ORIGINAL ACRST-3126

OFFICIAL TRANSCRIPT OF PROCEEDINGS

NUCLEAR REGULATORY COMMISSION

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

Title: ACRS MEETING: MATERIALS AND METALLURGY SUBCOMMITTEE

PROCESS USING ADAMS
TEMPLATE: ACRS/ACNW-005

Work Order No.: NRC-1501

LOCATION: Rockville, MD

DATE: Thursday, September 21, 2000

PAGES: 1 - 247

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UNITED STATES NUCLEAR REGULATORY COMMISSION'S

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

Septmeber 21, 2000

The contents of this transcript of the proceeding of the United States Nuclear Regulatory Commission Advisory Committee on Reactor Safeguards, taken on September 21, 2000, as reported herein, is a record of the discussions recorded at the meeting held on the above date.

This transcript has 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

4 ***

5 MEETING: MATERIALS AND METALLURGY SUBCOMMITTEE

6

7

8 USNRC

9 11545 Rockville Pike, Room T2-B3

10 Rockville, MD

11

12 Thursday, September 21, 2000

13

14 The committee met, pursuant to notice, at 8:30

15 a.m.

16

17 MEMBERS PRESENT:

18 GEORGE APOSTOLAKIS, Chairman, ACRS

19 THOMAS KRESS, Member, ACRS

20 WILLIAM SHACK, Member, ACRS

21 ROBERT SEALE, Member, ACRS

22 NOEL DUDLEY, Member, ACRS Staff

23

24

25

1 PARTICIPANTS:

2 E. HACKETT, RES

3 S. MALIK, RES

4 D. JACKSON, RES

5 L. ABRAMSON, RES

6 M. KIRK, RES

7 N. SIU, RES

8 H. WOODS, RES

9 D. BESSETTE, RES

10 D. KALINOUSKY, RES

11 T. DICKSON, ORNL

12 MODARRES, UNIV. OF MD.

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1 BEGIN TAPE 1, SIDE 1:

2 [8:30 a.m.]

3 -- activities associated with PTS thermal
4 hydraulic experiments, flaw distribution, fracture toughness
5 distribution and model uncertainties, embrittlement
6 correlations, and the favored probabilistic fracture
7 mechanics code.

8 The subcommittee will gather information, analyze
9 relevant issues and facts, and formulate proposed positions
10 and actions, as appropriate, for deliberation by the full
11 committee.

12 Mr. Noel Dudley is the cognizant ACRS staff
13 engineer for this meeting.

14 The rules for participation in today's meeting
15 have been announced as part of the notice of this meeting
16 previously published in the Federal Register on September 5,
17 2000.

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

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

24 We have received no comments or requests for time
25 to make oral statements from members of the public.

1 The staff briefed this subcommittee on March 16
2 and April 27, 2000 concerning the status of the PTS
3 technical basis reevaluation project. At the May 2000 ACRS
4 meeting, the staff presented a draft Commission paper that
5 described potential options and approaches for revising the
6 PTS acceptance criteria.
7 Today we will hear presentations about the results
8 from some of the ongoing activities associated with the
9 reevaluation project.
10 We will now proceed and I call upon Mr. Edwin
11 Hackett, Assistant Chief of the Materials Engineering
12 Branch, to begin.
13 MR. HACKETT: Thank you, Mr. Chairman. Nothing
14 controversial in there. That's who I am. I guess this is
15 starting to get kind of comfortable for us.
16 We took this on as a major item. We took this on
17 as a major commitment to be briefing the committee on a
18 regular basis and we have been doing that. This is the
19 background. I think Bill mentioned this. There's been a
20 lot of encouraging developments on 99.
21 We show potential for significant burden
22 reduction, in a paper by Shaw Mallick and Terry Dixon, both
23 of whom are here. Additional developments. Thermal
24 hydraulics and PRA have occurred over the timeframe which
25 we've been looking at this.

1 And you'll hear about all of these pieces,
2 improvements in thermal hydraulic codes, testing at the APEX
3 facility for flow stagnation, which is ongoing, the context
4 for PRA, and explicit considerations of uncertainties.
5 I guess we're about a year and a half into it now.
6 The project has also been fully participatory. The original
7 plan completion, and I'll mention a little bit about this,
8 is December 2001. We're currently assessing some schedule
9 impacts. I think bottom line is we're behind that schedule,
10 but we're right now working on exactly how much.
11 Like I said, the project was fully participatory,
12 which is a pretty major departure for us from things that
13 we've done in the past, with input from key stakeholders,
14 and, obviously, within the NRC, that's principally the
15 Office of Research and the Office of Nuclear Reactor
16 Regulation, and our contractors.
17 The industry has been very active in this effort,
18 as we've talked about before, with the primary lead coming
19 from the materials reliability project for the PWRs, in
20 cooperation with EPRI, also, and the vendors. They have
21 provided probably close to half of the support for this
22 project in terms of some of what we'll come to here.
23 The plants that are participating, the
24 participation has really been all coordinated by the
25 industry and the MRP.

1 EPRI and the MRP have also been very key players
2 in the area of flaw density and distribution, in
3 volunteering materials and time and expertise in that area.
4 Debbie Jackson will probably talk about some of that in her
5 presentation.
6 The public is --
7 SPEAKER: Do they have their own codes, for
8 example, for the probabilistic fracture mechanics? Do they
9 use FAVOR, do they use VISA?
10 MR. HACKETT: They generally -- the agreement
11 previously was -- I guess I'd have to go back a ways. When
12 Mike Mayfield was branch chief, quite a while back, or even
13 section chief in Materials Engineering Branch, he had an
14 effort with Tim Griesbock, through ASME and EPRI, to
15 benchmark VISA at the time.
16 So I think the bottom line is that folks were
17 using VISA as kind of an industry NRC-wide view of looking
18 at this particular problem.
19 VISA basically evolved, of course, into what is
20 now FAVOR, and that's not quite fair to Terry. Favor is
21 much, much more than VISA was, but VISA and OKA-P, I think,
22 formed the bases for what became FAVOR, and Terry can talk
23 about some of that when he speaks later.
24 But I think there is pretty much consensus between
25 us and the industry that FAVOR is the code that will be

1 used. That's not to say there haven't been other codes that
2 people have applied. And, again, Terry could probably
3 address that better than I could.
4 But from Oak Ridge, there was OKA and OKA-P, I
5 believe, vintage mid-'80s, something like that. VISA, of
6 course, originated here with Ron Gambel and Jack Strosnider,
7 and then later versions through PNNL.
8 But the bottom line is that it's mostly been
9 standardized and I think there is agreement, the
10 NRC-industry working group, that FAVOR will be the code that
11 will be used for the probabilistic assessment, which is a
12 good thing.
13 It's like we don't need --
14 SPEAKER: You probably ought to check to see if
15 everything is still -- I say you probably ought to try to
16 check to see if there has been any divergence in that
17 expected uniformity and agreement.
18 MR. HACKETT: Right now, one of the things you
19 will here today is right now we've been focusing down on
20 getting some of these key inputs ready for delivery for
21 Terry to incorporate in the code.
22 So right now, everybody, including the industry
23 participants, is looking at getting a revised FAVOR that
24 basically we can start turning the crank on.
25 So that one has been there. I think the chairman

1 mentioned the reviews that have happened, starting with over
2 a year and a half ago and I think most recently with full
3 committee in May. I think Mark Cunningham and I were here
4 in both March and May to talk about the risk acceptance
5 criteria and other pieces.
6 You may remember that are four full-scale plants
7 being analyzed, again, with an awful lot of help from the
8 industry participants, and they are listed here.
9 The major deviation, which occurred basically
10 earlier this year, was H.B. Robinson dropped out of
11 participating in the project formally and Beaver Valley 1
12 agreed to replace them, basically, and that's gone pretty
13 well, but there were some delays associated with that.
14 Palisades has been a participant in this from the beginning.
15 The three IPTS plants, the integrated PTS
16 assessments that were done in the 1980s were Oconee, Calvert
17 Cliffs and Robinson. So we wanted to basically try to redo
18 those, and we did lose Robinson along the way, but we think
19 we've made up for that and we've made up some ground there.
20 And this is kind of where we are overall. This is
21 just big picture, and, again, you're going to hear an awful
22 lot more detail the rest of the day.
23 But the work is progressing in the major technical
24 areas pretty well. Sometimes we're an awful lot in the mode
25 of one step forward, two steps back, and trying to

1 recalibrate, and there are schedule issues, at least one of
2 which was related to Robinson dropping out and picking up
3 Beaver Valley, but there are other areas that are taking us
4 longer. It is a fairly ambitious undertaking overall.
5 I did mention this piece here, though. The
6 finalization of the materials inputs, we were hoping to have
7 completed that earlier this year. It looks like right now
8 we're hopefully on track for October-November, finalizing
9 things like the statistical distribution of the fracture
10 toughness, the embrittlement correlations, the flow density
11 and distribution, so we can get those to Terry Dixon and
12 others for incorporation into FAVOR.
13 It's a very interesting piece here that Farouk
14 Eltawila and Dave Bissette and others are working on with
15 validation of some of the thermal hydraulics work at the
16 APEX facility has been basically reconfigured to simulate
17 the Palisades plant.
18 Experiments are underway there. As a matter of
19 fact, one has been completed, and I believe there are seven
20 more that are anticipated between now and approximately the
21 end of the calendar year. So that's a major step.
22 Obviously, we're looking at conditions for flow stagnation
23 and mixing.
24 Progress in the PRA aspects, I think, was covered
25 also by the chairman. A big part of this project, of

1 course, that we stress every time is a process for explicit
2 consideration of uncertainties. We've never really done
3 that before. This has always been done as more of a
4 bounding thing.
5 There was a Commission paper completed which Mark
6 Cunningham had the lead for on the acceptance criteria in
7 July 2000. I think based on some comments from the
8 committee, that was recast to the Commission as an
9 information paper as opposed to asking for their specific
10 input at this point.
11 DR. KRESS: Can I ask you a question about the
12 uncertainties?
13 MR. HACKETT: Sure.
14 DR. KRESS: What do you plan on doing with those
15 when you get them?
16 MR. HACKETT: Well, overall, we, for the first
17 time, are looking at doing explicit uncertainty analyses of
18 each of the inputs and hoping to cascade that through.
19 Now, one of the things that's caused us some
20 hesitation or some angst over this is where we're going to
21 end up with that, and I think it's fairly --
22 DR. KRESS: That's actually my question. When you
23 get there, what are you going to do with it?
24 MR. HACKETT: When you get there, what we're not
25 going to do, I think I can say, is we're not going to line

1 up all the worst case scenarios, like we have before, and it
2 looks like maybe Nathan wants to make a comment on that.
3 But the intent was to do this -- I'll just say,
4 and then let Nathan get into some details, the intent was to
5 keep this as a, quote-unquote, best estimate analysis. It's
6 not supposed to be a bounding analysis by just the way it's
7 written in 10 CFR 5061.
8 So the intent was to try to keep this as a best
9 estimate and not go to a bounding case.
10 MR. SU: This is Nathan Su, Office of Research.
11 That's a great question. Part of the answer is we don't
12 know until we start seeing what the results start looking
13 like. If the results look like, for example, we've been
14 very conservative in the past, then we may not have to do a
15 whole lot with the calculation, just say, okay, we know how
16 to calculate the mean very well, here it is and work with
17 that.
18 Of course, we'll have a sense of the uncertainty
19 about that mean. If we're closer to -- if the risk is
20 higher than we think it is at this point, then we'll have to
21 do something about that.
22 So you're asking the general question what do you
23 do with the distribution once you've generated it and --
24 DR. KRESS: I liked one of your answers, and that
25 is that's one way, in fact, probably the only way to know

1 you've got a real mean.

2 MR. SU: Yes. And we're certainly going to do our

3 best to calculate that. But in terms of using the full

4 distribution, I guess we haven't really worked that out.

5 DR. KRESS: I was hoping it might have something

6 to do with questions of defense-in-depth and risk acceptance

7 criteria, but that's sort of another subject.

8 MR. HACKETT: That obviously needs to be factored

9 in, in a big way, and that kind of brings us to the next

10 point anyway, because we did get a fair bit of good dialogue

11 here with the committee on the risk acceptance criteria

12 through the ACRS meetings in March and May.

13 Basically, what was discussed a lot at those

14 meetings and also in the paper that Nathan and Mark and

15 others put together is a risk approach that's,

16 quote-unquote, similar to what's contained in 1.174, which

17 would obviously include explicit consideration of

18 defense-in-depth and other factors.

19 But it also has the effect, of course, in this

20 case of resetting a risk criterion that was set in, I guess

21 it's fair to say, kind of an ad hoc way originally at

22 5E-minus-six, has the effect probably of starting that

23 baseline at 1E-minus-six, and arguing from there one way or

24 the other as to which way this is going to go.

25 DR. APOSTOLAKIS: What is defense-in-depth in this

1 case?

2 DR. KRESS: That's a very good question, George.
3 I think it has to do with inspection and looking at coupons
4 and monitoring and that sort of thing.

5 MR. HACKETT: Inspection is an element. I think
6 one thing I would say, too, and I don't know how much --
7 it's a very good question. I don't know how much this is
8 actually defense-in-depth, but basically one of the things I
9 would say for this project is that you're looking at a
10 reactor vessel where you're assuming initiation of flaws
11 leading to through-wall failure, which is leading to a big
12 hole in the vessel, which is then likely going to be a
13 pretty major event for the containment to deal with.

14 So you're making those assumptions and maybe you
15 could say there is some aspect of that that involves some
16 defense-in-depth, whether all of that actually happens.

17 We know, for instance, that you can initiate a
18 crack and then arrest it. So you might arrest the crack.
19 Or you could have a crack that goes through-wall, and Mike
20 Mayfield would probably want to shoot me, but it may not go
21 to this foot-wide, 13-foot long thing, maybe it doesn't.

22 But the problem with saying that is I don't think
23 there are any of us who could quantify that. It's beyond
24 the state-of-the-art in fracture mechanics.

25 SPEAKER: Dan Marzinski told me he sees is as you

1 just get leak before break.

2 SPEAKER: It strikes me that sometimes it's

3 worthwhile to go back and recognize that there was

4 enlightenment before RG-1.174. You know, we've kind of

5 gotten jaded, I think, in our appraisal of what

6 ten-to-the-minus-six means, because generally in the context

7 of the application of 1.174, where you're comparing between

8 two alternatives, which is one of the cases that 1.174 was

9 set up for, you're still talking about relatively

10 controllable consequences.

11 By that, I mean, sure, you had a core that went to

12 hell and breakfast with TMI, but it didn't do the Chernobyl

13 thing, if you will.

14 But if you go back far enough, you recognize, I

15 think, that there were two categories of concern. One was

16 the higher risk event; that is, the risk numbers were in the

17 ten-to-the-minus-four and higher numbers. But the other was

18 where the consequences were in the extraordinarily severe

19 range.

20 I wonder if we're being very smart if we allow

21 ourselves to think in terms of ten-to-the-minus-six with

22 those extraordinarily severe consequence events.

23 It sounds to me that we're almost setting

24 ourselves up for that. We're selling ourselves a bill of

25 goods if we're not careful.

1 So I guess I'm going to be the small mind that's
2 going to provide the refuge for this idea, to paraphrase our
3 chairman, but I worry.
4 DR. KRESS: Let me ask you another question about
5 that, along the same lines. Is it considered by you guys
6 that if you have a PTS event that fails the vessel, you also
7 fail containment? Is this a LERF, as well as a CDF at the
8 same time?
9 MR. HACKETT: That's why I put up -- and I have
10 that on the last slide -- that's why I put up that last line
11 there, because when we briefed the committee earlier, and I
12 remember Dr. Kress and also Tom King was here, there was a
13 pretty good discussion that ensued over that.
14 I think the materials perspective, myself, Mike
15 Mayfield, others like that, the answer would be yes, we
16 think there would be some violation of containment
17 somewhere.
18 I think if Mike were here, he's almost of the mind
19 that he thinks it's almost for sure that -- and he's not
20 coming from the standpoint of even pressurization of the
21 containment.
22 He's saying that you now have this big jet force
23 that you put a big hole in one side of the vessel and you're
24 really pushing water and steam out and the vessel is
25 designed to radially expand anyway on the supports.

1 So you would slam the vessel into one side of the
2 shield wall. You'd be into some plant specifics about gaps
3 and so on, and that, of course, is going to drag along with
4 it the other pieces of the primary and it would almost be
5 naive to think that at some point, some containment
6 penetration isn't going to be pulled loose or something.
7 DR. KRESS: Do you have estimates for those forces
8 and things or has that been part of the problem?
9 MR. HACKETT: Dave Bissette was discussing this
10 with us yesterday. The short answer is no, I don't believe,
11 but there are estimates for things like hot leg and cold leg
12 breaks, and I suppose jet force is associated with those.
13 I'm obviously out of my depth here. Dave might be
14 able to address some of that.
15 But I think the bottom line is the expectation
16 would be that it would be enough to move the primary in a
17 significant way. But to the present the other point of
18 view, I think if Mark Cunningham were here, I think Mark was
19 looking at it as a -- trying to bound the problem.
20 If you were to be able to take a subset, well, I
21 only have X number of plants that I think I have a PTS
22 problem with anyway and let's say it just happens to be
23 they're all large dry containments and maybe I've got
24 sliding supports on the generators and things aren't as bad
25 as I've just described, for whatever reason, that maybe you

1 could make that argument.

2 And that's, I believe, where the committee was

3 coming from, that, well, at least you could consider some

4 arguments about containment integrity to set this criterion

5 5E-minus-six or even lower, if you could argue convincingly

6 that your container was so robust.

