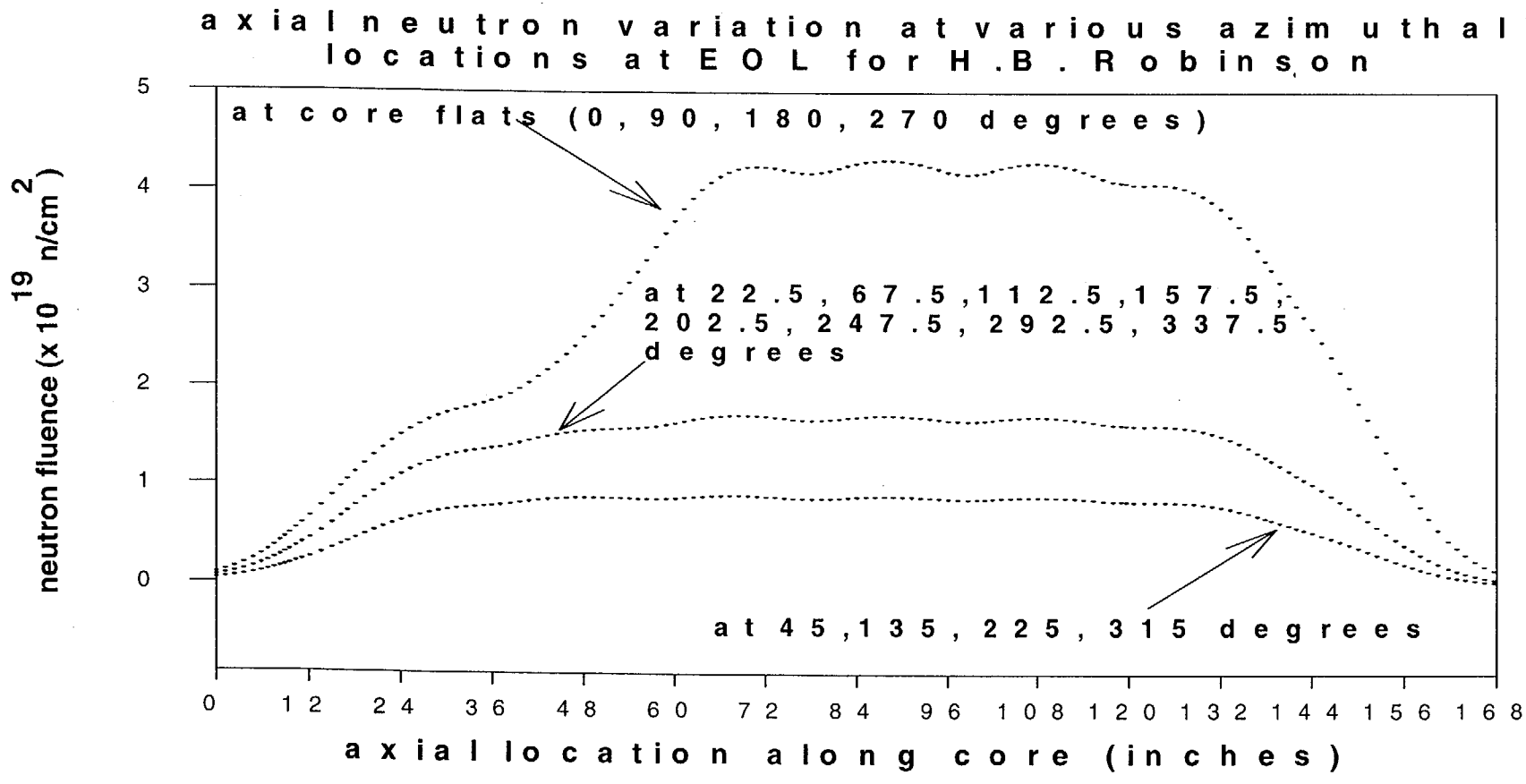
Beltline Neutron Fluence Calcs.

- Plants analyzed:
  - Palisades and HB Robinson-2 (has now opted out)
- Plants to be analyzed:
  - Oconee-1 (3/00), Calvert Cliffs-1 (7/00), Beaver Valley-1 (schedule to be finalized)
- Very refined axial, circumferential, radial grids used
  - 205 axial, 97 x 8 circum. grid for Palisades
  - 145 axial, 73 x 8 circum. grid for HB Robinson-2
- Fluence decay thru-wall, $e^{-0.24x}$, in RG-1.99 Rev. 2 is a somewhat more conservative than the calcs. (at about t/4 and greater distance from the inner surface of the vessel)

Sample Beltline Neutron Fluence Calcs.
Azimuthal Variation

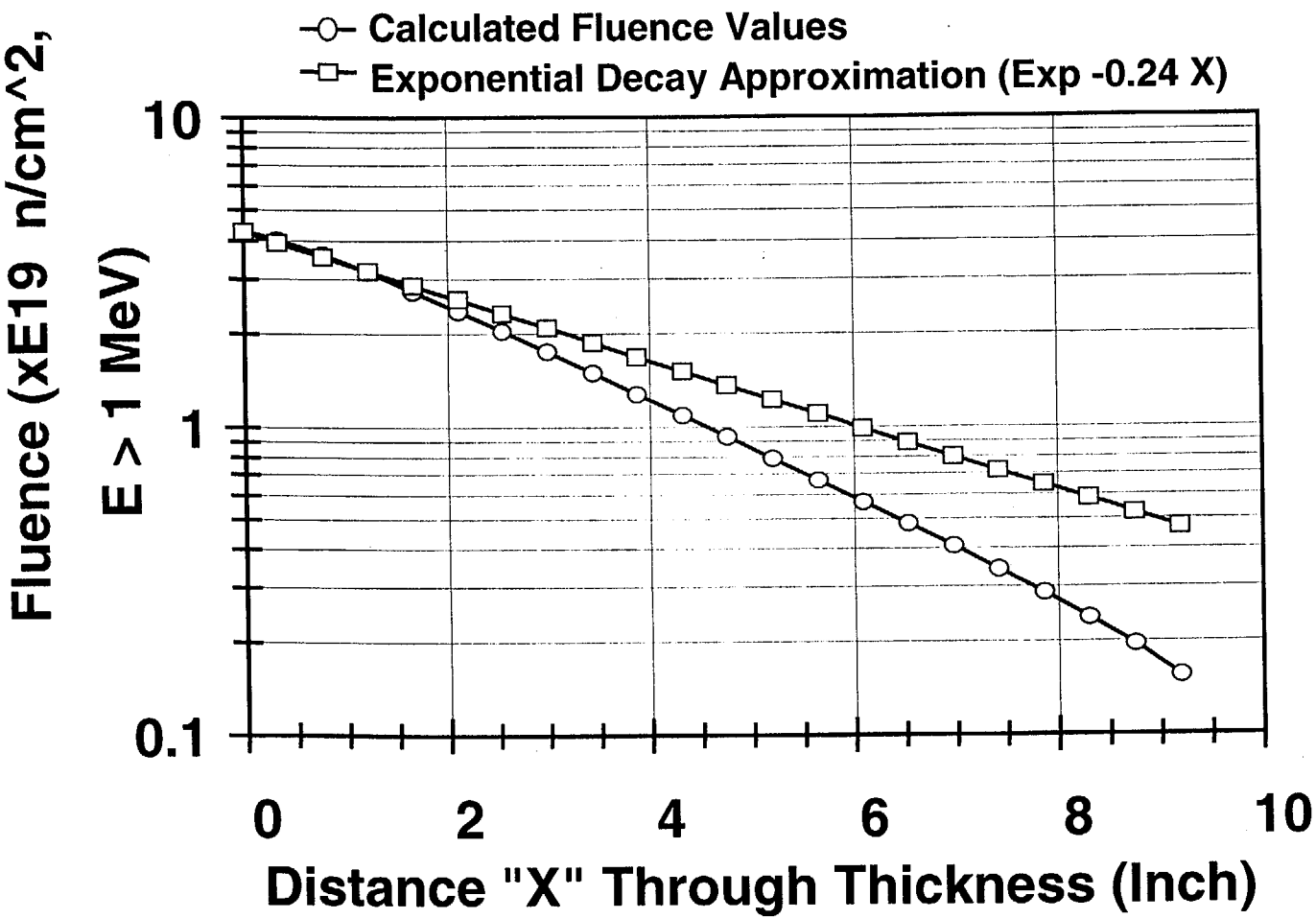


Sample Beltline Neutron Fluence Calcs.
Axial Variation



Sample Beltline Neutron Fluence Calcs.