7 The problem, I guess, that we see is that making

8 that argument, I think, would be a very difficult thing for

9 a licensee to do.

10 They would probably -- if I were a licensee, I

11 think I'd say to Mr. NRC, I'd like to see a reg guide on how

12 to come argue with you about my containment integrity, and

13 then we're off into another multi-year effort of trying to

14 define that.

15 DR. KRESS: One of my interests is in risk

16 acceptance criteria and I'm very interested in this

17 one-times-ten-to-the-minus-six. My interpretation is that

18 the Reg Guide 1.174, LERF is

19 one-times-ten-to-the-minus-five, and this is one set of

20 sequences and you don't want them to add the whole thing in,

21 so a factor of ten is a good idea, maybe.

22 So that's where the one-times-ten-to-the-minus-six

23 comes in.

24 But the question I have about that, and I think

25 the committee will recognize where this is coming from, it

1 seems to me that when you have a PTS event, that what it
2 suddenly turns into is an ire ingression accident. The
3 steam is not there. It's ire coming through the openings
4 and naturally convecting.
5 Ire ingression accidents are quite different than
6 steam ingression accidents and that causes me to pause when
7 I look at the ten-to-the-minus-six as the criterion, because
8 that's based on steam oxidation driven core melt accidents.
9 MR. HACKETT: Right.
10 DR. KRESS: So I just wanted to point out I think
11 that's where that's coming from and I have a little bit of a
12 concern about that.
13 MR. HACKETT: That's a good point and it's not
14 really one we've considered. Good point.
15 This, I'll go ahead and not take up too much of
16 the time myself here, because we did cover it. Dr. Kress
17 mentioned LERF and I have that on here just in terms of
18 summary and conclusions, but this, for us, obviously, I
19 think, is the first application of sort of the new NRC
20 risk-informed methodology to revise, and we've been talking
21 around this, but what basically is an adequate protection
22 rule, which kind of puts us in an interesting space
23 philosophically, I think as Dr. Kress has been pointing out.
24 I think the progress has been good. We've tried
25 this before. This is the project that's kind of defied my

1 boss since I've known him. It's frustrated Mike for years
2 and years, Mike Mayfield, and I think he was the driving
3 force behind getting this going. So it's been going about
4 as good as it ever has here and it's a lot of credit to Mike
5 for that.
6 The consideration of LERF and containment
7 integrity is a major departure from what we've done before
8 in this area, but I think it's incumbent on us to, in this
9 environment we find ourselves in, it's incumbent on us to
10 consider these aspects.
11 I don't think it was something anyone went into
12 thinking that we're going to have a lot of fun doing this
13 maybe, but it's a valid thing to consider in the current
14 framework. And the old rule does not, obviously, get into
15 those kinds of considerations at all.
16 Another interesting piece is that this project was
17 basically marketed or sold as a licensee burden reduction
18 type of project, but I would say right now it's very much
19 complex enough that the final outcome is not entirely clear.
20 Dr. Kress pointed out the insertion of the
21 uncertainties and any kind of cascading effects, where what
22 we're building up to right now, and maybe Terry will talk
23 about some of this, is by the project schedule, we have an
24 initial scoping study run for Oconee that's scheduled to
25 complete somewhere in the December timeframe, which will

1 hopefully give us an idea of which way this vector is going.
2 We are hoping, obviously, that we are looking at a
3 relaxation of the current PTS criteria, but I think right
4 now it's fair to say it's probably too early to tell.
5 So that's basically what we're hoping to get an
6 indication of in the bottom piece. I think as far as the
7 future goes, I don't remember the exact schedule, but we
8 would probably be on the hook for coming back and having
9 further discussions with the committee by about the turn of
10 the calendar year, and we are down for a Commission paper, I
11 think, Shaw, in February of next year, that's going to be
12 addressing progress.
13 Hopefully, this type of piece would have been
14 considered by then, but we're a good ways away from that
15 right now, so that we have some schedule impacts to
16 address. But we're hoping that the next time we come
17 forward, we'll actually have some results from incorporating
18 all this good science and so on into what's actually a
19 probabilistic run for the first time.
20 So we're getting there. We're not exactly -- we
21 were hoping to be there kind of about now, but we are behind
22 in that schedule.
23 So I guess I could take any overall questions, or
24 otherwise we'll go into kind of a rundown of the three major
25 technical areas.

1 I guess, not hearing any, it looks like what we --
2 if we go in order here, I guess Roy Woods was going to come
3 on up and talk about some details of the PRA aspects.
4 SPEAKER: We'll just note that -- is
5 ten-to-the-minus-six an adequate protection rule or an
6 improved safety rule and will we have to backfit to get to
7 that level?
8 DR. APOSTOLAKIS: Right now, it's
9 five-ten-to-the-minus-six, is it not?
10 DR. KRESS: Now you're going down to one and my
11 contention --
12 DR. APOSTOLAKIS: And that would lead to further
13 reduction.
14 DR. KRESS: No, that's going the other way.
15 DR. APOSTOLAKIS: I'm confused, because I thought
16 I heard that --
17 MR. HACKETT: The intent was -- the thought was
18 there was enough conservatism in the way that you calculated
19 the screening criteria that was used to assure you got to
20 the five-times-ten-to-the-minus-six.
21 If you removed that conservatism, you would get
22 burden reduction. If you lower the criteria, even though
23 you still have conservatism, you're going both ways now and
24 it's not clear.
25 If you kept it at five-times-ten-to-the-minus-six,

1 I don't think there would be much question it would probably
2 reduce some burden.
3 DR. KRESS: Yes, but there was no real technical
4 basis for the five-times-ten-to-the-minus-six and I think
5 they were searching for --
6 DR. APOSTOLAKIS: That would depend a lot on the
7 containment.
8 DR. KRESS: It certainly would, in my mind, yes.
9 DR. APOSTOLAKIS: And I think the definition that
10 the Commission was giving to defense-in-depth and they talk
11 about multiple barriers, there is an implication of
12 redundancy. Otherwise, it wouldn't be multiple.
13 DR. KRESS: Absolutely.
14 DR. APOSTOLAKIS: So say that if the uncertainties
15 are very large, we're going to inspect such things, so why
16 defense-in-depth.
17 DR. KRESS: No, but a lot of people consider that
18 as one element of defense-in-depth. It's not your classic
19 defense-in-depth.
20 DR. APOSTOLAKIS: It's something you have to do.
21 Is the containment defense-in-depth? I don't know.
22 DR. KRESS: In this case, it may not be
23 defense-in-depth, because what we heard is that when you
24 have a PTS event, you're likely to fail containment.
25 So in an event that it fails both at the same

1 time, then the containment is not defense-in-depth for that
2 event.
3 DR. APOSTOLAKIS: Or if you need it to contain the
4 accident consequence, that is not defense-in-depth.
5 DR. KRESS: That's right.
6 DR. APOSTOLAKIS: It's not redundant.
7 DR. KRESS: No, I don't think you can --
8 DR. APOSTOLAKIS: You came up with some ideas like
9 that. Remember that? You were very happy that day. Now it
10 comes back to you.
11 DR. KRESS: You got to be careful what you say
12 around here.
13 MR. WOODS: Good morning. I'm Roy Woods. With me
14 is Nathan Su. We're with the Office of Nuclear Regulatory
15 Research, PRA Branch. Also with us Eric Thornsbury, at the
16 table. It's got a lot of the background information that
17 you will be able to tell, if you've asked that kind of
18 question, by the mad shuffling through the paper over in the
19 corner there.
20 I also want to point out that we did go through
21 and kind of practiced for this and I'm aware that there's a
22 lot of material to cover in my talk and the next two, and so
23 I'm going to try to hurry through the stuff you've already
24 heard before. If I go too fast, you will, of course, stop
25 me, please.

1 What we're trying to do, we're trying to basically
2 support the development of the technical basis for the
3 revised PTS rule and in order to do that, we're trying to
4 ensure that it's a coherent risk-informed process, with
5 appropriate integration of thermal hydraulics, PRA and
6 fracture mechanics.
7 There is a slide to follow that you've seen before
8 that shows that as a picture. We're also trying to make
9 sure we have a consistent treatment of uncertainties.
10 DR. APOSTOLAKIS: Roy, speaking of uncertainties,
11 is the paper from Maryland part of today's discussion?
12 SPEAKER: We didn't include that in the schedule.
13 DR. APOSTOLAKIS: When will it be discussed?
14 Because I have a lot of questions.
15 MR. WOODS: I thought Mohammed was going to be
16 here, but --
17 SPEAKER: He was going to listen in, but we didn't
18 have that scheduled. I know Ed Shaw --
19 MR. HACKETT: This is Ed Hackett. I guess what
20 we'll do is we'll take an action, Professor, to make that.
21 We might need to make that the subject of another meeting,
22 but we --
23 DR. APOSTOLAKIS: I think we should, because I'm
24 not sure I understand everything that is being said there,
25 and, in some instances, I'm not sure I agree, and this seems

1 to be a very important part of FAVOR because it -- I mean,
2 it characterizes the uncertainties and then propagates them
3 and so on and I thought we were going to discuss it today.
4 SPEAKER: Although, just to clarify, the status at
5 the moment is that the FAVOR works strictly on the
6 statistical correlations at the moment, right?
7 SPEAKER: I guess I need to probably here more
8 about that, Bill. Just statistical as opposed to
9 mechanistic?
10 SPEAKER: Whether the treatment of uncertainties
11 that are given in the Maryland paper, they're using the
12 statistical correlations that were developed at Oak Ridge.
13 SPEAKER: That's my understanding.
14 DR. APOSTOLAKIS: No. They go beyond that. They
15 provide --
16 SPEAKER: But, I mean, the calculation is actually
17 not using that at the moment, I don't think.
18 DR. APOSTOLAKIS: Oh, I see. So maybe there will
19 be time here for us to discuss it before the --
20 SPEAKER: Well, FAVOR, and Terry, I'm sure, will
21 talk to this, is going to incorporate the uncertainties in
22 the different ways that we said in the white paper back in,
23 I don't remember when that was issued, June or September,
24 something like that, which is -- so in particular, we're
25 deal with the aliatory uncertainties in the K1C and K1A

terms and the epistemic uncertainties and all the other terms.

So FAVOR is being set up to address that. Now, what specific distributions are going to be input to FAVOR is the point of what Maryland is doing and you're right, we haven't spoken about that to the committee.

DR. APOSTOLAKIS: But before you guys invest significant amounts of effort in here, I think we ought to have a meeting, because I'm not sure -- you shouldn't take my comments as an ominous sign that there is major disagreement, but I just don't know right now.

And by reading the paper, I get more confused than I was before I started and I don't like that.

SPEAKER: Actually, I'm confused about that, too.

DR. APOSTOLAKIS: It's tough going, I'll tell you, and I'm no sure I agree with the calculation scheme that is proposed and given the emphasis that you guys have placed on uncertainties and consistent treatment and so on, I don't see it there.

SPEAKER: That's just self-defense. We keep beating them over the head with uncertainties. They've got to do some treatment of it.

DR. APOSTOLAKIS: Yes.

SPEAKER: But I went back to read Nathan's white paper and it seemed to me that the way FAVOR now treats the

1 K1 distribution is purely aliatory.

2 DR. APOSTOLAKIS: And it shouldn't be.

3 SPEAKER: And it shouldn't be. Maryland is an
4 attempt to go the other way, but I got confused as to --
5 just to get off the subject a little bit. Somehow I would
6 pick those K1 curves. I see a family of curves in between
7 there.

8 SPEAKER: Yes, and -- you're right and --

9 SPEAKER: You would pick one of those curves and
10 that's really an epistemic, because I don't know which of
11 those curves to pick. But once I pick a curve, I'm
12 following along that curve. I'm not walking up and down
13 that whole distribution.

14 SPEAKER: Right, right, right.

15 SPEAKER: And FAVOR now doesn't do that, as I
16 understand it.

17 SPEAKER: I guess maybe -- I don't know, Terry, if
18 you were planning -- I didn't think we were going to get
19 into that depth in this particular presentation, even though
20 --

21 SPEAKER: Actually, it used to take a curve and --

22 SPEAKER: That's because you picked a lower bound
23 curve.

24 MR. DIXON: I'm Terry Dixon, from Oak Ridge
25 National Laboratory. The way that -- before the University

1 of Maryland got into being our advisor on this, we did, in
2 fact, pick one curve and we sampled from a Galsion
3 distribution to determine which one of those curves and then
4 we followed that curve down through the cool-down.
5 Now, as you said, Dr. Shack, we don't do that. We
6 actually, at a given moment in time or, in other words, a
7 particular T-minus-RTNDT, we are dealing with the
8 distribution at that vertical slice through T-minus-RTIT.
9 DR. APOSTOLAKIS: So you've selected already a
10 curve, but it would be epistemic, because you are selecting
11 --
12 SPEAKER: No. It seems to me purely aliatory.
13 DR. APOSTOLAKIS: Aliatory, yes.
14 SPEAKER: The idea or at least -- and Professor
15 Maderas can speak to this better than I can -- doing this
16 method introduces the aliatory uncertainty.
17 SPEAKER: I would have thought that you would have
18 had a curve with a small scatter band around it to take care
19 of the aliatory part, but to treat the whole scatter as
20 aliatory seems to me to be incorrect.
21 DR. APOSTOLAKIS: I think we're going to get into
22 this, but I really think -- in fact, let me ask you. Is it
23 possible to have a discussion here where you will walk us
24 through a detailed calculation based on figure six of the
25 Maryland paper?

1 SPEAKER: I intend to this afternoon in my
2 presentation.
3 DR. APOSTOLAKIS: Today. Well, I won't be here
4 this afternoon, but this is for -- I mean, I want a
5 detailed, how do you pick things, then what do you keep
6 track of. Do you really start by selecting a vessel? What
7 does that mean?
8 DR. KRESS: That's just a figure of speech.
9 DR. APOSTOLAKIS: Yes, but there is a distribution
10 and so on. No, but I really would like, because there are
11 two uncertainties here that we have to keep track of.
12 SPEAKER: Well, I like Nathan's paper, where you
13 have an epistemic loop and an aliatory loop, and I'd like to
14 know what's in the epistemic loop and what's the aliatory
15 loop.
16 SPEAKER: Yes.
17 DR. APOSTOLAKIS: So how does figure six in the
18 Maryland paper --
19 SPEAKER: I think we need to walk you through that
20 and, again, as Tom pointed out, this is a nomenclature,
21 picking a vessel, to fix the epistemic parameters. But,
22 again, we --
23 DR. APOSTOLAKIS: That's not my problem.
24 SPEAKER: I know.
25 DR. APOSTOLAKIS: But following the loops, I think

1 that's --

2 SPEAKER: Right, right. And this has been a point

3 of discussion among us for a while, trying to make sure we

4 got it right, and we do need to talk with you about that.

5 SPEAKER: Some have actually floated back and

6 forth in FAVOR.

7 SPEAKER: Yes. And I intend to talk at some level

8 of detail this afternoon about this.

9 SPEAKER: And conceptually, again, we had every

10 intention of addressing the epistemic uncertainties in the

11 aliatory distribution. Now, whether we're doing it right,

12 that's worth discussing.

13 MR. HACKETT: I think what we can commit to do --

14 this is Ed Hackett, of Research, again. We'll take an

15 action to make that happen, because I think that would be a

16 very useful thing to do.

17 I guess I would also just mention that later

18 today, Mark Kirk will be giving a presentation, wherein he

19 was going to at least attempt to cover conceptually the

20 breakout, aliatory and epistemic, in the statistical

21 evaluation of fracture toughness, because that -- I think

22 the committee is absolutely right.

23 That has not -- model uncertainty has not been

24 addressed in that area before and we're attempting to do

25 that now for the first time. I think what's been in there

1 has been pretty much all aliatory so far.

2 So we'll take an action to address that

3 separately, but maybe some of what Mark will talk about this

4 afternoon will at least try and conceptualize.

5 DR. APOSTOLAKIS: So it's possible to go through

6 one loop, the calculational loop, that would be extremely

7 useful.

8 MR. WOODS: Okay. I'm going to continue on with

9 the second bullet here then and I'm going to skip over most

10 of it. I thought we'd get hung up on the second one, but

11 that already happened with Ed.

12 Obviously, we're trying to develop a new screening

13 criteria and it will be based on something like RTP or TS,

14 embrittlement parameter, and also on the figures of merit,

15 which would be CDF, and maybe LERF, and also what the

16 acceptance criteria for the CDF or the LERF value would be,

17 which is kind of a separate thing that we weren't prepared

18 to talk about today.

19 DR. APOSTOLAKIS: Incidentally, on the previous subject,

20 Bill mentioned Nathan's paper and I also -- I read it some

21 time ago, but I also read the Maryland paper and the paper

22 by Dixon and Mallick.

23 Is it possible, in the future, that you guys make

24 sure you refer to each other, cite each other, and make sure

25 that the stuff is consistent, instead of throwing in a

1 reference, Nathan Su, and then we don't see any connection
2 to Nathan Su.
3 It would be very useful, in other words, if these
4 things are coming from the same project, to have some
5 consistency. That's not a major thing, but it's knowing.
6 SPEAKER: I think what you're saying, it's partly
7 a function of -- you know, we're hot in the development
8 process.
9 DR. APOSTOLAKIS: Right.
10 SPEAKER: We are certainly intending to document
11 how we deal with uncertainty in PTS in a specific report
12 that will address that, and it will basically, as I see it
13 right now, be an expansion of the white paper.
14 So we'll talk about how we're dealing with it in
15 thermal hydraulics, how we're dealing with it in PFM, how
16 we're dealing with it in HRA and so forth, and put it all
17 under this consistent framework.
18 But I guess we didn't think about doing that early
19 on, but, yes, you're right. We're holding meetings and
20 talking, but we're not necessarily documenting that in what
21 you see.
22 DR. KRESS: The risk acceptance criteria have been
23 worked on by the Risk Analysis Group rather than the group
24 you guys are in. Is that a different, sort of a separate
25 project?

1 SPEAKER: They are us, yes.

2 DR. KRESS: They are us. Okay.

3 MR. WOODS: Okay. Well, the last bullet I think
4 everybody is probably aware of. We started with the IPTS,
5 the plants that Ed mentioned. We're trying to reflect
6 changes to those plants. In fact, one of the plants itself
7 changed, Beaver Valley instead of H.B. Robinson.

8 Also, the very last thing on that slide, we
9 obviously have to get our arms around the risk from all the
10 plants, based on the analysis of four plants.

11 I'm going to just show this next one, but I think
12 everybody has seen it. This is the basic framework. You
13 start with identifying the PTS event scenarios that you're
14 worried about with a fairly standard PRA.

15 I'm going to show you an event tree in a minute,
16 and that defines which thermal hydraulic analysis you need.
17 You'll group certain events into a group and use one thermal
18 hydraulic analysis for all those events.

19 And the ultimate objective is to do the
20 probabilistic fracture mechanics and what you're showing
21 here is you're not certain of what the stress would be from
22 a given event and there's also some uncertainty in the
23 strength of the material, but you're interested in this
24 little area right here, which would be the area where indeed
25 the strength of the material is less than the stress that

1 you put on it, and that area would be an indication of the
2 failure.
3 DR. APOSTOLAKIS: You are using the K's there
4 along this line, right?
5 SPEAKER: Correct.
6 DR. APOSTOLAKIS: K is less.
7 SPEAKER: That's right.
8 SPEAKER: Not directly, yes.
9 DR. APOSTOLAKIS: So all this now is the aliatory.
10 SPEAKER: That's correct.
11 DR. APOSTOLAKIS: And probably you will put the
12 epistemic.
13 SPEAKER: That's correct.
14 DR. APOSTOLAKIS: I like this figure much better
15 than figure six in the Maryland paper, although Maryland
16 tries to go through more detail, but if -- that's what I
17 mean by coordination. If they could refer to this and then
18 start developing the algorithm referring to this, that would
19 be a much better -- by the way, why do you use lambda? Do
20 you imply a rate?
21 SPEAKER: These are frequencies of the particular
22 thermal hydraulic scenario classes.
23 DR. APOSTOLAKIS: They are rates.
24 SPEAKER: They are definitely frequencies, yes.
25 You're ending up with a through-wall crack frequency at the

1 end.

2 DR. APOSTOLAKIS: Okay. But the aliatory part

3 here would be the occurrence of the sequence, something in

4 the thermal hydraulic, although I don't see how much

5 aliatory you can have there.

6 SPEAKER: That's a function of the -- that's

7 intended -- the primes indicate that you're taking the PRA

8 event frequencies and then you bend them, so you have a

9 different frequency, but it's still aliatory.

10 DR. APOSTOLAKIS: Then on the other side, the way

11 I understood it is it's primarily the material variability

12 that contributes to the aliatory part.

13 SPEAKER: That's where -- again, the variability

14 is largely the epistemic part, because we're looking at a

15 specific spot in a specific vessel and looking at the

16 characteristics of that point there.

17 The aliatory part comes in the K1C, K1A, and

18 that's, again, why we need to have this discussion about how

19 --

20 DR. APOSTOLAKIS: The variability in K is due to

21 material, isn't it? That's what it says here.

22 SPEAKER: That's sort of my gut feeling.

23 SPEAKER: No. The point is that if you fix -- how

24 far do we want to go into this, because --

25 DR. APOSTOLAKIS: We don't have to go into it.

1 DR. KRESS: It's materials and how you do the
2 measurement.
3 SPEAKER: Since George is leaving, maybe you could
4 spend a few minutes on it. He's not going to be around for
5 this afternoon's discussion, which is a better place for it.
6 SPEAKER: The argument in the original white paper
7 was that even if you knew your material properties
8 precisely, and it's knowable because you're at a specific
9 spot in the vessel, you're at the location of the crack tip.
10 So you could know those properties, but you're uncertain
11 about that.
12 And, yes, there are all sorts of uncertainties
13 that go into your distribution for quantifying that
14 uncertainty. So it's actually a transformation from the
15 aliatory uncertainties when you measure to an epistemic when
16 you're applying it in the calculation. It's all in the
17 context of the calculation.
18 But even if you know those properties, some
19 fraction of the times, your model will predict something and
20 it will be right, some fraction times will predict something
21 that will be wrong, basically failure or success of the
22 vessel.
23 And it's that fraction that's accounted for by
24 this P here.
25 DR. KRESS: K is not a perfect predictor of when

1 the vessel will fail.

2 SPEAKER: Exactly. That's the concept we're

3 trying to bring forward here.

4 DR. KRESS: In that same context, I know it's

5 illustrative, but the temperature on the thermal hydraulic

6 analysis, that's the temperature at the crack location as it

7 grows, at the tip?

8 SPEAKER: This is the downcomer temperature.

9 DR. KRESS: Oh, it's the downcomer.

10 SPEAKER: It's the environment temperature.

11 DR. KRESS: I see. You would put that in your

12 calculation of temperature.

13 SPEAKER: Exactly. The heat transfer is done.

14 DR. KRESS: You'd do another calculation.

15 SPEAKER: That's right, yes. Again, this is just

16 what the RELAP code will produce, for example.

17 DR. KRESS: That's the downcomer temperature at

18 the location you suddenly --

19 SPEAKER: That's right.

20 DR. KRESS: -- selected that we're looking at.

21 SPEAKER: That's right.

22 MR. WOODS: You'll probably see that one again.

23 It serves its purpose very nicely. Okay. The status of

24 where we are.

25 We are well into the Oconee and Beaver Valley PRA.

1 We've developed event trees, starting from the IPTS studies.
2 You remember we did Oconee before and we didn't do Beaver
3 Valley before, but H.B. Robinson is similar enough, so you
4 can start with those event trees.
5 We're using generic initiating event frequencies
6 and top event split fractions from industry data to focus
7 and develop and decide where to work on the model.
8 We are developing the fault trees for Oconee,
9 where you have data for the top events. In other words,
10 instead of just putting in a feedwater system fails, if you
11 have enough data to support what part of it failed, then you
12 would want to develop a fault tree to use that data.
13 We are putting in potential human failure events
14 developed from the Athena team and the quantification of
15 these things is currently ongoing.
16 We could give you more details, but I'll try to
17 leave it with that.
18 The other two things we intend to do are to review
19 the analyses that are done by the licensee for Palisades and
20 Calvert Cliffs and at the moment, what we're doing, we've
21 collected a great deal of information from Palisades and
22 some information from Calvert Cliffs, reason being we're
23 going to do Palisades next after Beaver Valley, and we are
24 assessing basically the adequacy of the information, but we
25 really haven't reviewed, started the detailed review of

1 those plants.

2 Now, before I get to the next slide, I want to

3 tell you, please, you're not supposed to try to read this.

4 I do have a magnifying glass in my pocket that we might have

5 to use to read it.

6 But the objective of showing this slide is to show

7 you that -- I think I can stand up here. This is part of an

8 event tree. It's not even the whole event tree. This is

9 the event tree for the initiating event and reactor trip,

10 and this is reactor trip and it trips.

11 Then across the top we have all the different

12 things that can happen or not happen and you probably can't

13 even read that, but the point is -- one point I want to make

14 here is we are developing, in further detail, a different

15 part of the tree from what you're used to probably, because

16 we're worried about pressurized thermal shock, which is an

17 over-cooling event.

18 Usually, when you do one of these event trees,

19 you're worried about core damage directly from failing to

20 provide cooling.

21 So you tend to develop the top side of the event

22 tree, where you have what normally would be successors, like

23 the HPI comes on, but it stays on and normally that would be

24 fine, but you need to develop that further to analyze the

25 over-cooling.

1 And what I'm going to do with the next three
2 slides, I think it is, is show you the details of this
3 slightly darkened path, if I can follow it. It goes on over
4 here and ends up on 14 or 15, whichever one we decided, but
5 to kind of walk you through that.
6 SPEAKER: Now, just from your comment there on
7 success in the normal PRA, are you arguing that many
8 conventional PRAs then don't pay enough attention to the PTS
9 event?
10 MR. WOODS: Conventional PRAs may not even include
11 risk from PTS at all.
12 SPEAKER: Okay. Because you're assuming it's
13 screened out.
14 SPEAKER: Because embrittlement is not an issue.
15 SPEAKER: Yes. As long as you're not embrittled,
16 who cares.
17 MR. WOODS: It's a good point, but they're not
18 there at all. They're not there at all.
19 SPEAKER: So you really have to develop these
20 event trees yourself.
21 MR. WOODS: Yes.
22 SPEAKER: You can't get them from the plant PRA.
23 MR. WOODS: That's the point.
24 DR. APOSTOLAKIS: They start with the plant.
25 SPEAKER: They start with it.

1 MR. WOODS: That one was developed from -- I just
2 took it down, but --
3 SPEAKER: If I could comment. We certainly use
4 the plant PRAs to the extent we can, but a lot of the
5 information comes from the earlier IPTS studies, which did
6 develop event trees, and we've expanded on those and
7 customized them for the studies we're doing.
8 MR. WOODS: I wanted to mention this, 163 end
9 states, you can't read that number, but that's what it says.
10 And this is only part of this one tree, because this
11 particular thing is turbine bypass valves sticking open.
12 This is none, one, two, and four.
13 So these two lines would lead to equal size -- each of them
14 would lead to an equal size of what's shown there and then
15 this has to do with the PORV or the primary side safety
16 valves sticking open, one or the other. So here's two more
17 lines that would lead to something that looks like that.
18 So that's a fourth or less of that one event tree.
19 DR. APOSTOLAKIS: So this is not a binary tree
20 anymore.
21 SPEAKER: Correct. That's correct.
22 MR. WOODS: And that's one of like six to eight
23 event trees, depending on which plant you're talking about.
24 There's one for steam line break and LOCA and whatever, in
25 addition to this tree.

1 DR. APOSTOLAKIS: So where in the tree do you have
2 human actions that ATHENA will come in to help?
3 MR. WOODS: That's coming up. That's why we
4 wanted -- one of the reasons we wanted to work through one
5 of these.
6 Now, this is the part that I showed you that was
7 highlighted and the next two slides have the words, some of
8 the words that I intend to use describing this. So I'm
9 really using three slides at once here.
10 But walking through this, I think I can point
11 better if I stand up. Okay. You start with a trip and the
12 first question is does a PORV or a safety valve on the
13 primary side stick open, and the one that we've chosen to
14 use as an example, we say that it doesn't. It's okay.
15 So having decided that it doesn't -- I mean, it
16 doesn't open; so, therefore, it can't stick open, so it just
17 goes straight through here.
18 But we do say that one turbine bypass valve sticks
19 open. You know, the turbine bypass valve would stock open
20 on a trip, in a turbine trip, because you've got to dump the
21 heat somewhere. So it's supposed to open, but it's not
22 supposed to stay open.
23 So we say that one sticks open and the operator
24 doesn't isolate it. Now, there's the first human event that
25 you have to look at.

1 And in this particular case, the ATHENA team
2 returns a table to the PRA analyst that says, okay, here's
3 the probability that he won't isolate given that there's no
4 other complicating factors in the plant or given that
5 something else is going on that might distract him or
6 mislead him or whatever, or several things maybe.
7 You might have two or three different numbers,
8 depending on the -- you choose which one you use depending
9 on the circumstances.
10 So this would be the one where it's most probable
11 to isolate it, because nothing else is going on in the plant
12 yet.
13 And then the main feedwater in Oconee, this is the
14 Oconee scenario, the main feedwater is supposed to run back.
15 That's the normal situation for this event.
16 But in this particular example fault tree, we say
17 that instead it trips and then the emergency feedwater comes
18 on and the normal situation that would control to a certain
19 level, but instead it over-feeds both steam generators. The
20 others are also in this event tree. I'm just showing you
21 the example of the one where it over-feeds both steam
22 generators.
23 And I guess there's a failure to recover. I
24 missed one.
25 SPEAKER: No, it doesn't matter. It doesn't

1 matter, because that's a fail to start.

2 MR. WOODS: All right. So that's the secondary

3 side. On the primary side, because of the over-cooling, the

4 pressure goes down and the HPI comes on at 15 to 1,600

5 pounds. Anyway, it goes low enough so it comes on.

6 And so we follow that part of the tree and the

7 last part would be whether or not you lose subcooling and

8 the main reactor coolant pumps trip or they don't. In this

9 case, we don't think we would lose subcooling, but we're not

10 absolutely sure of it.

11 So there's another split here that says it trips

12 or it doesn't. Then, finally, there's another split here,

13 which is another human factor, where HPI flow is throttled

14 or it's not, and then in this case, you don't take the

15 simplest no load type human factor. You take the one where

16 other things have already gone on, because you've already

17 had a stuck-open turbine bypass valve and you've already

18 failed to control the emergency feedwater.

19 So other things are going on in the plant and

20 it's, therefore, less likely that he will remember to

21 throttle the HPI, and they use a different number.

22 DR. APOSTOLAKIS: So ATHENA now has a way of

23 telling us how likely it is.

24 MR. WOODS: Yes. It's not exact, of course, but

25 based on their experience and the data that they've seen and

1 the simulator runs that they've seen for that sort of thing,
2 they do have an organized process by which they come up with
3 a table. But it probably has a name.
4 SPEAKER: No. This is just -- basically what
5 they're doing is a self-elicitation of the group. The group
6 discusses the event. The probabilities are chosen on a very
7 coarse scale. It's one of four values, it's either .5, .1,
8 .01 or .001.
9 So basically you're corresponding to notions of
10 likelihood given the scenario. There is no attempt to make
11 it any finer than that. And the group discusses it, brings
12 up the reasons why the failure might occur, what sorts of
13 things might prompt a failure, and then says, well, given
14 the circumstances, given our observation of the operating
15 crew, that performance scenario is for us, given our
16 understanding of the procedures, talking with the training
17 supervisors, here is what it is.
18 MR. WOODS: Okay. The explanation, like I say, is
19 on the next two slides. I hope that what I said is what's
20 on the next two slides. I'm not going to go through it now
21 and make sure I didn't miss anything. You can look at it
22 later. I think it's self-explanatory, or largely so.
23 I'll go on to slide nine. Information used in the
24 analysis. The point of this slide really is just to show
25 you that we don't just take a cursory look at these plants.

1 We collect quite a bit of information and it's all listed
2 there, and I don't think there's any need, again, we're
3 running very late, to read that to you.
4 But we basically start with the IPE and sections
5 of the FSAR and the P&IDs that are available. We collect
6 all the emergency operating procedures, some of the abnormal
7 operating procedures, because they give you an idea of human
8 actions that lead to the PTS initiators.
9 Then down about a little over halfway, training
10 provided to the operators is something that we really
11 concentrate on. The ATHENA team has actually witnessed a
12 simulator practice in both of the plants, in Oconee and in
13 Beaver Valley. They asked for operating experience from the
14 two plants on very related and relevant like PRVs, SRVs,
15 whether they stick and that sort of thing.
16 Now I've lost my next slide. I got my files mixed
17 up, sorry. We've probably discussed a lot of that.
18 Obviously, we're using the better operating experience. We
19 got three or four times more operating experience than in
20 1980 when we did this before, and, also, that will
21 contribute to the initiating event frequencies and also to
22 the failure probabilities.
23 We are using current plant design and operating
24 procedures. Some of the procedures are even new
25 specifically to avoid this kind of event since 1980, and

1 that makes a big difference.

2 We think we've got better coupling between the

3 event sequences and the TH, because we've got capability to

4 run more TH scenarios. Things are on a PC now instead of a

5 $100,000 per run for a RELAP run on a big machine.

6 I'll go on to the next one. It's a continuation

7 of this one. I think some of the main things are on this

8 slide, actually. We do think, and it's already come up,

9 that we are taking contextual factors affecting the operator

10 into account much better. In fact, I'm not sure it was even

11 done at all back in 1980.

12 I mentioned that there's two or three different

13 numbers that you choose from based on whatever is going on

14 in the plant other than that particular event. We're doing

15 that.

16 The last two bullets really are meant to show that

17 we are using this to take into account the pluses and the

18 minuses. With the new human methods that we have, we are

19 better able to take into account errors of commission. In

20 fact, we're able to try to take them into account. We

21 didn't even attempt before.

22 Such things as operator trips, RCPs when he's not

23 required to do so, or the operator isolates the wrong steam

24 generator or whatever. When that comes up in a tree like

25 this that we have a number to put in, which is not an exact

1 number, but it's better than no number, we think.

2 Also, on the other side of the coin, then, like

3 when we went to one plant, we could see that they were

4 trained on not having safety injection on when you didn't

5 need it on. It's one of the first steps that they go to and

6 one of the procedures they always go to and they drill on it

7 and we just -- the ATHENA team just thinks that it's very

8 unlikely that they'll forget to take that action.

9 So previously, where we might have had a fairly

10 high probability of that, it isn't anymore. So it's a

11 balance and it's a representation of the plant more as it

12 really is rather than as you might think it would be from an

13 analyst bench.

14 Concluding remarks. There's not much new to say

15 here either. We think we are able to screen out some event

16 sequences that won't be a problem and like normal trips and

17 the vents that don't cool down past a certain point, and we

18 don't spend a lot of time, waste a lot of times on events

19 that won't be a PTS problem.