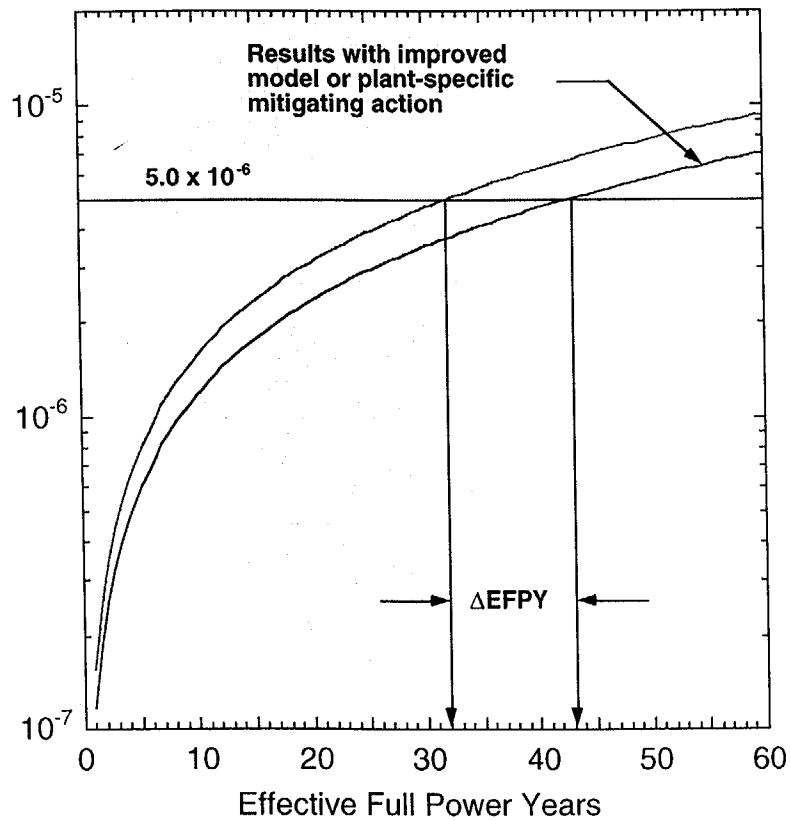
Fluence Decay Through Vessel Wall-Thickness



The Probabilistic Fracture Mechanics (PFM) FAVOR Code is Being Updated

- FAVOR (Fracture Analysis of Vessels - Oak Ridge)
- Implements refined PFM methodology and up-to-date materials data
- Makes it consistent with current PRA and thermal-hydraulics output data and methods
- Participants include
  - RES Staff: Shah Malik, Nathan Siu, Lee Abramson
  - NRC Contractors: ORNL (Terry Dickson),
    Univ. of Maryland
    (PRA: Modarres, Mosleh)

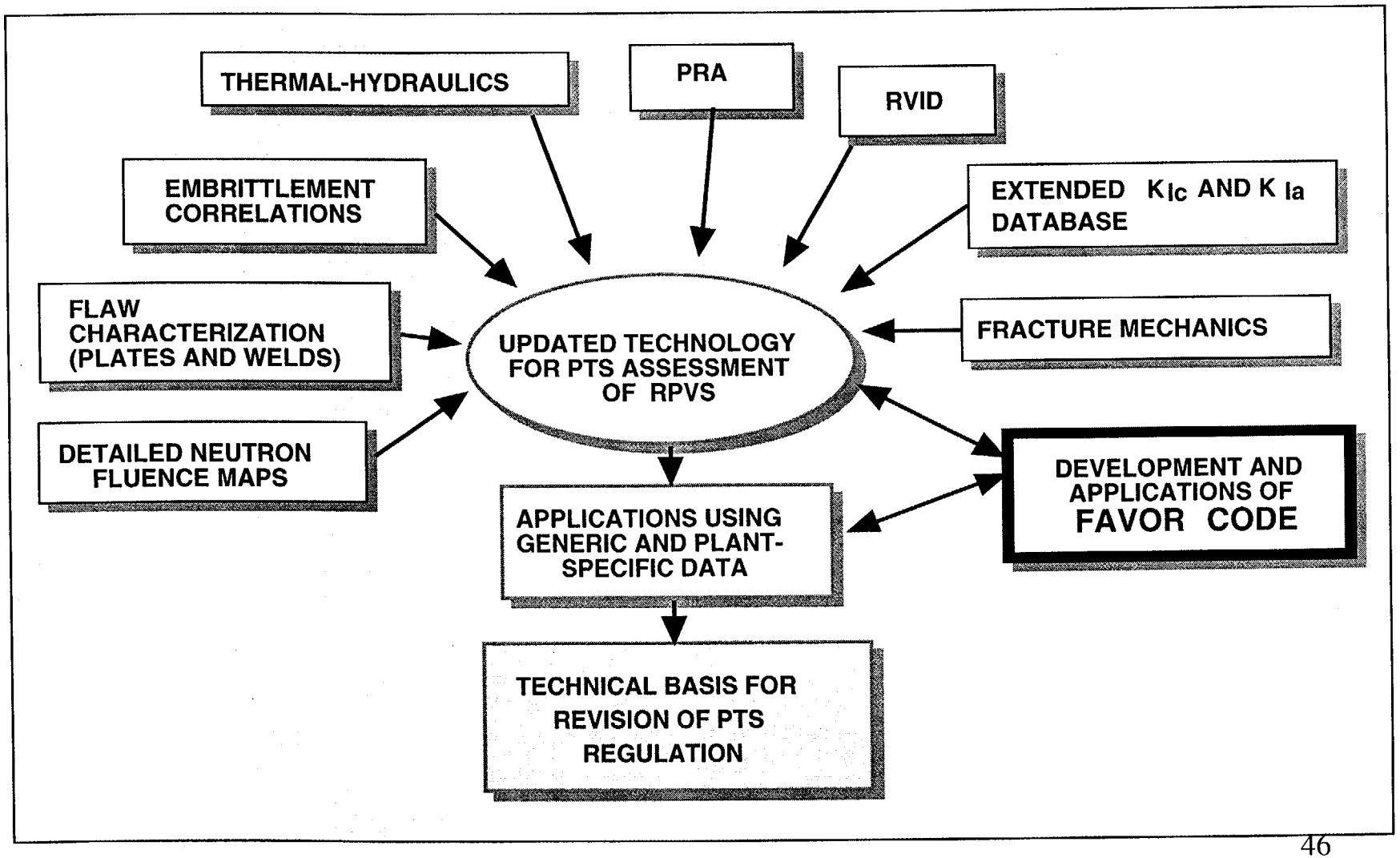
PFM Applications (via FAVOR) will Provide Answers to Two Questions



At what time in operating life does frequency of RPV failure exceed acceptable value (currently 5 x 10e-06)?

How does integration and application of advanced technology affect the calculated result?