20 We think we're doing a better characterization of

21 the event sequences, better binning of them, especially for

22 Oconee. That's not to say we aren't doing a good job on

23 Oconee and Beaver, it's just to say that they didn't do a

24 very good job on binning things in Oconee back in 1980.

25 They dumped most of the things into the "other" category and

1 then ended up giving it a much higher consequence than they
2 should have. So we are certainly correcting that.
3 We mentioned we think we're doing an improved
4 treatment of uncertainties, which Dr. Apostolakis wants to
5 hear more about and we will do that.
6 The issues are we haven't yet handled external
7 events like we want to. An example of that would be a fire.
8 A fire could certainly burn up some cables and cause all
9 sorts of problems at once that maybe we haven't taken into
10 account by the analyses that we've already shown you.
11 We do know that when we get through with the four
12 plants, we will have two analyses that we've done, being
13 Oconee and Beaver Valley, and we will have two analyses that
14 we have reviewed, that will be Palisades and Calvert Cliffs,
15 and there are bound to be inconsistencies and we're going to
16 have to come to grips with how we handle --
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18 END TAPE 1, SIDE 1.
19 TAPE 1, SIDE 2 FOLLOWS:
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1 BEGIN TAPE 1, SIDE 2:

2 -- four analyses that really are on a different

3 basis. You're kind of trying to put apples and oranges in

4 the same bin and we have to deal with that.

5 Then the generalization is that obviously we've

6 got four analyses and we're going to have to try to use that

7 to represent the risk at all the plants, and we have some

8 idea how we're going to proceed to do that.

9 Then the acceptance criteria, which we mentioned,

10 is sort of a separate presentation.

11 That's all I had. And I'm sure we're way over,

12 but we'll answer any questions that we can.

13 SPEAKER: Thank you.

14 SPEAKER: A non-controversial one.

15 SPEAKER: Sure it is.

16 MR. BISSETTE: My intention was just to give a

17 brief summary of where we stand on the thermal hydraulics

18 part of this three-part program, just so you have all the

19 pieces.

20 I'm David Bissette, from the Thermal Hydraulics

21 Branch in Research. The objective of the thermal hydraulics

22 work is to ensure that for the risk-significant classes of

23 events, the thermal hydraulic input developed at the time of

24 the IPTS study back in the early '80s are still operative or

25 updated as needed, provided the uncertainty, estimating

1 uncertainty of these calculated values, and, as you heard
2 before, the IPTS study, there were three PWRs selected for
3 analysis, one from each vendor, Oconee, Calvert Cliffs and
4 H.B. Robinson.
5 And as you've heard, in the current study, we've
6 switched to a fairly similar, also a three-loop plant,
7 that's Beaver Valley.
8 These are the principal thermal hydraulic issues
9 that we encounter in single and two-phase loop natural
10 circulation, criteria for interruption of loop flow which
11 causes flow stagnation in the cold leg and downcomer, number
12 of cold legs which are supposed to be flowing to assure
13 mixing in the downcomer, local fluid, fluid mixing, and
14 non-thermal stratification in the cold leg, plume, this is
15 the plume entering the downcomer, plume mixing in the
16 downcomer, and all these are being studied in the
17 experimental program underway in the APEX facility.
18 DR. APOSTOLAKIS: Are you going to do a detailed
19 uncertainty analysis, just as the other guys are proposing,
20 the fracture mechanics? I mean, you're going to identify
21 model uncertainty and parameter uncertainty and everything,
22 or thermal hydraulics is immune to that.
23 DR. KRESS: There is no aliatory.
24 DR. APOSTOLAKIS: I know.
25 MR. BISSETTE: It follows along similar lines.

1 DR. APOSTOLAKIS: Flaws of nature.

2 MR. BISSETTE: It's being done also at the

3 University of Maryland. Do you want me to say more about

4 it? Do you want to say anything?

5 It's kind of a combination. Well, in the thermal

6 hydraulics area, the way we treated uncertainty to this

7 point in time is sort of the CSAU methodology, which you

8 probably all have some familiarity with.

9 What that is is you identify the most important

10 phenomena and you -- for each phenomena, you find the models

11 in the code that models phenomena and you vary them

12 according them according to the uncertainty, which you

13 physically understand the phenomena.

14 So you run the code repeatedly and you see the

15 sensitivity on the final answer that you're interested in;

16 in this case, it's pressure and temperature in the

17 downcomer.

18 SPEAKER: Dave, maybe I can -- the short answer is

19 yes, we're trying. We're taking our best shot. Some issues

20 we think we can handle reasonably well, like what happens in

21 the scenarios where it's basically single phase. For

22 two-phase scenarios, it's more complicated.

23 That's certainly where the model uncertainty

24 issues arise. For the single phase kinds of situations, it

25 looks more like it's an input parameter based on what's

1 happening in the event sequence, which has only been defined
2 to a certain level of detail.
3 So when exactly is a particular action taken, for
4 example, that's an aliatory issue which we need to reflect
5 in the results.
6 We're in the process of still developing the
7 methodology and we're test applying it to Oconee. There's
8 been ongoing discussions among the PRA thermal hydraulics
9 and thermal hydraulic uncertainty analysis groups, but I
10 don't know that we have a great answer for you at this
11 point.
12 Again, it sounds like something that would be
13 worth talking about in the meeting when we talk about how we
14 deal with uncertainty.
15 DR. APOSTOLAKIS: But the amount of effort will be
16 the same.
17 SPEAKER: It's a significant effort on our part, I
18 think.
19 MR. BISSETTE: The plant, the first plant we
20 started with parallels the other efforts, it's Oconee.
21 We've been performing analyses using RELAP. Thus far, we've
22 calculated 25 transients with RELAP-5, Mod 3. I don't know
23 if you recall, but the picture Roy Woods showed, basically,
24 these are 25 transients out of the hundreds of thousands of
25 the sequences that he showed on his event tree.

1 We've run these - the objective was to run these
2 transients to at least 10,000 seconds. We have achieved
3 that. This is a significant improvement over the former
4 study, where most of the transients were only run out to
5 about one or two thousand seconds and extrapolated out to
6 two hours. Just some fairly simple straight line
7 extrapolation.
8 Also, contrary to the earlier study, we modeled
9 the downcomer as a two-dimensional configuration as opposed
10 to the former 1-D that was used before.
11 SPEAKER: In the past, with RELAP, there have been
12 some problems with running out for extended periods of time.
13 Was this stable?
14 MR. BISSETTE: It was surprisingly stable. We had
15 a few code failures, but we were able to run through them by
16 reducing the time step. So for all the 25 cases, we went
17 out to 10,000 seconds.
18 So I found it remarkably stable compared to what
19 sometimes we've experienced in the past.
20 DR. KRESS: You don't use REMIX at all anymore.
21 MR. BISSETTE: We are going to use REMIX. We are
22 using REMIX and I'll mention that a little bit further on.
23 I don't have too much to say about it.
24 So this is going to show you the conclusions from
25 the 25 cases that we've generated so far. Rather a useful

1 interchange between the PRA and the thermal hydraulics work,
2 and I think that's also an improvement over the old IPTS
3 study in the early 1980s.
4 We've covered a great spectrum as part of the work
5 we did for Oconee and it covers a range of interests, but
6 the primary system pressure phase, let's say, high near the
7 secondary side pressure, to where the primary system
8 pressure drops below the accumulator pressure and further
9 down to about 200 psi, which is the low pressure injection.
10 Finally, results are sensitive to the trip
11 criteria for the reactor coolant pumps. Procedures call for
12 tripping the reactor coolant pumps on loss of subcooling.
13 And once subcooling is lost in a small break LOCA,
14 it will generally not be reestablished unless the break can
15 be isolated. So that means that when the pumps trip, they
16 stay off.
17 We find that we've done combinations of primary
18 side and secondary side failures. We find that when we
19 combine secondary side failures, like stuck-open valves
20 with, say, a small break on the primary side, it helps
21 maintain subcooling and, therefore, reactor coolant pumps
22 are not tripped.
23 Like I say, it's a big difference if you trip the
24 pumps or not, because if the pumps are running, basically
25 you have a tightly coupled system between all the loops in

1 the primary side and all the generators on the secondary
2 side. So your heat sink is very large compared to a
3 situation where you trip the pumps and now your focus is
4 just on the volumes of water associated with the downcomer.
5 So when you trip the pumps, at least for Oconee,
6 stagnation begins very quickly. The downcomer cools in
7 response to the high pressure injection. And, finally,
8 comparing the primary side between breaks in the hot side
9 and the cold side for a given break size, hot leg breaks are
10 a little bit worse than the cold leg breaks. That just
11 confirms something we saw in the old IPTS study.
12 We have a small activity right no to coupling
13 REMIX with the TRAC code. We're also going to run -- so
14 we've got a couple the REMIX and TRAC code and run a
15 two-inch break with the coupled code.
16 We're also running the same break with REMIX using
17 the boundary conditions that come out of the RELAP
18 calculation.
19 So this is right now what we're doing with REMIX
20 in terms of the calculations.
21 SPEAKER: So it's not a thermal hydraulic type.
22 What is this giving you?
23 MR. BISSETTE: It gives you -- REMIX gives you
24 another indication of downcomer temperatures.
25 SPEAKER: REMIX is a two-dimensional code.

1 MR. BISSETTE: REMIX is, let's say, basically a --
2 it treats the mixing volument of interest. REMIX applies to
3 stagnant flow conditions. It treats a part of the system
4 that's of interest, which is the cold leg, the HPI
5 injection, the downcomer and the lower plenum.
6 It treats that as, let's say, a single volume that
7 has five mixing regions in it. And the mixing regions are
8 treated on the physical basis of -- based on like through
9 number treatment of mixing and stratification and plume
10 dissipation.
11 So it's basically a physically based engineering
12 tool to give you mixed temperatures.
13 DR. KRESS: That's stuff you can't get out of
14 RELAP.
15 SPEAKER: Yes, right.
16 DR. KRESS: And you really need that.
17 SPEAKER: So it basically comes in when you get
18 the stagnation.
19 MR. BISSETTE: That's right. You use some
20 boundary conditions that you get from RELAP, depicts the
21 inlet and outlet boundary conditions.
22 Our plan is to repeat selected cases that we've
23 done already with RELAP and we're just about to get these
24 calculations underway and we'll have the results in about
25 one month.

1 Now, this is the only further slide I had on
2 uncertainty evaluation. This is the study that's being
3 performed by the University of Maryland for Oconee. I had
4 mentioned CSCU before. What they are also doing is we came
5 up with a simplified model of the Oconee system. It was
6 based on simply conservation of mass of energy, and
7 performed calculations.
8 DR. APOSTOLAKIS: Model uncertainty there.
9 MR. BISSETTE: So my advice is we --
10 DR. KRESS: We don't have a write-up on that, at
11 least I haven't seen it.
12 DR. APOSTOLAKIS: I haven't seen it either. Is
13 there anything we can read about it?
14 MR. BISSETTE: We have a partial draft report
15 that's in preparation. There should be, let's say, a first
16 draft in a few months. There's nothing really -- right now,
17 it's not much more beyond viewgraphs you can look at.
18 DR. APOSTOLAKIS: That should be part of whatever
19 subcommittee meeting.
20 DR. KRESS: Yes. This should be part of the same
21 one, when we talk about the other one.
22 MR. BISSETTE: Yes, it should be. I had mentioned
23 the testing program we have underway at APEX. APEX is
24 located at Oregon State University. The objective is to
25 provide experimental data on the thermal hydraulic PTS

1 issues, as well as for code assessment. We did a scaling
2 evaluation to compare the APEX facility to Palisades and, as
3 far as that goes, to other CE plants, like Calvert Cliffs
4 and Fort Calhoun.
5 APEX was originally configured to model AP-600.
6 CE plants are similar in size to AP-600. The facility is
7 modified to add loop seals, HPI connections to the cold
8 legs, and additional thermocouples in the cold legs and
9 downcomer.
10 We performed pre-test calculations using RELAP and
11 REMIX. There's REMIX again. We conducted our first test in
12 August and the remainder of the test program is scheduled to
13 be done by the end of the calendar year.
14 I'm just going to show you -- put this up just to
15 briefly show you what the facility looks like. It's a
16 two-by-four arrangement, similar to the CE plants, with two
17 hot legs, two generators, four reactor coolant pumps feeding
18 into four cold legs.
19 Then this is just a top view, comparing the APEX
20 loop layout with Palisades.
21 DR. KRESS: The injections in the hot leg are all
22 the same. High pressure injection is in the hot leg?
23 MR. BISSETTE: No, the cold leg. Because all
24 plants have connections to the hot leg, as well as the cold
25 legs for the injection systems, but normal injection path is

1 the cold legs.

2 So I won't go through the test matrix, in the

3 interest of time, but here it is. You can look at it.

4 Basically, the tests are PTS sequences, in addition to more

5 basic and separate effects kind of testing to cover the

6 range of issues that I had mentioned earlier.

7 Now, in addition to Oconee, we will be doing

8 Beaver Valley, Calvert Cliffs and Palisades. We haven't

9 done any calculations thus far beyond exercise the input

10 models for these plants. We started converting H.B.

11 Robinson decks to Beaver Valley.

12 We're scheduled to have a set of calculations

13 completed by January of the coming year and we'll follow

14 that with Calvert Cliffs and Palisades, hoping to have the

15 calculations by March of next year.

16 The final slide is we have our Oconee

17 calculations, RELAP, ready for transmittal to Oak Ridge.

18 They use them as boundary conditions for FAVOR. We expect

19 to provide the calculations for a Westinghouse three-loop

20 plant based on Beaver Valley by, say, early the coming year,

21 and Calvert Cliffs and Palisades by the middle of next year.

22 SPEAKER: Are the thermal hydraulic boundary

23 conditions for Oconee different than they were in the '81?

24 I mean, have they changed substantially?

25 MR. BISSETTE: I haven't done a -- we haven't

1 looked at that in detail yet. That's something that we will
2 be doing in the next month or two.
3 DR. KRESS: Well, you had a single curve for the
4 pressure and temperature.
5 MR. BISSETTE: Yes.
6 DR. KRESS: But now you're going to have a
7 distribution.
8 MR. BISSETTE: Well, we may have a curve with that
9 uncertainty band on it.
10 DR. KRESS: There may not be much uncertainty
11 about the pressure, but there can be about the temperature,
12 I guess.
13 MR. BISSETTE: Yes. What we've found, in terms of
14 looking at the phenomena, is that a lot of the phenomena are
15 pretty well -- we believe the dominant phenomena are pretty
16 well modeled by RELAP. There are some uncertainties because
17 you can't model two fluids, two liquids in a one-dimensional
18 code.
19 DR. KRESS: That's your cold liquid and your hot
20 liquid.
21 SPEAKER: Which is one of the reasons we use
22 REMIX, too. What we're going to do, we're going to hold off
23 on the discussion of the probabilistic fracture mechanics
24 until this afternoon and we'll have all the probabilistic
25 fracture mechanics discussion together.

1 We're going to take a break now and then come back
2 and go into the flaw distribution discussion.
3 SPEAKER: Great.
4 SPEAKER: So be back at 10:15.
5 [Recess.]
6 END TAPE 1, SIDE 2.
7 TAPE 2, SIDE 1 FOLLOWS:
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BEGIN TAPE 2, SIDE 1:

SPEAKER: The next discussion is the generalized flaw distributions, and I guess that's Debbie Jackson and Lee Abramson will be making the presentation.

The first test is in. Okay. Passed.

SPEAKER: They found it.

MS. JACKSON: I'm Debbie Jackson, and Lee Abramson. We're going to present the results from the expert judgment process for the development of the flaw distribution.

The first two slides just go over a little bit of background information and reasons why we are doing this flaw distribution. The last major work on flaw distribution was done in the mid '70s and early '80s. It was a Marshall distribution, and that was done not only with nuclear vessels, but also with non-nuclear vessels. So this work that we're doing now is a lot more expensive than the previous work on the Marshall distribution.

This slide just discusses a few of the reasons why we decided to do an expert judgment process for development of the generalized flaw distribution.

This is a list of the fabricators for domestic reactor vessels and the list is in order of the percentage of vessels that were manufactured by each organization.

1 The last Rotterdam and Society Crusoe, they
2 finished the fabrication. One of the fabricators, Babcock
3 and Wilcox, ran behind schedule during their fabrication
4 processes. So some of their vessels were finished by the
5 Rotterdam and Society Crusoe.
6 This is a slide that lists the reactor vessel
7 material that's been inspected by PNNL that's going to --
8 that was used for the flaw distribution. The Midland vessel
9 was inspected in the early '80s and it was with a different
10 type of SAF-UT system, and since the Midland inspection, the
11 UT exams have advanced a lot.
12 So the inspection techniques were different, so
13 we're actually not going to include the Midland data. We're
14 only going to do the PVRUF-C, Shoreham, the River Bend and
15 Hope Creek vessels.
16 SPEAKER: PVRUF, what is that?
17 MS. JACKSON: Pressure vessel research users
18 facility. It's a cancelled vessel that was at Oak Ridge,
19 and we've used that.
20 SPEAKER: Debbie, I couldn't find it anywhere in
21 the report. The three boilers, Shoreham, River Bend and
22 Hope Creek, what are the weld processes that are used there?
23 MS. JACKSON: The weld processes for those were
24 submerged arc and then they are back-gouged with -- the
25 inner sods were done with submerged arc.

1 SPEAKER: How about the axial welds?

2 MS. JACKSON: The axial welds were -- I believe
3 they were submerged arc, but some of them may have been
4 electroslag. I need to look that up.

5 SPEAKER: Okay. I just wondered if we were mixing
6 electroslag data in with the other data.

7 MS. JACKSON: Not with the -- not for the PTS, no.
8 We don't have a lot of data on the electroslag weld
9 processes, because a lot of that was done with the boilers.