FAVOR Code Developed for Integration and Application of Updated PTS Assessment Technology



Development of FAVOR Code Initiated After Yankee Rowe Review in Early 1990s

- Objectives: - Combine best attributes of NRC funded OCA-P and VISA-II codes into a single, validated, user-friendly, fracture code that complies with regulatory criteria
  - Incorporate lessons learned from IPTS and Yankee Rowe
- Status: - Code now in third generation (FAVOR 99.01)
- Plan: - Continue development to incorporate advanced technology derived from NRC and industry R&D

Advanced Technology is Integrated into FAVOR to Support Possible Revision of PTS Regulation

- Flaw characterizations from NRC research (plates and welds)
- Detailed fluence maps
- Embrittlement correlations
- RVID
- Fracture toughness models
- Surface-breaking and <u>embedded</u> flaws
- Inclusion of through-wall weld residual stresses

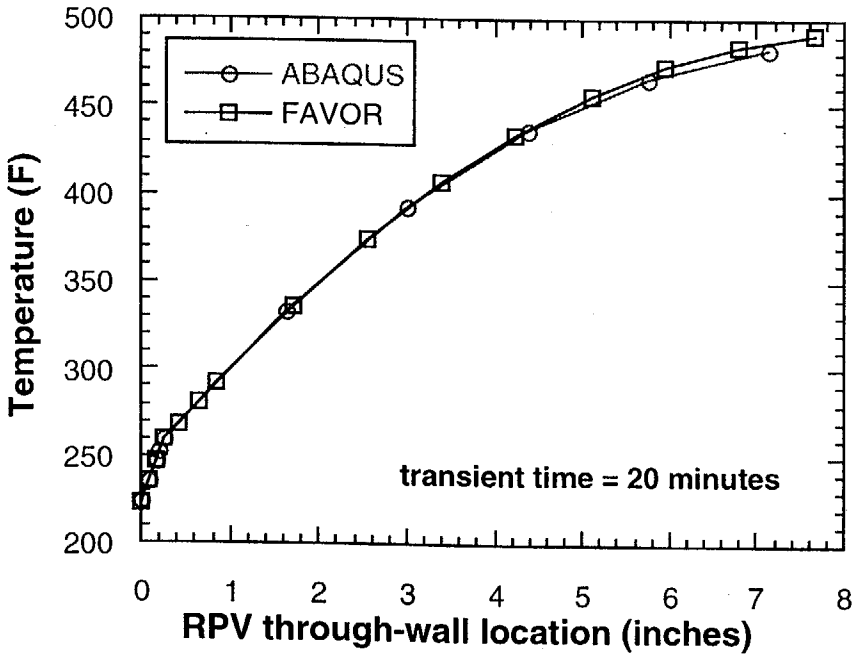
Continued Development of FAVOR is a Cooperative Effort Among NRC Staff/Contractors and Industry

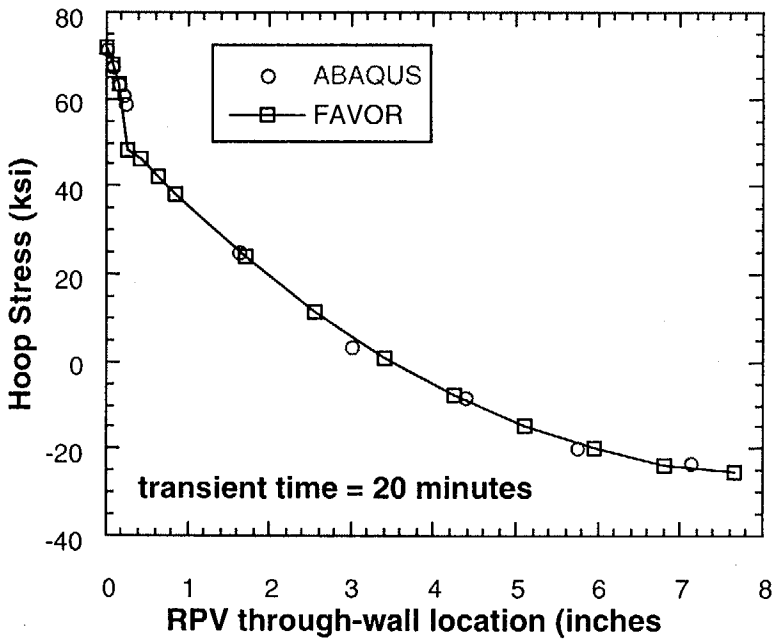
- Interim versions released to industry for application and evaluation
  - Version 9901 (October 1999)
  - Next version planned for May 2000

- Evaluations are vigorously assessed via frequent combined NRC/industry public meetings

- Goal is to gain understanding on PFM methodology

FAVOR Thermal and Stress Analysis Solutions Have Been Validated Against ABAQUS* Solutions

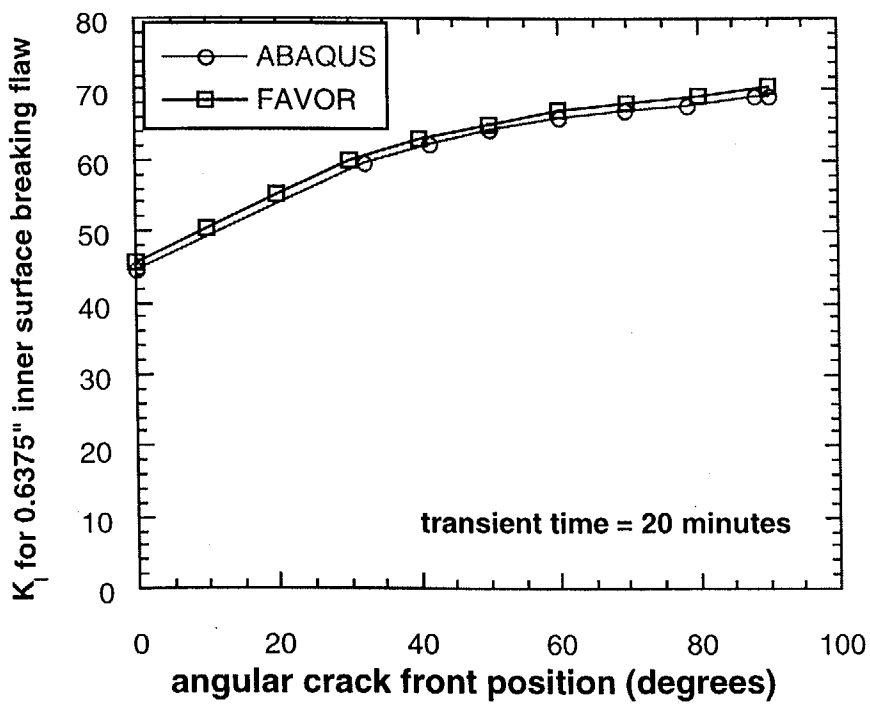




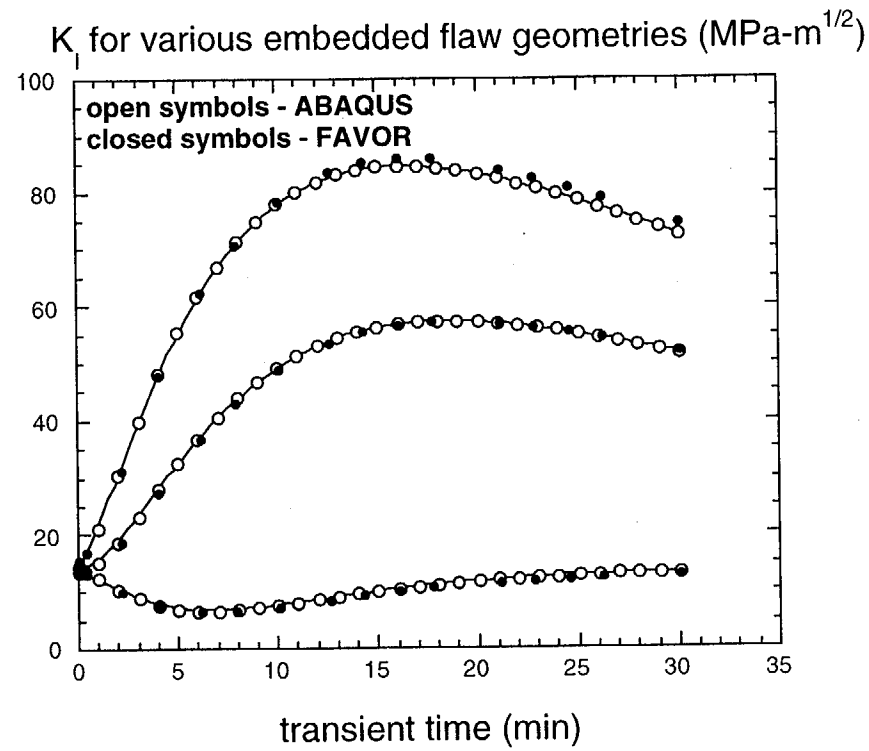
*ABAQUS is a Commercial Multi-dimensional Finite Element Code with Fracture Mechanics Capabilities

FAVOR K_I Solutions were Validated Against ABAQUS Solutions for Inner Surface-Breaking and Embedded Flaws

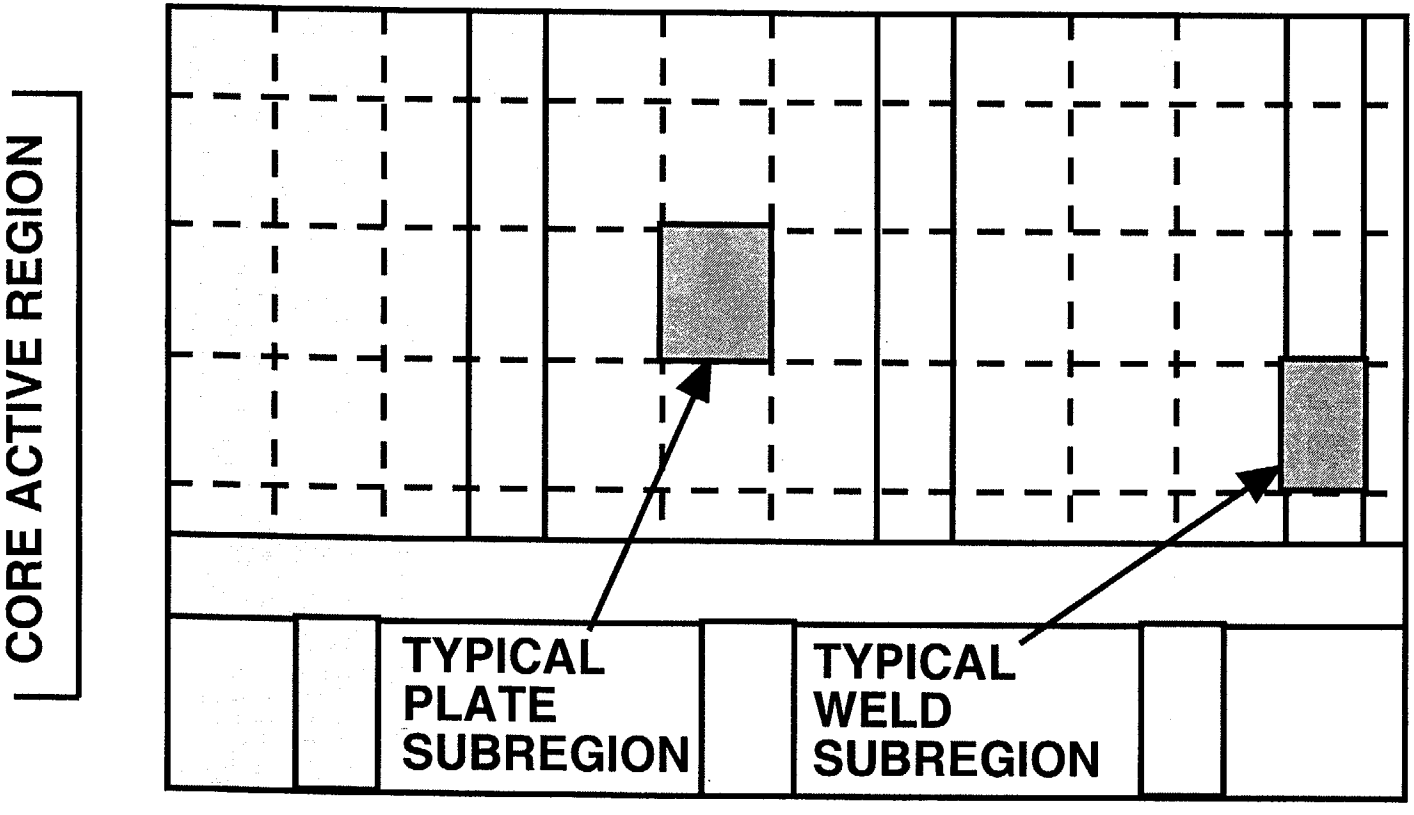
Surface-Breaking Flaws



Embedded Flaws

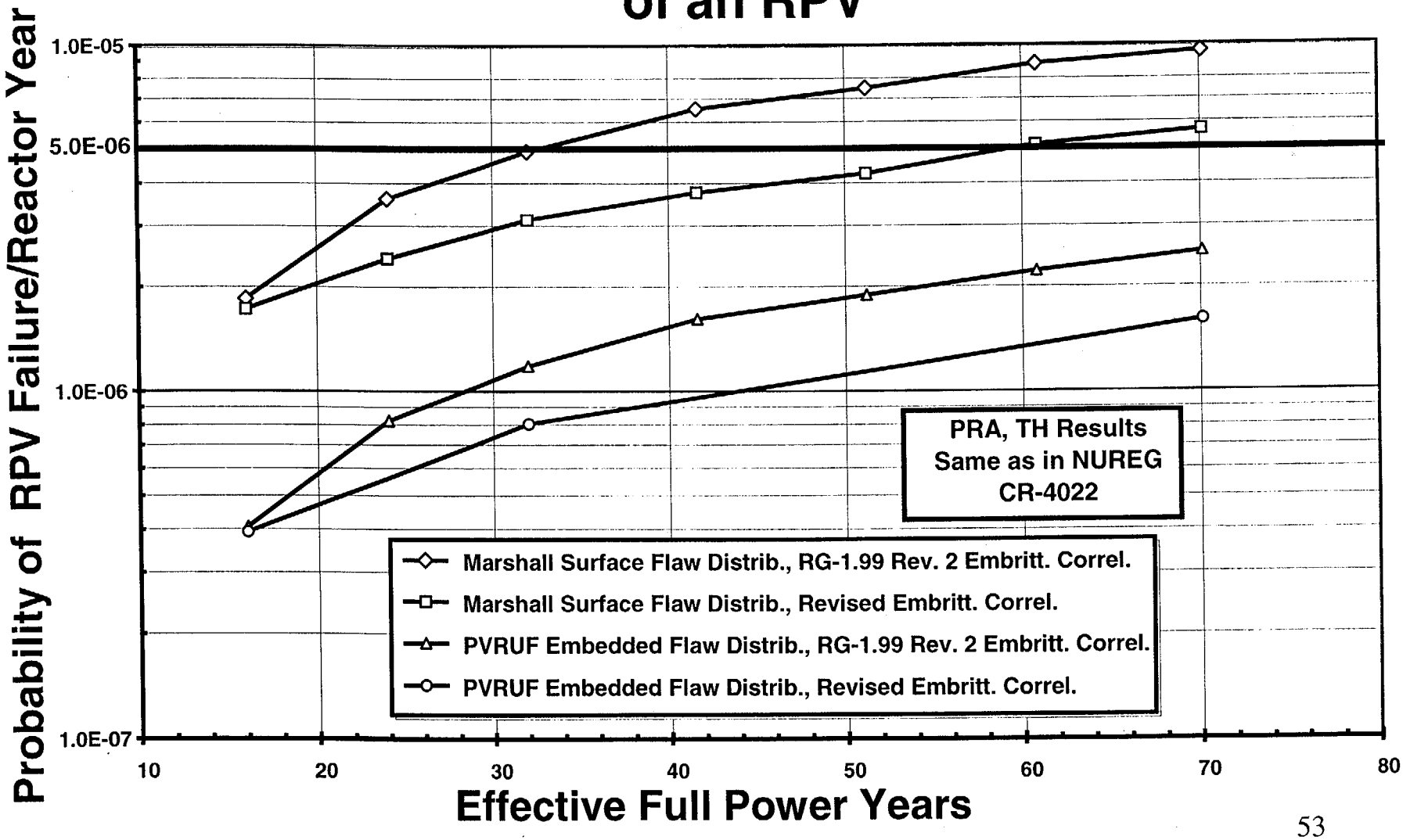


FAVOR Allows Analysts to Divide Beltline into Discrete Subregions to Accommodate Detailed Fluence Maps



TYPICAL VESSEL BELTLINE LAYOUT

An Application of Advanced Technology Shows Potential for Extending Operating Life of an RPV



Probabilistic Fracture Mechanics Concluding Remarks

- Work in various PFM technical areas continuing vigorously
- Major technical activities expected to be completed during April/May
- FAVOR code planned for release in May
- Technical enhancements to be implemented in FAVOR as they are completed
- Coordination and interaction with PRA/Risk and TH Subgroups continuing
- HB Robinson's opting-out and additional developments have moved the schedule by 2 months or so in PFM area.

DEVELOPING A GENERALIZED FLAW DISTRIBUTION FOR REACTOR PRESSURE VESSELS

ACRS Subcommittee on Metallurgy

March 16, 2000

Presented by:

Deborah A. Jackson, Division of Engineering Technology

Lee Abramson, Division of Risk Analysis Applications

Office of Research

Topics Presented

- Objective of presentation
- Background
- Approach
- Reactor Vessel Fabricators
- Reactor Vessel Material
- Expert Elicitation Process
- Concluding Remarks

Objective of Presentation

- Discuss the need for a generalized flaw distribution
- Explain the process that is being used to develop the distribution
- Discuss the status of the expert elicitation process

Background

- US NRC is re-evaluating the guidance and criteria in the Code of Federal Regulations as it relates to reactor integrity, specifically Pressurized Thermal Shock (PTS)