10 SPEAKER: Okay. But I just wanted to make sure it
11 wasn't being included for the PTS study.

12 MS. JACKSON: During the examinations that PNNL
13 was doing, we came up with categories to categorize the
14 different flaws and what we came up with were different
15 regions of the vessel.

16 The inner region is the NR-25 millimeter, the
17 inner one inch. The outer region was the outer one inch,
18 outer 25 millimeter, and the mid region was the remaining
19 part of the vessel wall.

20 Volumetric and planar, we have the weld, the clad
21 and the base metal and repair weld versus non-repair welds.

22 We found out from some of the data that there are
23 quite a few flaws in the repaired areas of the vessel.

24 These next two slides are going to go over just
25 the steps that we used in the expert judgment process. We

1 first defined some of the issues, determined the level of
2 complexity. We identified an expert panel. We sent some
3 issues to the panel.
4 The panel had a meeting and we had elicitation
5 training, which was performed in Atlanta by Lee Abramson.
6 DR. APOSTOLAKIS: I have a question here.
7 MS. JACKSON: Yes.
8 DR. APOSTOLAKIS: I think I read the report and,
9 in my opinion, it's not clear how the expert judgment was
10 used, what the objective of the elicitation was, and I
11 formed an opinion after I read the whole report, and please
12 correct me. This is my impression.
13 That you actually started with a distribution for
14 the size, the crack depth, and also for the density that is
15 based on data and what you did with the experts is you
16 modified that, depending on the various things that you have
17 here, on whether it's unrepaired weld metal or unrepaired
18 cladding or the various other things that you have here,
19 plate versus welds.
20 Is that correct? In other words, you did not
21 elicit from the experts information that would give you the
22 actual density. You didn't ask them that.
23 SPEAKER: That's correct.
24 MS. JACKSON: No, we did not.
25 SPEAKER: That's correct.

1 MS. JACKSON: You're right.
2 SPEAKER: We just asked relative values.
3 DR. APOSTOLAKIS: Relative values.
4 SPEAKER: That's correct.
5 DR. APOSTOLAKIS: So I suggest, since this is
6 still draft, that you add a section someplace explaining
7 this, because I was really trying very hard to understand
8 what was going on and then you hit me on page 25 with all
9 the information that comes from statistics and then I had to
10 figure it out myself.
11 MS. JACKSON: Okay. That's a point well taken and
12 we'll make those --
13 DR. APOSTOLAKIS: And also it would be useful if
14 you showed how these various factors were used, what was the
15 arithmetic, in other words.
16 SPEAKER: Okay. There is a considerable -- there
17 is some detail in the report as to how --
18 SPEAKER: It's sort of lost in those notes.
19 SPEAKER: Well, it's in the notes.
20 DR. APOSTOLAKIS: The report says that this is the
21 mid value of the median and so on.
22 SPEAKER: Correct.
23 DR. APOSTOLAKIS: And using that, we get. And I
24 guess the "using" is the thing, how exactly -- I mean, maybe
25 it's a simple multiplication.

1 SPEAKER: It is, yes.

2 MS. JACKSON: The report has been revised since
3 then and the first revision, because it's going to be
4 revised quite a bit before the final NUREG comes out at the
5 end of next year, but the notes have been revised
6 extensively.

7 SPEAKER: I'm not sure which version you saw,
8 George. The second version hopefully will be more explicit
9 and the intention of the notes was to give you a road map to
10 let you reproduce the calculations yourself without a great
11 deal of trouble.

12 SPEAKER: But George is right. You really ought
13 to separate the ones where you're working from data from the
14 ones where you've essentially modified the distributions
15 based on the --

16 SPEAKER: This is -- we tried to make this
17 extremely explicit in the notes.

18 DR. APOSTOLAKIS: Yes, I understand that.

19 SPEAKER: And some of the numbers that we got --

20 SPEAKER: Well, I ended up highlighting my table
21 so I could tell which was which.

22 SPEAKER: That's right.

23 MS. JACKSON: That's been revised.

24 DR. APOSTOLAKIS: I've read already 26 pages. On
25 the 27th, there is note number three, these values are

1 multiplied by -- this is such a big thing, it should be up
2 front some place that this is what the objective was. We
3 will rely on statistical data to get density and --
4 SPEAKER: We'll try to make it more explicit.
5 DR. APOSTOLAKIS: -- distribution. And the reason
6 why we have to go to experts is because the data is a
7 mixture and you can't tell where it comes from, because if
8 you could, then you wouldn't need the experts.
9 Then you had to modify it or to adapt it to the
10 particular circumstances of interest.
11 SPEAKER: That's right.
12 DR. APOSTOLAKIS: And that's what we're doing,
13 that's what we're eliciting. Okay. And then here, and, for
14 example, for this factor and this factor and this factor, to
15 get this, we multiply this by that. That would go a long
16 way towards helping the reader really place it in context.
17 SPEAKER: Okay.
18 MS. JACKSON: Okay.
19 DR. APOSTOLAKIS: Good.
20 MS. JACKSON: Thank you for that.
21 SPEAKER: Just on that, too, I mean, you give the
22 tables up front for the distribution and the PVRUF and I
23 can't make the numbers add up to get the numbers in table
24 5-1 for the small flaws and large flaws and greater than
25 five millimeter flaws, and you're referring me back to the

1 original PNNL report.

2 You ought to just bring those tables from the PNNL

3 report and put them in here so that --

4 DR. APOSTOLAKIS: And I would like, by the way, to

5 get your reference ten, Shuster, Dr. Hessler,

6 characterization of flaws in U.S. reactor pressure vessels.

7 It's a NUREG published in 1999.

8 It seems to be an important document in this

9 context.

10 MS. JACKSON: It is. There's three --

11 DR. APOSTOLAKIS: So if you can send me a copy, I

12 will appreciate that.

13 MS. JACKSON: We have copies.

14 DR. APOSTOLAKIS: NUREG-CR-6471.

15 MS. JACKSON: There's three volumes of that now.

16 The third volume just came out.

17 DR. APOSTOLAKIS: That will do it. Three volumes.

18 I would like to get that.

19 SPEAKER: Beginning to get indigestion, George.

20 DR. APOSTOLAKIS: That will teach me.

21 SPEAKER: There's 10,000 flaws, George. When you

22 discuss each one --

23 DR. APOSTOLAKIS: Each one, what happened.

24 MS. JACKSON: Okay. Well, that will be good.

25 This next --

1 DR. APOSTOLAKIS: Now, just to -- you know, we
2 have to be nitpicky here. How the hell do you know it was
3 successful? You just got some numbers and you used them.
4 Why was it successful?
5 MS. JACKSON: Because we completed 17 --
6 MR. HACKETT: This is Ed Hackett. I think I could
7 speak for Debbie and Lee, because they're going to be humble
8 and modest. But I think it's just the fact they made it
9 through and people didn't die in the process. So it was
10 kind of -- maybe this is a low bar for success, but at least
11 that was part of it.
12 MS. JACKSON: Our first elicitation session was
13 with Vic Chapman. He's one of the authors of the Marshall
14 report.
15 DR. APOSTOLAKIS: I know him.
16 MS. JACKSON: And the session lasted --
17 DR. APOSTOLAKIS: You don't call him Lord
18 Marshall?
19 MS. JACKSON: Retiree Marshall, now, Retiree
20 Chapman.
21 DR. APOSTOLAKIS: He's bored.
22 MS. JACKSON: But this session was borderline nine
23 hours. So after that, we decided we had to make some
24 changes.
25 And I say it's evolving because the first few

1 elicitation sessions that we did were different than the
2 final few. Each session, we learned some additional
3 information from the experts. One thing in particular, we
4 had cladding as a group in itself and then one of the
5 experts suggested that we break cladding down into the
6 different specific methods of cladding, strip cladding,
7 multi-wire and single-wire.
8 With that, we had to re-elicit the experts after
9 we finished the final elicitation session, because there
10 were so many changes throughout the process.
11 DR. APOSTOLAKIS: Are you eliciting the experts or
12 their opinion?
13 MS. JACKSON: We elicited the experts to get their
14 expert judgment and opinions on some things.
15 This is a list of the areas of expertise we had
16 for the different experts.
17 DR. APOSTOLAKIS: Now, I have another question
18 that's not on the viewgraphs. You say here in the report
19 that in addition to the empirical data, PNNL has used the
20 flaw simulation model of R.R. Prodigal to estimate the
21 numbers and sizes of flaws in the welds of the PVRUF and
22 Shoreham vessels.
23 To estimate the number and sizes. What kind of a
24 code is that? What input do you put in there?
25 DR. KRESS: That's an expert.

1 DR. APOSTOLAKIS: It's another expert.

2 MS. JACKSON: It's an expert.

3 DR. KRESS: It's expert-based code.

4 MS. JACKSON: Prodigal was done some years ago and
5 it was another expert judgment, as you said.

6 SPEAKER: It puts a flaw in and then has a
7 probability distribution for whether that flaw then goes to
8 the next bead in the weld, depending on what you're doing.

9 MS. JACKSON: It simulates a weld, the given
10 welding process.

11 DR. APOSTOLAKIS: This is a different use of
12 expert judgment. Now you're referring to density. I would
13 like to have that, too.

14 MS. JACKSON: Okay. And that was one of the
15 comments we got. We need to provide some additional
16 explanation on the Prodigal code in that report.

17 DR. APOSTOLAKIS: The commitment by the NRC's
18 Office of Research to develop a generic flaw distribution
19 has been received positively by the NRC's Advisory Committee
20 on Reactor Safeguards. We said that?

21 DR. KRESS: Yes, we said it was a good idea.

22 SPEAKER: With the Marshall flaw distribution.

23 DR. KRESS: Yes.

24 SPEAKER: Too long.

25 SPEAKER: Yes.

1 DR. KRESS: Yes.

2 SPEAKER: Even if he's a Lord.

3 DR. KRESS: In fact, I think we said if you could
4 do that better, you could go a long way to solving the whole
5 problem of PTS.

6 DR. APOSTOLAKIS: A lot of questions have a depth
7 for information.

8 DR. KRESS: I see. You've got too many answers.

9 MS. JACKSON: The next two slides have three
10 definitions that were developed for the flaw distribution
11 for this process, and for consistency, we developed a
12 definition for the flaw. This was done through a consensus
13 process with the experts and the definition is an
14 unintentional discontinuity that has the potential to
15 compromise the reactor vessel integrity and is in the vessel
16 after pre-service inspection.

17 [Tape stopped and restarted.]

18 MS. JACKSON: We began to use the definition that
19 was in ASME and some of the experts felt that was
20 inappropriate. So this is what we came up.

21 DR. KRESS: So if it's an intentional one, it
22 doesn't count.

23 MS. JACKSON: Right. If it's an intentional -- if
24 the base metal dinged during travel or something like that.
25 And two additional definitions were for a small flaw and a

1 large flaw and that's additionally broken down into a small
2 flaw in the weld metal and cladding and flaws in the base
3 metal.
4 We developed a list of --
5 SPEAKER: When you do that, it would be helpful if
6 you gave us bead sizes then for each of the welds we're
7 looking at.
8 MS. JACKSON: Yes, because the bead size does vary
9 so much with the different processes.
10 SPEAKER: I couldn't back that out of the reports.
11 SPEAKER: The bead size range, I think, is in the
12 tables, in one of the tables, 5.1.
13 MS. JACKSON: Or some of them.
14 SPEAKER: Or some of them. We gave the range of
15 bead sizes in there. It varied.
16 SPEAKER: Everything is in 5.1, if you can find
17 it.
18 DR. APOSTOLAKIS: How come you don't name the
19 experts?
20 MS. JACKSON: We do have them now in the backup
21 slides. We've listed --
22 DR. APOSTOLAKIS: It's here?
23 MS. JACKSON: Yes. That was one of the difficult
24 processes, because many of the people who were actually in
25 reactor vessel fabrication are retired and some of them are

1 no longer here. So that was kind of a torturous process.
2 I almost called someone and then someone informed
3 me that the person had just passed away. So I didn't make
4 that phone call.
5 SPEAKER: That's a hard call.
6 MS. JACKSON: This is the list of issues. We
7 tried to come up with a comprehensive list so that we would
8 include every aspect of reactor vessel fabrication and all
9 of the different areas where a potential flaw could be
10 introduced during the fabrication process.
11 DR. APOSTOLAKIS: This is now another interesting
12 point here. Since you're planning to adopt distribution
13 that's based on data using information from these elements,
14 is there a possibility that you are considering too many
15 issues and that may lead to too many factors multiplying
16 things?
17 In other words, you are going to such detail that
18 you may start getting optimistic results. And were the
19 experts asked?
20 MS. JACKSON: Yes. I'm going to go --
21 DR. APOSTOLAKIS: And, also, I'm not sure you can
22 treat these things as independent.
23 MS. JACKSON: That was one of the things
24 throughout as we learned through the process. We broke the
25 characteristics down. Some of the characteristics, the

1 experts were able to give us quantitative numbers.

2 I'm going to explain how we got information from

3 them regarding the introduction of a flaw, but in the end,

4 we found out that most of these in this column and some in

5 this column -- oh, I'm sorry.

6 DR. APOSTOLAKIS: See, my point is it's the same

7 like in a fault tree. You can go way down into detail and

8 --

9 DR. KRESS: But in this case, it's like entropy,

10 though. It just broadens the distribution, the more you put

11 in it.

12 DR. APOSTOLAKIS: No.

13 DR. KRESS: I think it does.

14 DR. APOSTOLAKIS: Because they multiply by

15 fractions the various -- the statistical density.

16 DR. KRESS: That broadens it, though.

17 DR. APOSTOLAKIS: They haven't done any

18 uncertainty yet.

19 SPEAKER: They blur the resolution, but it should

20 keep --

21 DR. APOSTOLAKIS: Keep it down, because now you

22 have -- and because of filled versus short and then welder

23 skill are multiplied independently.

24 SPEAKER: As Debbie said, some of these are

25 qualitative and some are quantitative. It's only the

1 quantitative and actually in the left-hand column --
2 actually, more than half are qualitative, and I'll explain
3 more in detail when I give my presentation.
4 And when you look at the report, we used data
5 wherever possible and there was quite a bit of data. We
6 only used the expert judgment to fill in when there wasn't
7 any data.
8 DR. APOSTOLAKIS: Yes, but that was not really my
9 question, because if you have a bunch of experts and you
10 give them the issues, then they tend to focus on, okay, what
11 does product four mean, is it important and so on.
12 But if you look at the whole list, are these
13 really independent characteristics, so that I really have to
14 worry about welder skill independently of the field,
15 independently of the repairs and so on? Am I introducing
16 additional factors that will start pushing the density down
17 in an artificial way?
18 SPEAKER: When we did the real elicitations, we
19 tried to condition every question so that you got an answer
20 -- for example, we said if you're interested, say, in weld
21 material, we talked about unrepaired weld material done with
22 a manual weld and so on and so forth, and they say compare
23 repair to non-repair.
24 So things were conditioned and presumably,
25 hopefully, the experts took account of this conditioning in

1 their judgments and we never, in the table 5.1 and the
2 results, we never multiplied -- we only multiplied by one
3 thing. We didn't multiply two of the expert judgments,
4 because we didn't have to do that.
5 DR. APOSTOLAKIS: Did any one of the experts raise
6 the issue of overlapping? Did they overlap much, some of
7 them?
8 MS. JACKSON: Some of them do, but in the backup
9 slides, on slide 35, that is the beginning of the breakdown
10 of the quantitative and the qualitative characteristics. So
11 in the end, we're only using the numbers from the
12 characteristics that we were able to get exact numbers from
13 the experts for.
14 Specifically, that was for the product form, the
15 weld processes, the flaw mechanisms, the repairs, the flaw
16 location and the flaw size.
17 So the majority of the characteristics, we don't
18 have any -- we're not going to use numbers. In the first
19 few elicitation sessions, we did ask the experts to compare
20 welder skill for the different weld processes and finally
21 some of them said, you know, that is such a human factors
22 related issue, you can't pinpoint a number, same for
23 inspector skill.
24 So some of the things, we're not going to use the
25 numbers. It will be used when we do the uncertainty

1 studies, but --

2 DR. APOSTOLAKIS: I thought this kind of

3 discussion will be beneficial if you were to insert it into

4 section four, where you discuss the issue.

5 MS. JACKSON: Section four, okay.

6 DR. APOSTOLAKIS: So the qualitative issues were

7 not used.

8 MS. JACKSON: Well, they -- I have a slide here.

9 Let me --

10 SPEAKER: The qualitative issues were not used to

11 generate any of the numbers.

12 MS. JACKSON: If we can go to this, this is a

13 distinction that we came up with between the two different

14 types of characteristics.

15 The quantitative are the ones where the experts

16 were actually able to provide numerical comparisons and we

17 will be able to get some records.

18 We're still receiving some construction records

19 for some of the vessels that PNNL has. And these

20 qualitative characteristics, the experts were unable to

21 meaningfully quantify or the records are unavailable. So in

22 essence, we're not going to be able to get any numbers for

23 those qualitative characteristics.

24 DR. APOSTOLAKIS: What do you mean necessary

25 records are unavailable?