- Fracture mechanics calculations are used to address the consequences of transients in a commercial nuclear power plant reactor vessel
- Reactor vessel flaw distribution is an important input to fracture mechanics calculations

Background (con't)

- Fabrication process of reactor pressure vessels presents a number of variables that can have a significant effect on the flaw distribution
  - reactor vessel plate fabrication process
  - welding process

Approach Used to Develop Generalized Flaw Distribution

- Expert judgment is needed to review, interpret and supplement available information on reactor vessel fabrication processes and reactor vessel flaw distributions
- Structured expert elicitation process
- Expert panel to resolve specific technical issues for which there is significant scientific uncertainty
- Areas of expertise of experts will allow us to address all aspects of the reactor vessel fabrication process

Approach Used to Develop Generalized Flaw Distribution (con't)

- Reference documents for the expert elicitation process
  - NUREG 1150-Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants - 1990
  - NUREG/CR -5411 Elicitation and Use of Expert Judgment in Performance Assessment for High-Level Radioactive Waste Repositories - 1990
  - NUREG 1563 - Branch Technical Position on the Use of Expert Elicitation in High-Level Radioactive Waste Program - 1996

Domestic Reactor Vessel Fabricators

- Combustion Engineering - 50
- Babcock and Wilcox - 21
- Chicago Bridge and Iron - 19
- Rotterdam - 9
- Societe Creusot - 2
- New York Shipbuilding - 1

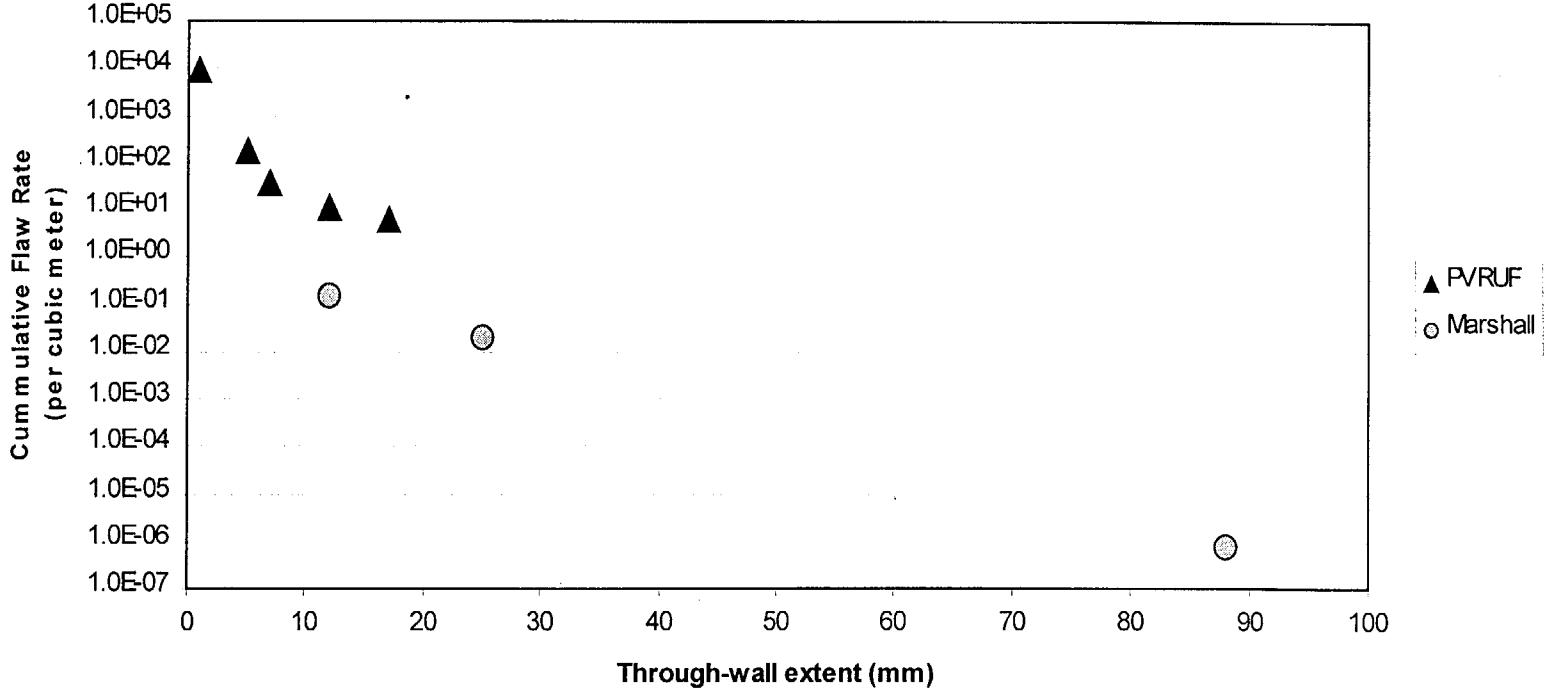
RPV Material Selected for Generalized Flaw Distribution

	Midland	PVRUF	Shoreham	River Bend 2	Hope Creek 2
Manufacturer	B&W	CE	CE	CB&I	CB&I
LWR Type	PWR	PWR	BWR	BWR	BWR
Meters of Weld	4	20	25.45	15	4
Years of Construction	1968-1974	1976-1981	1968-1974	1974-?	1972-
Fabrication Process	Circ Welds	Circ and Axial Welds	Circ and Axial Welds	Circ and Axial Welds	Circ and Axial Welds
Welds Inspected	Circ Welds	Circ Welds	Circ and Axial Welds	Circ and Axial Welds	Circ and Axial Welds
Base Metal Inspected	N	Y	In progress	In progress	In progress
NDE Inspection Completed	Y	Y	Y	In progress	In progress

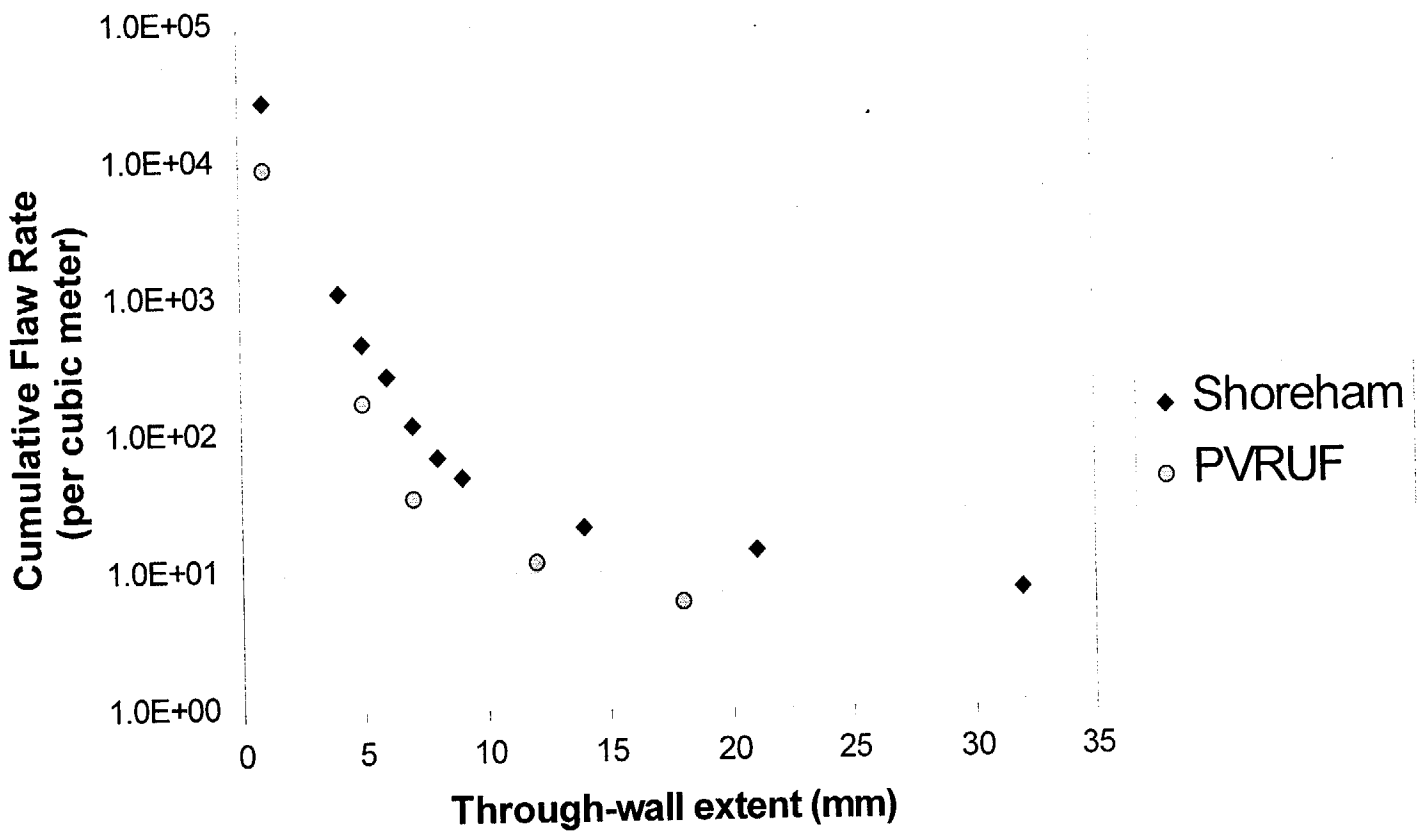
Categorization of Flaws

- Inner Region (25-mm of wall) versus outside inner region
- Volumetric versus planar
- Weld versus clad versus base metal
- Repair weld versus original weld

Comparison of PVRUF and Marshall Flaw Rates



Pacific Northwest National Laboratory Data
PVRUF and Shoreham
Size Distribution all Flaws



Expert Elicitation Process

- Define the specific issues/scope to be addressed
- Determine level of complexity
- Identify an expert panel
- Send strawman of issues to panel
- Panel meets to agree on scope, and issues
- Elicitation training

Expert Elicitation Process (con't)

- Identify elicitation team
- Elicitation of experts
- Technical facilitator integrator (TFI) processes results
- Expert panel meets to review responses and rationales
- TFI aggregates panel responses and summarizes rationales
- Publish results and rationales

Expert Panel

- US Navy
- Academia
- EPRI
- Independent Consultants
- Community of Retirees
  - Rolls Royce
  - Reactor vessel fabricators
  - Steel manufacturer
  - Supplier of welding materials

Areas of Expertise

- ASME Construction Code
- Failure Analysis
- Fracture Mechanics
- Metallurgy
- NDE
- Reactor Vessel Fabrication
- Reliability of Flawed Welded Structures
- Welding

Schedule

- ✓ Send Issues to Panel - 10/99
- ✓ Identify Expert Panel - 11/99
- ✓ Panel meets to discuss issues - 1/00
- ✓ Elicitation Training – 1/00
- ✓ Identify Elicitation Team - 1/00

Schedule (con't)

- Elicitation of experts - 2/00 to 4/00
- Technical Facilitator Integrator processes elicitation results – 3/00 to 4/00
- Expert panel meets to review responses and rationales - 5/00
- Technical Facilitator Integrator aggregates panel's final responses and rationales - 5/00
- Publish results and rationales - 6/00

Some of the Issues Presented to the Expert Panel

- Clarification of objective
- Definition of a flaw
- What is a generalized flaw distribution?
- What must be done to create a surface breaking flaw?
- Where has industry located surface breaking flaws?
- What are the differences in steel used in domestic nuclear power plants and naval vessels?

Some of the Issues Presented to the Expert Panel (con't)

- Are NDE results of pre-Hatch vessels less reliable than post-Hatch vessels?
- What are the limits of NDE in determining
  - the depth of a long surface flaw?
  - the length for a deep flaw?