1 MS. JACKSON: Like for some of the things on
2 welder skill, there's really no records for welder skill.
3 There is no way for you to quantify that on the welder
4 skill, because that varies so much from welder to welder,
5 what day; if, five days before a Super Bowl, welder skill
6 goes down. There's just so many factors, it's hard to
7 pinpoint exact numbers to compare welder skill for a
8 submerged arc versus an electroslag, the automatic
9 processes.
10 So that's what we meant when we said the necessary
11 records are unavailable.
12 DR. KRESS: Measure of welder skill is how many
13 flaws there are. It's kind of strange trying to use the
14 same measure to determine the outcome.
15 MS. JACKSON: Let me put these two slides up. I
16 think in your handouts, they are in a different format, but
17 this shows them a little larger.
18 This is the sheets that we used when we were going
19 for the elicitation sessions with the experts. So I'm going
20 to do this as an example.
21 We asked them about the product form and the
22 product form was broken down into four different parts;
23 forgings, plate, the cladding and the weld metal.
24 So we asked the experts, we said which one of
25 these is most likely to have a flaw, using that definition

1 of a flaw that I showed you earlier. So we asked them to
2 write them and for this one, for example, say this was one,
3 weld metal had more -- more likely to have a flaw, one, two,
4 three and four. I'll just use that arbitrarily.
5 And then after that, we asked them to compare,
6 okay, so weld metal has the most number of flaws. Compare
7 the weld metal to the cladding. Which would have more
8 flaws, the weld metal to the plate, and the weld metal to
9 the forgings.
10 Then after that, we asked them -- we added this
11 late, because initially flaw size was not in here, but we
12 wanted to know would you have a variation of flaw size and
13 what effect the fabricator would have.
14 We had three major fabricators and Combustion
15 Engineering, Babcock & Wilcox, and Chicago Bridgeni.
16 Chicago Bridgeni, most of their vessels were partially field
17 fabricated.
18 So a lot of information that we had received
19 before eliciting the experts for the field fabricated
20 vessels were not fabricated as well as shop fabricated
21 vessels, and we found that not to be true, and we actually
22 finished the elicitation process because even though the
23 vessels were finished in the field, a lot of them were
24 partially shop fabricated and we actually had two experts
25 who actually worked with Chicago Bridgeni and one person was

1 the actual welding inspector and we found out that they
2 compensated for a lot of the problems that you would have in
3 the field with the environmental conditions and things like
4 that.
5 So that's how we got the numbers. We went through
6 this for each one. We went through the weld processes. We
7 had five different processes.
8 This is one of the areas that was since revised
9 and went through the elicitation process because a few
10 experts told us that you need to break this down, because
11 there were manual and automatic types of cladding, and we
12 needed to break that down. So that was actually broken down
13 further.
14 You had many, many different types of flaw
15 mechanisms for base metal and for weld metal. So we went
16 through this and this is where we began to find problems
17 with the experts. They said the weld procedures were -- a
18 lot of them -- most of them were qualified, so the weld
19 procedure should not have that much effect.
20 So that's where we decided we had to break down
21 the characteristics into the quantitative and qualitative,
22 because we couldn't actually get numbers from the experts.
23 The next two slides just state some of the
24 conclusions from the expert judgment process. They feel
25 that it can be done, but it's going to have a wide range of

1 uncertainty. The flaw density of base metal is
2 substantially less than for weld metal. The number that's
3 been used for many years is that the base metal had ten
4 percent of the flaws of weld metal and the basis for that
5 was a phone call between Mike Mayfield, Spence Bush. Now we
6 have some additional data, so we have a basis for that.
7 Discontinuities in the cladding, that was another
8 issue that we discussed with the experts.
9 DR. KRESS: When you say weld metal, are you
10 counting the region around the weld part or just the weld?
11 MS. JACKSON: The heat affected zone?
12 DR. KRESS: The heat affected zone.
13 MS. JACKSON: No, the heat affected zone, that was
14 a big problem because it still is actually base metal, but
15 it's been affected by the heat from the weld. So we include
16 it as base metal, but take into account that it has been
17 altered.
18 DR. KRESS: Okay.
19 DR. APOSTOLAKIS: I guess you're not getting into
20 the actual processing of the numbers.
21 MS. JACKSON: Lee is going to go into that a
22 little bit.
23 DR. APOSTOLAKIS: So we should hold off. Are you
24 going to use the methodology, slides on methodology?
25 MR. ABRAMSON: Yes.

1 MS. JACKSON: This is another slide, the last
2 slide, with some of the conclusions from the experts.
3 The issue with the large flaws, most of those
4 should be detected NDE. This discusses two of the
5 qualitative characteristics, the welder skill and the
6 inspector skill, and the weld processes are an important
7 factor in the introduction of flaws.
8 SPEAKER: When you say NDE, do you mean --
9 MS. JACKSON: The UT.
10 SPEAKER: The UT rather than the radiography. But
11 not all the vessels were UT, right?
12 MS. JACKSON: They were all -- final to being put
13 into service, they were all given a 100 percent UT, we
14 understand, from the experts, prior to being put into
15 service, either before the actual shell courses were welded,
16 but we do understand that there was 100 percent UT of the
17 vessels prior to being put in service.
18 It may not have been that --
19 SPEAKER: Even though it only went into the code
20 at a somewhat later time then.
21 MS. JACKSON: Right. And it wasn't the extent of
22 the UT exams that are done now, because these were done so
23 long ago, but there were UT exams done on the vessels.
24 MR. HACKETT: I think, Debbie, if I could. This
25 is Ed Hackett again. I think maybe the more correct

1 statement would be to say that they all received 100 percent
2 volumetric exams and maybe the volumetric was a combination
3 of radiographic testing and ultrasound.
4 But, of course, given the vintage of when some of
5 these vessels were fabricated, I think UT was, as Debbie
6 pointed out, nowhere near in the kind of state it's in today
7 in terms of the level of advancement.
8 Plates were typically UT'd. I know if it's a
9 plate fabricated vessel, as part of the certification for
10 basically nuclear QA coming out of Lukens, they would have
11 probably UT examined the plates.
12 The final composite structure of the reactor vessel,
13 probably, you could say for sure it received 100 percent
14 volumetric exam and that's probably, at that point,
15 restricted to the welds and the adjacent areas. And that
16 was more than likely, with the early ones, majority RT and
17 then maybe supplemented by UT, because we are aware of some
18 of the vessels and it was an issue with the BWRs that some
19 of them did not receive those level of exams that we would
20 have liked to have seen and that was -- the committee maybe
21 remembers the issue, Debbie was involved in this and so was
22 Lee, over the inspection effectiveness of the
23 circumferential welds in the BWRs.
24 And part of the issue there was that some of them
25 had never actually received one that people would have

1 agreed upon was a reasonable inspection. And then you got
2 into the question probabilistically of how important is that
3 anyway and the industry demonstrated fairly convincingly,
4 for circ welds in BWRs, that it really didn't matter a whole
5 lot, is what it boiled down to, because these things were
6 pretty well made from the beginning, a lot of the things
7 that Debbie and Lee have been discussing.
8 So I think I would probably say that is --
9 MS. JACKSON: That was one of the issues the
10 experts brought up. The NDE that was done during the period
11 of the Marshall distribution, it basically picked up larger
12 flaws. So just the quality of the NDE is a question when
13 you talk about the final vessel inspections.
14 SPEAKER: Prodigal gives you a fair amount of
15 credit for the x-ray, the radiography.
16 MS. JACKSON: Yes, it does. It does. I just have
17 some concluding remarks regarding the whole process.
18 We still have a lot of work left to do. The
19 report that you have that was dated in July, that's under
20 revision, and one is coming out at the end of the month and
21 then it will be revised again periodically before the final
22 one comes out at the end of next year.
23 DR. APOSTOLAKIS: But you don't have access to the
24 experts anymore.
25 MS. JACKSON: No, I do. I still --

1 DR. APOSTOLAKIS: The ones that are alive.

2 MS. JACKSON: -- discuss with them. That's an

3 issue.

4 DR. APOSTOLAKIS: So you do. So you maybe can get

5 some more information.

6 MS. JACKSON: Some of them -- yes, because I've

7 had some -- we weren't able to get an expert who was from

8 Lukens, but I do have a gentleman who retired from Lukens

9 who does answer questions that I have occasionally.

10 But some of the people just didn't want to

11 participate or were retired, and they were retired and they

12 didn't want to have to go through the process.

13 Lee?

14 DR. APOSTOLAKIS: So you did conclude that the

15 expert judgment process is complex.

16 MS. JACKSON: Successful and complex, yes.

17 MR. ABRAMSON: I'm going to talk about the flaw

18 distribution methodology, and that's in contrast to the --

19 this is what was intended. It was an upgrade to the

20 Marshall distribution.

21 The Marshall distribution essentially combined all

22 the various factors and came out with a distribution. What

23 we've done is to separate out these things and I'll talk

24 about, of course, how it was done and there are certain

25 advantages to this.

1 There are essentially three elements to the
2 distribution. One is the flaw densities and two is the
3 volumes or areas, and each of these is plant-specific. Then
4 we have the distribution of crack depth, given that there is
5 a flaw. So it's combined into these three elements and this
6 is -- we're treating this so far as generic.
7 DR. KRESS: Are all flaws treated as cracks when
8 they get around to doing the fracture mechanics?
9 SPEAKER: I can give that one a go. I don't think
10 that's fair to Lee.
11 MR. ABRAMSON: Yes.
12 SPEAKER: The report that Dr. Apostolakis was
13 referring to, at least on PVRUF, there were distinctions
14 made between volumetric and planar. So from the detailed
15 NDE, where the defect was considered to have volumetric
16 characteristics, those were screened out.
17 So in other words, if you had, in the idealized
18 sense, a spherical defect of some sort, that was not
19 considered to participate. The others were just assumed to
20 be crack-like.
21 MR. ABRAMSON: This is an outline of the
22 methodology. The ultimate goal of the distribution, at
23 least as far as the computation is concerned, this is what
24 will be input to the FAVOR code, is to get two numbers, the
25 number of small flaws and the number of large flaws. We do

1 everything for small and large, because the experts have
2 told us and, actually, we know from our own experience and
3 knowledge, but mostly the experts have told us that there is
4 a difference between small and large flaws. There could be
5 a difference.
6 And it's defined in terms of the bead thickness.
7 A small flaw is one such the crack depth is less than the
8 bead thickness, the large is larger than the bead thickness.
9 Now, everything is -- distribution is dependent on
10 three characteristics of a weld. The first is the product
11 form, the second is the weld process, and the third is the
12 repair state.
13 The weld process we considered was estimated
14 manual welds, automatic welds, electroslag, when it's
15 appropriate, and then for the cladding, single and
16 multi-wire, and repair state is repaired and unrepaired.
17 So the distribution we're going to get is going to
18 be dependent upon the various combinations of these.
19 Then what we have is we have a density of small
20 and large flaws as a function of the product repair state
21 and it's per unit volume or area. Areas we use for
22 cladding. For unit area, everything else is -- the weld
23 metal is per unit volume. And you do the obvious thing.
24 We first have, we have N-sub-S, which is just the
25 number of small flaws. This, of course, is going to be a

1 sum of products. We have particularly density as a function
2 of the various characteristics multiplied by the appropriate
3 volume or area for that point.
4 So that takes care of the first two parts,
5 aspects, and the last one, of course, is the density of
6 flaws and they're defined as G-sub-S, these are the CCDFs,
7 the complimentary distribution functions. For small flows,
8 the probability of the crack depth is larger than whatever
9 the quantity of X is, define those.
10 And then putting all this together, each GFC, this
11 generalized flaw distribution, is the product of the number
12 -- actually, that should be the sum of -- oh, each one is
13 the product of the number of flaws in the corresponding
14 crack depth distribution.
15 So we have -- this is what I started out with in
16 the first slide. This is a number larger, flaw larger than
17 X, it's the number of small flaws multiplied by the
18 probability of it being larger than X, given there's a flaw,
19 and just pull all this together.
20 Now, what we have in this -- and this has been
21 revised based on additional input and commentary from PNNL.
22 So this is not example -- this is not what you got here, but
23 this is the latest that we have now.
24 This is the PVRUF distribution, because it's based
25 on the PVRUF examination which PNNL did, and specifically

1 for the volumes and areas. So this is, as I said, the
2 distribution, of course, is going to be plant-specific and
3 the plant -- the vessel we're using is a PVRUF vessel here.
4 Let me just go over this. First of all, here we
5 have the combination of product form, weld process and
6 repair state. So we have this for relevant ones here,
7 first, for the weld metal and plate and, secondly, for the
8 cladding. We divided this up here.
9 Then here are the measured PVRUF volumes in terms
10 of cubic meters for these quantities. There were no -- this
11 is the plate manual repair. There were no repairs that
12 we're aware of in the plate. That's why this is zero rather
13 than a dash. And similarly, for the cladding. Again, here,
14 there was no multi-wire in the cladding. So that's why the
15 zero here.
16 And this is unknown, they're still working on
17 this, I believe. There's a possibility that they haven't
18 finished that yet.
19 So that this column here is the plant-specific, in
20 this case, PVRUF-specific numbers.
21 Now, the densities, that is based on the PVRUF
22 data and also on Shoreham data. Now, this may very well
23 probably -- I'm sure it will change, because the PVRUF data
24 has been validated. The Shoreham data has not been
25 validated. So as we go through with this, it will be

1 revised, but this is our best estimate on it so far.
2 I should also say, too, talking about best
3 estimates, the numbers here are best estimate values. They
4 are based on data, where it's available, because data trumps
5 expert judgment all the time, as far as I'm concerned, and
6 we only use the expert judgment when it's necessary and we
7 don't have the available data.
8 So we're just using the actual data, the point
9 estimates, if you will. And then the expert judgment, and I
10 can discuss this later, if you like, we're using essentially
11 the median values. We're using a best estimate for the --
12 DR. APOSTOLAKIS: But eventually there's going to
13 be number two.
14 MR. ABRAMSON: That's right. No. Absolutely.
15 We're very definitely going to use the uncertainties and for
16 the data, we'll be able to have it statistically based. The
17 expert judgment, I'm not quite sure how we're going to do
18 it, because the experts differed a lot among themselves.
19 So we have variability, even when we use their
20 best estimates, but we also elicited low values and high
21 values for everything that we elicited. So we do have a lot
22 of information that we can use to construct an uncertainty
23 distribution, and we certainly are going to do that.
24 DR. APOSTOLAKIS: Was the Marshall distribution
25 based on expert judgment? I don't know.

1 MR. ABRAMSON: Yes. My understanding of it is
2 yes. Very much -- I think it was expert judgment and, of
3 course, the available data at the time. That's right,
4 definitely.
5 DR. APOSTOLAKIS: You make the observation here
6 that the density of flaws in the PVRUF and Shoreham vessels
7 is significantly greater than predicted by a Marshall
8 distribution.
9 So I guess that's an indication that the experts
10 were optimistic. Is that observation going to affect
11 anything you're doing?
12 MR. ABRAMSON: Depends on ultimate -- I mean,
13 affect it, all of this is going to be input into the FAVOR
14 code, which will ultimately calculate a probability of
15 vessel failure.
16 DR. APOSTOLAKIS: I understand that. But
17 regarding the density, is it possible that your own experts
18 will be optimistic just as those who helped the Lord?
19 MR. ABRAMSON: Well, it's certainly possible. We
20 did not ask any of them for density numbers. All of these
21 are based on data.
22 DR. APOSTOLAKIS: You're modifying them.
23 MR. ABRAMSON: We're modifying it, that's right.
24 DR. APOSTOLAKIS: So those factors --
25 MR. ABRAMSON: It's possible. Well, it certainly

1 is possible, but --

2 DR. APOSTOLAKIS: I mean, there is no way you can

3 take this into the ratio, I suppose. I don't know.

4 MR. ABRAMSON: You have to look at the whole

5 process. When we elicited the experts, we not just elicited

6 the opinion. Matter of fact, in a sense, that was the least

7 time spent on that. We wanted to know their rationale for

8 all of this and in the report itself there's going to be a

9 much more fuller summary of the rationales for all of this.

10 There was also a significant amount of

11 disagreement among the experts and so on.

12 So the only thing I can say is -- and there was

13 certainly significant uncertainty and insofar as the

14 uncertainty is going to affect the answer, that will

15 certainly be reflected in it. In some cases, it won't

16 matter.

17 DR. APOSTOLAKIS: Speaking of uncertainty, I have

18 a couple of comments on the report. You have used, in this

19 calculation, as we just said, the mid value of the range of

20 the medians.

21 MR. ABRAMSON: Essentially. Or the median of the

22 mid values. However you want to look at it.

23 DR. APOSTOLAKIS: Median of the mid values. Now,

24 I hope you're not going to define medians and high values

25 and low values when you actually do your uncertainty

1 analysis. I think the accepted way of doing it now is to
2 actually have the distribution of each expert, put them all
3 on the same plot, like NUREG-1150 did or the Shack report
4 did -- not this Shack -- it's S. Shack -- and you select a
5 point on the abscissa and you go up and you find all the
6 experts take the mean, and that will give you a distribution
7 of the fraction because of the expert assessments, or you
8 can analyze it in a different way and there is a long
9 discussion in the appendix of that seismic report.
10 If you want to single out the variability -- the
11 expert-to-expert variability, I don't know what you're going
12 to do with it when you go to FAVOR, but maybe that would be
13 an additional insight.
14 But what I think -- and the whole idea behind all
15 this -- this is the idea of equal weights. You are giving
16 equal weights to the expert distributions because, as you
17 make a point here on page 14, the ensuing discussion served
18 to ensure a common understanding of the issues and the data.
19 Since you had this feedback, then there is no
20 reason really for you to give different weights from
21 different experts, which is really --
22 MR. ABRAMSON: We have no intention of doing that.
23 Absolutely not.
24 DR. APOSTOLAKIS: But I think you should give
25 equal weight to their distribution, not to the -- don't take

1 the medians and add them up and divide by 17.

2 See the difference?

3 MR. ABRAMSON: I'm not sure that a distribution

4 has any meaning here, because all we're asking is low, mid

5 and high values. I don't see that -- it doesn't make any

6 sense, to me, to --

7 DR. APOSTOLAKIS: You would have to make some

8 assumption regarding the distribution. I mean, is it a lot

9 -- normally, these things are --

10 MR. ABRAMSON: I don't think so. I don't think it

11 has any meaning. All we did is we asked -- when we asked

12 the experts for the low, mid and high values and we went

13 through a training session, I think they all understood what

14 we were asking.

15 The mid values, of course, are the approximately

16 median and a low value is one such that there's only a five

17 percent chance, in their judgment, that you could be lower

18 than that, and a high value is only a five percent chance

19 you could be above that.

20 DR. APOSTOLAKIS: Yes, but the fact that you don't

21 have that piece of information probably doesn't justify

22 adding the medians and dividing by 17.

23 MR. ABRAMSON: I'm not adding the medians. I

24 don't --

25 DR. APOSTOLAKIS: All I'm saying is in the future,

1 if you do that, it will not be consistent with what the
2 community thinks.
3 Now, you don't have the information of the
4 distribution between low, medium and high, but maybe you can
5 put something there and speculate and then see how the
6 summation comes up.
7 I mean, you will have to do something anyway,
8 because you don't have sufficient information.
9 MR. ABRAMSON: I know.
10 DR. APOSTOLAKIS: All I'm saying is there are two
11 major studies, 1150 and the other one, the senior seismic
12 hazard analysis committee report, which really spent a lot
13 of time on these issues. They both recommend that when you
14 are reasonably satisfied that the experts deserve equal
15 weight, then you do what NUREG-1150 did.
16 You have the variable, you put the distributions,
17 and then you go up each point and you add up the
18 probabilities of what the experts gave you and find the
19 value, and that gives you the composite uncertainty. And
20 there are other ways you can analyze it, too, but this is
21 the accepted way.
22 This is just a suggestion for the future that you
23 may want to consider, because you're on the right track. I
24 mean, you had this discussion of the issues and assuring a
25 common understanding. Then you can say because of that,

1 this is what we're going to do.

2 Let's see. Now, for these purposes here, taking

3 the mid value is just a representative example.

4 MR. ABRAMSON: We're just trying to get a ballpark

5 estimate at this point, that's right.

6 DR. APOSTOLAKIS: Okay. I guess that's it for the

7 time being.

8 MR. HACKETT: This is Ed Hackett. I'd like to add

9 a comment on what Professor Apostolakis mentioned on the

10 density, so as not to cause undue alarm. Several factors

11 come into play there. The issue with saying this

12 distribution has produced a much higher density of flaws

13 than Marshall, first off, shouldn't be surprising, because

14 what you're seeing is advancement in the state-of-the-art of

15 the NDE.

16 Then you could direct your attention to the boxes

17 over to the bottom right on Lee's chart there and that's

18 kind of illustrative right there. You look at the number of

19 small flaws and you see this 22,000 number and then you get

20 down to large flaws, which are getting closer to the

21 category of what would participate, as Terry would put it,

22 if you were looking at FAVOR probabilistically in a PTS type

23 transient. It's going to be a much, much reduced number.

24 So the fact that you're seeing, which is mainly

25 focused at the clad-base metal interface or in the weld

1 metal, is not an alarming thing. It is one of the things
2 I'd just like to leave everybody with.
3 DR. APOSTOLAKIS: I think it would be helpful and
4 useful to have these comments in the report, because this
5 statement is hanging there.
6 MR. HACKETT: That's one of the reasons I brought
7 it up, because it has tended to alarm some people and it's
8 really not the case. Most of those flaws are not going to
9 -- the vast majority of that number there that's got 22,000
10 is not going to participate significantly in response to a
11 PTS transient.
12 MS. JACKSON: I think in one of the documents that
13 we're going to send you, you'll see that a lot of the flaws
14 are just very, very small and they have no interest, no
15 interest at all.
16 MR. ABRAMSON: The details are going to be given
17 in the report and these densities are based where they were
18 applicable, and, in many cases, they were based on data from
19 the PVRUF, both from the Shoreham and the PVRUF flaws.
20 And when they weren't, we augmented it with expert
21 judgment.
22 SPEAKER: Well, I mean, let's be specific. The
23 welds are based on data, the others are based on expert
24 judgment, right?
25 MR. ABRAMSON: Let's take a look. Well, there's

1 also a question of repair and non-repair. I think, yes, I
2 would say the welds were the expert judgment, where the --
3 SPEAKER: The repair is probably an expert
4 judgment.
5 MR. ABRAMSON: Where the expert judgment was used
6 was -- it was in the plate, that's right.
7 DR. APOSTOLAKIS: And this is the expert judgment
8 --
9 MR. ABRAMSON: Now, the plate --
10 DR. APOSTOLAKIS: The 17 experts?
11 MR. ABRAMSON: Yes, that's what I mean. The
12 expert judgment, modified. That's right. They do not have
13 very much plate data, but they are getting some. So this
14 will be replaced by the plate data once we get it, and the
15 cladding, also, I think, was used to some extent in the
16 expert judgment.
17 And then, of course, to fill this out, we just
18 took these estimated densities by the measured volumes and
19 multiplied and that's where these came out.
20 Now, there were a very large number of small
21 flaws, but we fully expect that they really are going to
22 contribute essentially nothing or very close to nothing when
23 it comes down to the fracture mechanics in the FAVOR.
24 The ones that, of course, will contribute will be
25 the large flaws.

1 Now, we divided this table into two parts. The
2 bottom half is the cladding and there large flaws can be
3 most of the thickness of the cladding, which is six to eight
4 millimeters. So, again, we feel that that will probably not
5 contribute at all once it goes through the fracture
6 mechanics.
7 So the ones that will contribute will be the large
8 flaws here and, again, we emphasize, this is just a
9 preliminary estimate base that we have now. A vast majority
10 of these were from the weld metal manual, repaired, and
11 repairs are manual.
12 And this is what we've learned from the experts,
13 that repairs are much more likely than non-repair for metal
14 to have flaws in them. So that's what is driving this.
15 And we do have data on this, as well. I think
16 this was based on data because there were some repaired
17 regions here, like we see here.
18 DR. APOSTOLAKIS: So the density of large flaws is
19 96.
20 MR. ABRAMSON: No. The number, this is the number
21 of flaws. This is the estimated number of large flaws in
22 the entire -- in the PVRUF vessel, the part of it's subject
23 to PTS. That's the estimated number. A total of 96 large
24 flaws in the valve line.
25 DR. APOSTOLAKIS: So what will be the input?

1 MR. ABRAMSON: Into FAVOR?

2 DR. APOSTOLAKIS: Yes. Ninety-six?

3 MR. ABRAMSON: The number will be 96. Of course,
4 it will be distributed to location, and Terry will go into
5 this in detail.

6 But if we used this, if we ran FAVOR tomorrow, we
7 would say, yes, you start with a total of 96 flaws in the
8 valve line region.

9 DR. APOSTOLAKIS: So you start with 96 flaws.

10 MR. ABRAMSON: Right, exactly. Of all sizes, I
11 should say. This is the total number of large flaws. And
12 you would apply the distribution, which I'm coming to, to
13 get the specific sizes of those.

14 DR. APOSTOLAKIS: Now, if I go back to the
15 Maryland paper on uncertainty, that figure six, it says
16 flaws exhausted. What does that mean? They will do it for
17 each of the 96?

18 MR. ABRAMSON: Yes.

19 DR. APOSTOLAKIS: Each of the 96. Why? I mean,
20 they have a distribution, don't they? I don't understand
21 that. Anyway, we'll discuss that when the time comes.
22 Flaws exhausted, you do it for every single one? You're
23 going to take the probability that there is a flaw there and
24 the distribution of the size and just do it? I don't
25 understand what it means to exhaust the flaws.

1 You're given the total number, you have a certain
2 volume, right?
3 SPEAKER: You're talking about in the context of
4 the University of Maryland paper, flaws exhausted. What
5 that means is each vessel, let's say, has 96 flaws, if
6 that's what the case is. You calculate the probability of
7 fracture for each one of those flaws and then the
8 probability of fracture for the entire vessel is kind of a
9 summation process.
10 DR. APOSTOLAKIS: How do they differ?
11 SPEAKER: Well, flaw number one, you're going to
12 first sample it to find the size of it, and it may be in a
13 different location.
14 DR. APOSTOLAKIS: Each flaw may have a different
15 size.
16 SPEAKER: Yes. As well as be located at a
17 different part of the belt line region.
18 DR. APOSTOLAKIS: All right.
19 SPEAKER: As well as be located at a different
20 location through the wall.
21 DR. APOSTOLAKIS: Anyway, we'll discuss that in
22 November.
23 DR. KRESS: And if you get enough samples, we'll
24 just sample 96, you sample thousands to cover that.
25 SPEAKER: However many flaws are in the vessel,

1 that's how many you sample.

2 DR. APOSTOLAKIS: See, if you postulate that you

3 have 96, then you have to do it, right? But I don't know.

4 That's new to me.

5 DR. KRESS: I would have thought --

6 DR. APOSTOLAKIS: You're postulating that there

7 are 96, no matter what, and now you worry about where they

8 are and what the distribution of the size is.

9 DR. KRESS: Yes, but if you just take one flaw and

10 then fix its location and size by sampling, it seems to me

11 like 96 samples is not enough. You have to -- you don't

12 cover the map that way.

13 DR. APOSTOLAKIS: I guess that's why it's

14 important to understand what sampling means. Is it from the

15 aliatory -- is it epistemic, aliatory, how do they come

16 together, but I guess we'll have another subcommittee

17 meeting on this.

18 All right. Back to you.

19 SPEAKER: Maybe a point that's not clear for

20 Professor Apostolakis' question. Of course, you're going to

21 be doing many vessels, perhaps a million vessels, each with

22 the 96 flaws.

23 DR. KRESS: That's what I'm --

24 SPEAKER: Each one of the vessels has a certain

25 number of flaws and you're doing many, many vessels.

1 DR. KRESS: That covers many vessels, yes.

2 DR. APOSTOLAKIS: You select the vessel.

3 DR. KRESS: It's the way you phrase it.

4 MR. ABRAMSON: As I said before, this is also a
5 modification. To show that I meant what I said, I'm going
6 to modify it right now. Actually, this was a slide taken
7 from the presentation we made in August, but subsequent to
8 that, we've modified it and as I said, the current thing is
9 going to appear in the report, which is going to be out, I
10 guess, in a couple of weeks or so.

11 Where it's going to be modified is that this --
12 the large density, this is --

13 DR. APOSTOLAKIS: I don't think it matters.

14 MR. ABRAMSON: -- 700, densities. The numbers --
15 this becomes 40, the number was 40 here, so the total
16 becomes 66. So it's somewhat less than this. Don't rely on
17 this as far as -- and it may be modified -- it's a new table
18 and, also, since the FAVOR runs are not going to start for a
19 number of months, the numbers that we put into it, as we get
20 more information from PNNL, we certainly are going to modify
21 the inputs for FAVOR. So that may change it further.

22 But right now, it's somewhat less than 66, rather
23 than 96.

24 SPEAKER: Which is certainly different than 2,581.

25 MS. JACKSON: Right.

1 MR. ABRAMSON: That's right. It keeps going down
2 apparently. Now, the final part of this is the -- this is
3 CCDF for the large and small flaws and here is what we're
4 using right now, what's available right now.
5 This is based on the large and small flaws that
6 were observed by PNNL.
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8 END TAPE 2, SIDE 1.
9 TAPE 2, SIDE 2 FOLLOWS:
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1 BEGIN TAPE 2, SIDE 2:

2 Most of these came from Shoreham, which has not
3 been validated, and some of them, maybe about a third or so,
4 came from PVRUF, which has been validated.

5 But I put them all together and we get this
6 distribution, empirical distribution, which is based on
7 something like 64 total flaws all together, which, to my way
8 of looking at it, is remarkably smooth.

9 This has not been smoothed, by the way. We just
10 connected up the points.

11 DR. APOSTOLAKIS: So this is large flaws anywhere.

12 MR. ABRAMSON: That's right. Large flaws -- well,
13 in the weld metal, that's right. Repaired, non-repaired
14 material, we just threw them all together. That's right.
15 And the assumption we're making, working assumption we're
16 making right now is that this is a legitimate thing to do.

17 We can combine flaws from all different kinds of
18 weld metal and so on made under different welding conditions
19 and, in other words, a large flaw is a large flaw, as far as
20 this is concerned.

21 It doesn't matter what material it was in as far
22 as the crack size distribution is concerned. So this gives
23 us the power of doing that. That's how we're planning to
24 use it at this present time.

25 And there's a --

1 DR. APOSTOLAKIS: So ten percent chance of having
2 a flaw greater than ten millimeters. Wow.
3 MR. ABRAMSON: That's what the data showed. I
4 mean, this is based on the data, that's right. This is
5 based on the data. Ten percent of the large flaws were --
6 that's right, exactly. Which isn't a very large --
7 remember, George, this is -- we're talking about maybe six
8 flaws all together.
9 DR. APOSTOLAKIS: How many?
10 MR. ABRAMSON: We're talking about maybe six flaws
11 all together, but that's how it's coming out.
12 DR. APOSTOLAKIS: So if the process was faulty and
13 there is a large flaw, then probability that it's really
14 large is not negligible. What saves you is that you don't
15 have too many of those.
16 MR. ABRAMSON: And, of course, there is a
17 significant amount of uncertainty in this.
18 DR. APOSTOLAKIS: The process.
19 MR. ABRAMSON: A significant amount of uncertainty
20 in this distribution and when we do the final analysis, that
21 will be reflected in that.
22 DR. KRESS: Is that for the base metal?
23 MR. ABRAMSON: It's for flaws found everywhere.
24 Actually, I don't think we have any flaws in the base metal
25 because they didn't inspect any of that yet.

1 DR. KRESS: Okay.

2 MR. ABRAMSON: This is just flaws in the weld

3 material.

4 MS. JACKSON: A small area.

5 MR. ABRAMSON: Only a small area.

6 DR. KRESS: That's why the distribution goes below

7 five millimeters.

8 MR. ABRAMSON: That's right, yes.

9 DR. KRESS: Because it's bead size rather than --

10 MR. ABRAMSON: Bead size, right. We did that

11 definition. Exactly, that's right.

12 MR. HACKETT: I guess the other comment I would

13 add -- this is Ed Hackett -- is this is not -- I think Lee

14 stated this earlier. This is also not addressing location.

15 So it could be that even out of the six, in all the greatest

16 likelihood, they're not located on the surface, in which

17 case you may not have any participation at all, depending on

18 where these flaws are located.

19 SPEAKER: How does this compare with what you find

20 when you do UT inspections in the field? How many one-inch

21 long cracks have you found?

22 MR. HACKETT: This is Ed Hackett, again. I know

23 there may be some others in here who could comment on this,

24 too. My understanding is nothing in that range has been

25 found, that I'm aware of. Bob Hardy is here.

1 MR. ABRAMSON: We're predicting six per vessel.
2 MR. HACKETT: I think what you're looking at is
3 the statistics of the process and then, also, we have not
4 gotten into -- and Lee and Debbie haven't included this --
5 how good are the inspections versus what was done for PVRUF
6 and Shoreham. Obviously, these are laboratory conditions
7 and they're able to destructively verify what's there and
8 what isn't.
9 Of course, you can't do that in the field. The
10 NDE is better than it's ever been. But I don't believe --
11 maybe others in the room can comment. I'm not aware of
12 hearing anything in that kind of size range that's come from
13 a field inspection that would be in a surface location.
14 I think there have been isolated cases where
15 larger flaws, like on the order of multiple millimeters,
16 have been located at different points in the depth or maybe
17 towards the outer surface, but I'm not aware of any.
18 I don't know if you are, Debbie.
19 MS. JACKSON: No.
20 MR. HACKETT: Not in field inspections.
21 MS. JACKSON: On the large flaws that we've been
22 finding in the PVRUF and Shoreham are in the repaired area.
23 There was a large one that we found in Shoreham that's about
24 30 millimeters, but it hasn't been validated. So we don't
25 know.

1 According to proximity rules, if it's a cluster of
2 many small flaws, but the largest one found so far in PVRUF
3 was 17 millimeters.
4 MR. HACKETT: I would also add, though, Bill,
5 you're right in that if we do enough of these and we're
6 right about what we're doing here in the lab, eventually we
7 should find these things. I think it's just a question of
8 the statistics of the process and how good is the field NDE.
9 MS. JACKSON: Right.
10 MR. HARDIES: This is Bob Hardies, from Baltimore
11 Gas & Electric Company. The largest flaw so far that's been
12 validated, the 17 millimeters, was a cluster of small
13 volumetric things.
14 So really everything so far that's been
15 destructively examined that's been larger than ten
16 millimeters are really little porosity clusters.
17 MS. JACKSON: Right.
18 MR. ABRAMSON: Three of those, and here are 14,
19 21, and 32, these are from Shoreham data, which has not yet
20 been validated. Also, these large flaws bigger than ten,
21 three of them -- some of them were repaired, but others were
22 non-repaired.
23 We had -- again, this is not validated. It's 21
24 and 32 came from non-repaired material. Again, this is all
25 subject to possible revision once they validate the data.