First Meeting of Expert Panel

- January 19-21, 2000; Atlanta, Georgia
- Completed elicitation training
- Developed definition of a flaw
- Determined characteristics which were important to the development of a fabrication flaw

Elicitation Sessions

- Each expert meets individually with the elicitation team (normative expert, subject matter expert, and recorder)
- List of characteristics presented to each expert
- Experts identify and discuss pairwise interactions between characteristics
- For each characteristic, experts access relative effects of alternatives on the flaw distribution

Interaction Matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Product Form (Forg, Plate, Clad, Weld)														
2. Weld Processes (Automatic & Manual)														
3. Flaw Mechanisms														
4. Field vs. Shop fabrication														
5. Repairs (Weldment, Basemetal, Cladding)														
6. Weld Procedure														
7. Weld metal materials														
8. Welder skill														
9. Inspection procedure														
10. Inspector skill														
11. Base metal properties (thickness, chem,)														
12. Surface preparation parameters (geometry)														
13. Flaw location														
14. Flaw size														

Relative Assessments of Alternatives

- For each characteristic, identify that alternative with the largest likelihood of leading to a flaw
- Compare each alternative with the highest ranked alternative
- Assess relative change in likelihood of a flaw
  - High value
  - Mid value
  - Low value

List of Characteristics

- Product Form
  - forgings
  - plate
  - cladding
  - weldment
- Weld Processes
  - automatic
    - SMAW
    - SAW
    - ESAW
  - manual

List of Characteristics (con't)

- Flaw Mechanisms
  - weldment
  - base Metal
    - forging material
    - plate material
- Field vs. Shop fabrication
- Repairs
  - weldment
  - base metal
  - cladding

List of Characteristics (con't)

- Weld Procedure
  - plate to ring
  - ring to shell
  - repairs
  - cladding
- Weld Materials
  - plate to ring
  - ring to shell
  - repairs
  - cladding

List of Characteristics (con't)

- Welder Skill
  - plate to ring
  - ring to shell
  - repairs
  - cladding
- Inspection Procedure
  - forgings
  - plate
  - weldment
  - repairs
  - cladding

List of Characteristics (con't)

- Inspector Skill
  - forgings
  - plate
  - weldment
  - repairs
  - cladding
- Base metal properties
- Surface preparation
- Flaw location

Concluding Remarks

- Expert elicitation process is complex
- This process is expected to identify significant issues in the development of a generalized flaw distribution
- Combination of the relative effects of the characteristics, and the PVRUF distribution will yield a flaw distribution for any pressure vessel
- The flaw distribution may vary significantly by pressure vessel

United States
Nuclear Regulatory Commission

Potential Revisions to PTS Acceptance Criterion

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Presentation to ACRS
Materials and Metallurgy Subcommittee

March 16, 2000

Overview

- Provide status of planned Commission paper on PTS acceptance criterion
  - PTS acceptance criterion
  - More recent Commission guidance
  - More recent severe accident information
  - Potential revisions to acceptance criterion
- Plans to complete paper
- No letter requested at this time

PTS Acceptance Criterion

- PTS Rule issued in 1983 as adequate protection rule
- Established an acceptance criterion (embrittlement screening criterion), above which licensees are required to demonstrate pressure vessel safety
- Acceptance criterion is a frequency of a through-wall crack in the pressure vessel
  - Acceptable crack frequency -- less than 5×10^{-6} per reactor year

PTS Acceptance Criterion (cont.)

- Key underlying assumptions
  - Through-wall crack equivalent to:
    - large opening in reactor vessel
    - core melt
  - Containment performance not substantially impaired by PTS event

More Recent Commission Guidance

- Safety Goal Policy Statement
- Station blackout and ATWS rules
- Backfit rule
- Regulatory Guide 1.174

More Recent Commission Guidance (cont.)

- Safety Goal Policy Statement
  - Defined qualitative and quantitative goals for acceptable risk
  - Subsequent Commission decisions established a subsidiary core damage frequency goal of 1×10^{-4} per reactor year
  - Intended for generic decisions using industry-average core damage frequency and risk estimates.

More Recent Commission Guidance (cont.)

- Station Blackout and ATWS Rules
  - Developed as cost-beneficial safety enhancements
  - Used probabilistic goals for the acceptable frequency of core-damage accidents
    - Goal was 1×10^{-5} per reactor year
  - Justified on averted offsite risk basis

More Recent Commission Guidance (cont.)

- Backfit Rule (and Regulatory Analysis Guidelines)
  - Includes initial screening on potential reductions in CDF and conditional probability of early containment failure
  - Uses screening criteria based on the Safety Goal QHOs and subsidiary CDF goal
  - Uses final decision criteria based on averted public risk

More Recent Commission Guidance (cont.)

- Regulatory Guide 1.174
  - Describes a set of general principles for risk-informed license changes
  - Provides probabilistic guidelines defining acceptable changes in CDF and LERF
    - Consistent with Safety Goals and Regulatory Analysis Guidelines

More Recent Severe Accident Information

- Major improvements in understanding accident phenomenology since rule established
  - NUREG-1150
  - Direct containment heating analyses

- Impact on containment performance issues in PTS accidents
  - Dynamic loadings on core and vessel internals
  - Dynamic loadings on reactor vessel and piping
  - Containment pressure loadings
  - Dispersal and coolability of core material
  - Availability of containment engineered safety features

Potential Revisions

Alternatives focusing on core damage frequency

- Apply goals used for Station Blackout and ATWS Rules

Alternatives focusing on core damage frequency and LERF

- Develop and apply "reverse" backfit test
- Apply RG 1.174 principles and acceptance guidelines

Potential Revisions (cont.)

- Apply goals used for Station Blackout and ATWS Rules
  - Goals:
    - CDF of 1×10^{-5} per reactor year
    - Offsite consequence risk
  - Establishes consistency among three principal risk-informed rules
  - Permits increase in acceptable PTS core damage frequency
  - Includes no explicit consideration of LERF/CCFP

Potential Revisions (cont.)

Develop and apply "reverse" backfit test

- Provides most clear link between the present backfit process and a new "reverse" backfit process
  - Use or adapt Regulatory Analysis Guidelines to determine if burden reduction outweighs risk increase
- Development of reverse backfit analysis process would take significant effort
  - Adequate protection issue
  - Policy decision

Potential Revisions (cont.)

Apply RG 1.174 principles and acceptance guidelines

- Ensures consistency with current Commission policy
- Requires consideration of LERF
  - Physical process uncertainties
  - Potential for containment-specific acceptance criteria

Future Plans

- Develop draft Commission paper (March)
  - Basis for original acceptance criterion
  - More recent Commission guidance
  - More recent accident information
  - Potential revisions
    - Including discussion of containment performance issues
  - Recommendation
- Discuss with ACRS/CRGR (April/May)
- Transmit to Commission (May)

United States
Nuclear Regulatory Commission

PRA for PTS Rule Revision

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Presentation to the ACRS Subcommittee on Reactor Safeguards, Materials and Metallurgy
March 16, 2000

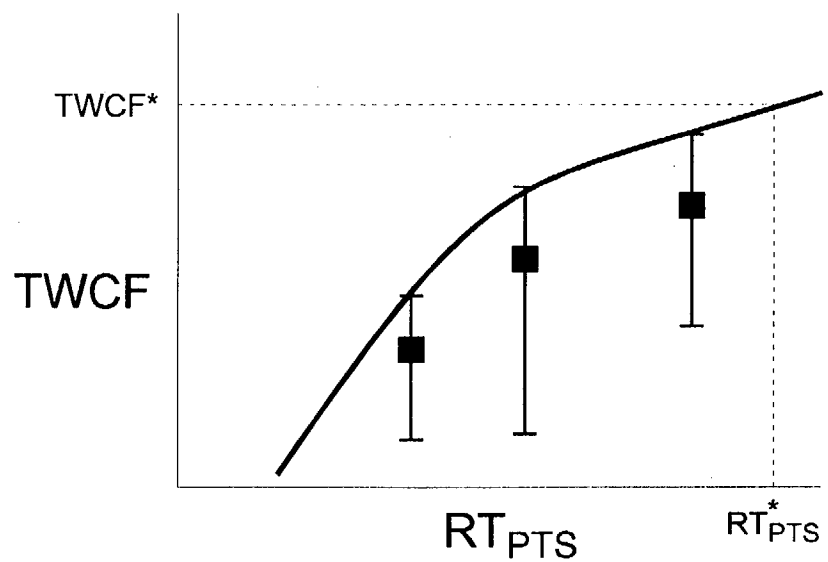
PRA Objective

Support development of technical basis for revised rule

- **Ensure overall process is coherent, risk-informed**
  - **Appropriate integration of T/H, PFM, and PRA**
  - **Consistent treatment of uncertainties**
- **Support development of screening criteria**
  - **Derivation of embrittlement criteria from risk figures of merit**
  - **Criteria for risk figures of merit**
  - **Treatment of qualitative issues (e.g., defense in depth)**
- **Update old PTS/PRA studies**
  - **Reflect changes to study plants**
  - **Reflect changes to PRA state of the art, knowledge base**
  - **Address other plants**

Overall PTS/PRA Analysis Approach

- **Estimate PTS-induced through-wall crack frequencies (TWCFs) for 4 plants, including uncertainties**
  - **Develop PTS/PRA models for Oconee and Beaver Valley**
  - **Review PTS/PRAs for Calvert Cliffs and Palisades**
  - **Resolve inconsistencies, generalize results to at-risk population**
- **Develop TWCF vs. RT_{PTS} relationship, e.g.,**



Open Questions - PTS/PRA Analysis Approach

- Treatment of internal fires and floods and external events
- Relationship of TWCF and CDF
- Treatment of LERF

PTS PRA Model Development

- Build on the original IPTS PRA analyses

- Improve by:
  - Utilizing the results and insights of the original PRA
  - More thorough review of potential initiating events and operating experience
  - Update to current plant design, procedures, and operational practices; use current reliability estimates (including initiating event frequencies)
  - Generally update to current state-of-the-art; improve on state-of-the-art in HRA

Initiating Events

Initiating Event	Oconee IPTS (events/yr)	This Analysis (events/yr)	Comments
Reactor/Turbine Trip	6	0.9	
Excessive Main Feedwater (MFW) At power Hot standby, zero power (HZP)	0.1	0.1	By itself, might be minor concern. (Likely high probability of recovery.)
Large Steamline Break (at power) Small Steamline Break (at power)	1E-3 1E-2	1.3E-2	Prototypical PTS concern
Large Steamline Break (HZP) Small Steamline Break (HZP)	N/A	TBD	Could be worse than at power case, but small exposure time.
Loss of CCW/SW	N/A	9E-4	Fails HPI and feedwater
Loss of AC/DC Bus	N/A	6E-3/1E-3	Plant-specific
Loss of Instrument Air	N/A	5E-3	Could affect MFW and TBVs
Failure of Integrated Control System	N/A	TBD	Plant-specific
Inadvertent Safety Injection	1E-2	3E-2	HPI
SBLOCA	0.1	4E-3	May be dominant contributor
MBLOCA	1E-2	4E-5	Need high RCS pressure for PTS
SGTR	1E-2	5E-3	Motivates RCS depressurization
Loss of MFW	0.5	7E-2	Depends on operator response

Human Reliability Analysis

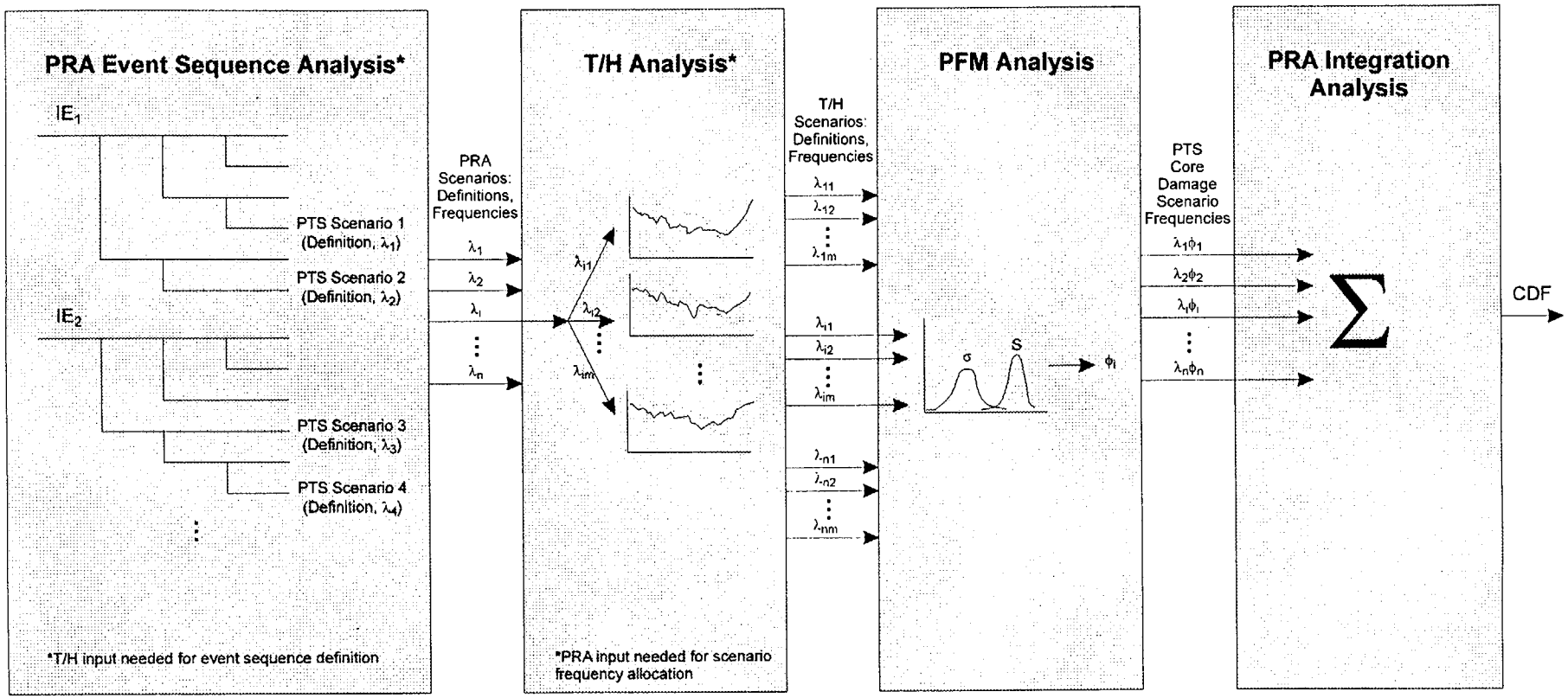
- HRA recognized to be an important source of uncertainty in previous studies

- Issue: addressing the role of operator decision making in balancing need to keep the core covered and the need to avoid overcooling the core

- Approach

  - Integrate ATHEANA methodology into PTS/PRA analyses for the NRC analyses
  - Support analysis with development of event database
  - Use results to focus reviews of utility analyses and to develop an integrated picture of TWCF

Uncertainty Analysis Framework



Note: the quantification of epistemic uncertainties in all parameters is not shown explicitly, but is assumed.

PFM Uncertainty Analysis Approach

- Identify sources of uncertainty in all model elements and categorize as being aleatory or epistemic
- Address aleatory uncertainties through T/H subscenario frequencies and conditional probability of vessel failure, given the subscenario
- Address epistemic uncertainties using standard estimation and uncertainty propagation techniques (e.g., Monte Carlo simulation)
- Assemble results using FAVOR

Thermal Hydraulic Uncertainty

- Objective: Characterize and quantify uncertainties in thermal hydraulic calculations used in PTS analysis
- Expectation: Characterization will be compatible with FAVOR requirements
  - T/H scenarios have uncertain frequencies
  - T/H scenarios have associated, deterministic pressure-time and temperature-time traces
- Planning initiated at U. Maryland under cooperative research agreement
- Approach is likely to involve considerable screening, efficient methods to propagate uncertainties
- Follow-on to PTS work may lead to a more generalized approach

Concluding Remarks

- Development of Oconee PTS PRA model is progressing well
  - Integrated PRA/HRA team is developing plant model and has visited the plant
  - Screening level results expected shortly
- Beaver Valley work is being initiated
- NRC team has received excellent cooperation from participating utilities
- Uncertainty analysis framework has been developed and is being implemented in FAVOR
  - T/H uncertainty work being initiated
  - Uncertainties in K_{1c} being analyzed