1 And this is the CCDF for small flaws and this, I
2 believe, is based only on the PVRUF, I believe. This is a
3 lot choppier, but, again, this is what the data show at the
4 present time. Again, I repeat that we don't expect the
5 small flaws are going to contribute in any significant way
6 to vessel failure.
7 So this is of interest, but it's not really going
8 to affect the bottom line as far as PTS is concerned.
9 Now, how is this going to be used in the FAVOR
10 code? There's a little bit more detail here.
11 First of all, we have large flaws and small flaws
12 and we have weld material and plate material. We don't
13 expect the cladding to contribute anything significantly,
14 although certainly we will put it in, but we don't expect it
15 to contribute anything very significantly.
16 And what will the -- what the actual input will
17 be, we'll take the total number of large flaws, in this
18 case, it's the revised number of 66, and then we'll apply
19 that distribution to it and come up with the specific
20 X-sub-I, those are the crack depths.
21 So we'll take these 66 flaws, 66 large flaws in
22 the weld material, a certain number in the weld material,
23 whatever the number is, and a certain number in the plate
24 material, whatever that total number is, and then we'll just
25 assign numbers from the large flaw distribution.

1 These will then be a set of numbers, a set of
2 crack depths, and this is the weld large flaw and so on.
3 And similarly for small flaws.
4 So the input to PVRUF will be the specific; that
5 is, specific in terms of their crack depth. That will be
6 the input to PVRUF and then FAVOR, and then FAVOR will take
7 it from there, locate them and so on.
8 DR. APOSTOLAKIS: This will be both the aliatory
9 and epistemic component.
10 MR. ABRAMSON: I don't know if that is here.
11 DR. APOSTOLAKIS: You have a distribution.
12 MR. ABRAMSON: We have a distribution.
13 DR. APOSTOLAKIS: That would reflect the aliatory
14 and if you have many distributions, then epistemic.
15 MR. ABRAMSON: Okay. For any -- that's right.
16 How we're going to do the uncertainty analysis, that's
17 right. In effect, we could do -- we'll make draws from
18 those distributions, correct. That's right.
19 DR. APOSTOLAKIS: So this would have both.
20 MR. ABRAMSON: Yes. We'll certainly reflect all
21 of the uncertainty, absolutely.
22 SPEAKER: Again, I think that this is something
23 that we'll need to talk to you guys about at the
24 subcommittee meeting, because I think depending on how you
25 view the problem, even though you can talk about aliatory

1 components leading to observed variability, let's say, in
2 samples or in vessels, when you lock down on a vessel now,
3 say, you're hypothesizing a vessel with certain
4 characteristics and I think it's arguable whether the number
5 of cracks, for example, is aliatory or you could, in
6 principal, find them and characterize them, which is a
7 function of how this is being used in the model.
8 So that's, again, worth, I think, talking about
9 when we get together.
10 DR. APOSTOLAKIS: Okay. See, the problem is that
11 if you were talking about certain conditions which are from
12 all different plants, then, of course, it's aliatory because
13 you pick one plant.
14 SPEAKER: That's right.
15 DR. APOSTOLAKIS: Now, if you have one, though,
16 that distribution becomes subjective.
17 SPEAKER: That's right. That's how we're viewing
18 it right now.
19 DR. APOSTOLAKIS: But the problem is even if you
20 pick one and you find, say, ten flaws, they will probably
21 have different lengths, and if you don't have the aliatory
22 element, then you will probably assume that all of them are
23 of the same length.
24 SPEAKER: Again, this process, as I understand it,
25 is going to say you pick a location -- you effectively,

1 although it doesn't literally do this, you're going to be
2 picking a particular flaw with certain characteristics and
3 those characteristics will include not only the
4 characteristics of the flaw itself, but the properties in
5 the neighborhood of the flaw, and that's knowable, in
6 principal.
7 DR. APOSTOLAKIS: Okay. We'll discuss that.
8 SPEAKER: And, George, we would never assign the
9 same length to every one of those.
10 DR. APOSTOLAKIS: See, that's the fundamental
11 distinction between the two, that if you have an aliatory
12 component, you allow for this randomness. But as Nathan
13 says, if I understand, will you know enough about this
14 particular vessel so that you eliminate the random element.
15 You know the conditions and so on and this and
16 that, will you have only epistemic.
17 SPEAKER: The CCDF, this thing, this distribution
18 is strictly aliatory.
19 DR. APOSTOLAKIS: That's what I thought. For a
20 particular vessel, it may not --
21 SPEAKER: We're going to be sampling using that
22 distribution. It's how we use that sample in the
23 calculation that is the point that we're talking about.
24 There is certainly variability in the flaw sizes
25 if you look across the population of flaws. How you use

1 that uncertainty -- this is the plant to plant variability
2 versus a single plant issue that we look at in the PRA side,
3 and I see it as the same thing.
4 Once we start fixing on a particular location of a
5 particular vessel, and, again, this is all hypothesized,
6 once you've done that hypothesis, that's what FAVOR is
7 doing, given that now, is there really going to be that kind
8 of variability that you're talking about.
9 And that is where I think -- we have made certain
10 assumptions in the white paper which try to bring these
11 things out explicitly. This is why we're saying that this
12 particular issue is aliatory, this is epistemic, and I think
13 that would be a good basis to go through the paper.
14 DR. APOSTOLAKIS: But that would not apply to K.
15 SPEAKER: Right. That argument does not apply to
16 K. That's why we said in the paper now we think there is an
17 aliatory component that needs to be addressed separately
18 from the things that you're talking about, because there is
19 the model issue.
20 DR. APOSTOLAKIS: If you can walk us through a
21 particular calculation with all these observations, I think
22 that will be very helpful.
23 SPEAKER: One thing, again, I need to point out.
24 I think we've been working through this as part of the
25 overall PTS analysis and I don't know that we are fixed

1 right now on the approach that's going to be everlasting
2 that way.
3 It's evolving, we're discussing these things. We
4 will talk to you about where we are, of course, at the time
5 that we meet. But things certainly can change. I think
6 we've had a lot of discussions on these specific issues and
7 how to address them and we do need to walk you through how
8 we're looking at it now.
9 MR. GUNTER: Paul Gunter, Nuclear Information
10 Service. Noting the number of small flaws that you've
11 noted, I'm wondering if it's too quick of a judgment to
12 eliminate them as participating in a PTS event.
13 So could you just give me a quick idea of how you
14 can make that blanket statement that that many flaws and --
15 SPEAKER: I'm making that statement based on what
16 I heard about the likely effects when you put this through
17 the fracture mechanics code and everything like that, that
18 small flaws will just contribute very, very little, if at
19 all, to the probability of vessel failure.
20 And, actually, I'm not the person -- you need
21 somebody who can maybe speak more eloquently about that.
22 MR. DIXON: Terry Dixon, again, from Oak Ridge.
23 All of the flaws will be input into the FAVOR code. The
24 small flaws, as well as the large flaws.
25 Small flaws will be in the analysis and as much as

1 they contribute, they contribute. But, I mean, we know
2 certain things just about fracture mechanics. We know that
3 probably a flaw below four millimeters would never
4 contribute, but it will be in there.
5 Essentially, it will be part of the bookkeeping,
6 but we anticipate that it will contribute very, very little.
7 So it will be in the fracture mechanics analysis. It won't
8 be culled out.
9 MR. ABRAMSON: And just some concluding remarks
10 about the generalized flow distribution. What it does here
11 is it combines three areas, three elements, the densities,
12 which is generic, that would be the flaw distributions.
13 That's right.
14 The densities are generic in the sense that they
15 are not plant-specific. They are certainly product form
16 specific. They are certainly weld process specific and they
17 are repair state specific, but they don't depend on the
18 particular plant that we're talking about. So in that
19 sense, it's generic.
20 Crack depth distributions, as I indicated, are
21 generic, and the plant specific will, of course, have to be
22 the specific volumes and areas of the weld metal and the
23 base material in the plant and how much of that was
24 repaired, how much of that was not repaired, and the weld
25 process and so on. All of them are very specific about that

1 plant.

2 And the generic inputs are based on all available

3 data and where we don't have the available data, we have to

4 fill in, then we use the expert judgment from this panel of

5 17.

6 So that's the general structure of the generalized

7 flow distribution, as we have it now.

8 That's the end of my presentation, if you have any

9 questions.

10 SPEAKER: You make the comment in the report that

11 this thing agrees reasonably well with the Prodigal

12 predictions. I just wonder what --

13 MR. ABRAMSON: I didn't make that comment. I'm

14 not familiar with the Prodigal.

15 MS. JACKSON: That was some work that PNNL has

16 done before the PVRUF data was validated. So we've made

17 some changes to that.

18 But it was the data from PVRUF and Shoreham was

19 put into the Prodigal and the predictions came out pretty

20 close to what came off of Prodigal. That's one of the

21 things we're going to put in the repot, comparisons of the

22 PVRUF and the Shoreham.

23 SPEAKER: I think it's safe to say, Debbie, that

24 we're also planning to use -- or we don't have data to use

25 Prodigal runs, as well as expert judgment.

1 DR. APOSTOLAKIS: See, Prodigal is expert
2 judgment. That's what confuses me all the time when I see
3 that.
4 SPEAKER: It's a different kind of expert
5 judgment.
6 SPEAKER: George, it's different expert judgment.
7 The questions are very different and Prodigal -- I mean, you
8 need certain inputs into the Prodigal. The Prodigal does
9 model very explicitly the physical process of welding and
10 creating flaws and how they would propagate.
11 MS. JACKSON: And the same with Prodigal. The
12 Prodigal doesn't deal with base metals. So when we get into
13 the base metal issue, we can't use Prodigal. It only deals
14 with weld.
15 SPEAKER: I just wondered. These numbers seem to
16 be floating around so much and I assume that depends on
17 whether you're multiplying by the right weld volumes times
18 the densities or --
19 MS. JACKSON: That was another thing, because
20 initially we had had a different -- I was just concentrating
21 on the weld volume in the belt line area, that's all. Not
22 every other thing, the belt line.
23 SPEAKER: Every other weld.
24 MS. JACKSON: Right. And then we just recently
25 got some construction records from PVRUF. So we found some

1 of the numbers were a little different from what PNNL had.
2 So hopefully we'll be able to get more information on the
3 construction records from the fabricators themselves, that's
4 what we're hoping to do.
5 SPEAKER: It's comforting to find numbers that
6 converge. When I see numbers that go from 2,581 to 90 to
7 66.
8 MS. JACKSON: Right. Some of those were due to
9 operator error, also, with the calculators at some point.
10 SPEAKER: I guess we can start with Shaw's
11 presentation.
12 MR. MALLICK: I am Shaw Mallick, the Materials
13 Handling Branch, and I will be providing a bit on
14 probabilistic fracture mechanics within the PTS project.
15 A brief outline is we're going to go provide one
16 of the major technical areas, the progress made in all those
17 technical areas, and some concluding remarks.
18 Here are the six technical areas we are currently
19 working on. You already have heard about the fabrication
20 flaw distribution and there will be presentations on
21 distribution, fracture toughness, improved irradiation
22 involvement, and the computer code. So this will be a more
23 explicit presentation.
24 I will briefly discuss these ones. I'm not sure
25 if I should go and tell you a little more on that, that you

1 already have for over an hour.

2 So I will skip that part of the presentation.

3 DR. APOSTOLAKIS: I wish you didn't say

4 statistical representation. Presentation of the

5 uncertainties.

6 MR. MALLICK: Okay.

7 SPEAKER: Well, but this report is statistical.

8 DR. APOSTOLAKIS: It shouldn't be.

9 SPEAKER: Well, there is the Oak Ridge report,

10 which is statistical. Whether it should be or shouldn't be.

11 I would like to go over the fabrication, number

12 six, which is the fracture toughness distribution. The

13 objective here is to provide initiation of fracture

14 toughness based on expanded ASTME-399, the standard type of

15 data, and using statistical methods.

16 And just as background, our latest revision was

17 developed based on '70s and '80s toughness data and they

18 were -- not only that, those data were put through an ad hoc

19 distribution based on lower bound curve.

20 The Research staff is Mark Kirk, myself and Nathan

21 Su, in PRA area, and our contractors at Oak Ridge, as well

22 as University of Maryland, and we are also getting some help

23 from EPRI and a contractor PEI, Phoenix Engineering

24 Associate, Professor Marge Natisha, who used to be at

25 University of Maryland earlier.

1 Briefly describing the progress made, we will hear
2 that in about 45 minutes worth of presentation on that in
3 the later afternoon. Searched and collected additional data
4 and almost doubled the rate and based on those data, set the
5 distribution for both different parameters and those
6 distributions for initiation of fracture toughness K1C, as
7 well as the K1A.
8 And one thing in that report that's missing was
9 uncertainty in the normalizing parameter RTNDT. That is
10 being looked at separately.
11 And University of Maryland is assisting in
12 separating those into epistemic, as well as aliatory
13 uncertainty, as well as effect of material variability and
14 model uncertainties. And we expect to have completion by
15 November.
16 DR. APOSTOLAKIS: So the variable distribution is
17 aliatory.
18 MR. MALLICK: Yes.
19 DR. APOSTOLAKIS: And then you have three
20 parameters, A, B, C, each one being a complex function of
21 delta RTNDT.
22 MR. MALLICK: RTNDT.
23 DR. APOSTOLAKIS: RTNDT now will have epistemic
24 and aliatory itself?
25 MR. MALLICK: Yes.

1 SPEAKER: If someone will explain to me again. I
2 still have problems with whether I'm following a curve or
3 I'm walking up and down this whole distribution, and I
4 assume we'll talk about that.
5 MR. MALLICK: There will be discussion on that
6 this afternoon.
7 DR. APOSTOLAKIS: Are you going to have any expert
8 elicitation exercises in addition to what Lee did?
9 MR. MALLICK: In the flaw distribution area --
10 DR. APOSTOLAKIS: You are saying here that
11 Maryland and EPRI are assisting in model uncertainty. How
12 are you going to assess the model uncertainty?
13 MR. MALLICK: They are going through the root
14 cause diagram, going through what are the basic parameters
15 building up to the model uncertainty and deciding what are
16 the uncertainties in those areas.
17 DR. APOSTOLAKIS: Yes, but there is a model
18 someplace that is not in a good shape. Somehow you have to
19 evaluate the uncertainties associated with the predictions
20 of this model.
21 MR. MALLICK: Yes.
22 DR. APOSTOLAKIS: How are you going to do that?
23 SPEAKER: Let me try that a different way. Short
24 answer is between us on the staff and University of Maryland
25 and Oak Ridge, but the question that you're getting to is

1 the how good of a model is RTNDT at predicting what the --
2 if we're assuming truth of the situations, we want to get to
3 the fracture toughness and we get there by using RTNDT as an
4 index, how good is that as a model.
5 We have never addressed that explicitly before and
6 as you mentioned, there are both aliatory and epistemic
7 components to that. That is going to be addressed -- I
8 guess I can back up and say this is another area that could
9 have easily lended itself to expert elicitation. I think
10 what we're looking at is running up against resource
11 limitations on being able to do that.
12 So what we're doing is trying to do that as a
13 group between the staff and, in this case, University of
14 Maryland and Oak Ridge.
15 DR. APOSTOLAKIS: Internal experts.
16 SPEAKER: Right.
17 DR. APOSTOLAKIS: But you will do it.
18 SPEAKER: Yes, absolutely.
19 DR. APOSTOLAKIS: That seismic -- is Lee here?
20 SPEAKER: Yes.
21 DR. APOSTOLAKIS: That seismic report gets you way
22 out of this, because it defines two ways, two major ways for
23 doing an analysis using the technical integrator or the
24 technical facilitator integrator, and depending on the
25 significance of the issue, you may go with the technical

1 integrator, which is a less formal way of eliciting
2 judgments and I think that's what they have just described.
3 But as for the other stuff that you just
4 presented, you really did the tier five, because it was
5 bigger, broader and so on.
6 So I think there is a lot if information there
7 that will help you. There are two volumes and -- I don't
8 know. Do you know which volume I'm referring to?
9 SPEAKER: Yes.
10 DR. APOSTOLAKIS: Okay. Because the technical
11 integrator approach was used without this for Diablo Canyon,
12 we were told at the time, and it worked very well.
13 Everybody liked it very much.
14 You didn't have to go out of your way to bring
15 experts and fly them over to Albuquerque, usually, and do
16 these things.
17 SPEAKER: We did a lot with video conferencing.
18 DR. APOSTOLAKIS: So there is some merit to that.
19 You know, if you give something a name, it's automatically
20 more respectable.
21 MR. MALLICK: The next area we are looking at is
22 embrittlement correlation development and the objective here
23 is to revise the predicted shift in RTNDT using up-to-date
24 data, as well as the statistical data, and not only that, we
25 are also trying to -- in the process to revise the Reg Guide

1 1.99, which two of the three -- there will be a three
2 document draft developed and we want to have consistency
3 with that guide, as well.
4 Then they become part of the rule, as well as a
5 guide, going in parallel and they are addressing the same
6 issues.
7 Currently, we're looking at the correlation for
8 Reg Guide 1.99, and it's based on earlier data. Again, we
9 have at least three times more data now on embrittlement
10 correlation than we had at that time of the data set.
11 And this is Mark Kirk and Carolyn Fairbanks, and
12 the contractor for the NRC side is Modeling and Computing
13 Associates, which is Ernie Leeson. Oak Ridge National Lab
14 is Randy Nanstadt and his group, as well as University of
15 Maryland is, again, helping us.
16 SPEAKER: What is PEAI?
17 MR. MALLICK: It's the Phoenix Engineering
18 Associates Incorporated.
19 Progress made in this case. We have a mean
20 correlation. End of August -- end of July, sorry, we have a
21 mean correlation.
22 DR. APOSTOLAKIS: What is a mean correlation?
23 MR. MALLICK: Mean is best estimate correlation
24 and we are trying to -- the next step is to characterize.
25 DR. APOSTOLAKIS: So much educating to do. So the

1 uncertainties characterize using the approach that Debbie
2 described.
3 MR. MALLICK: Yes.
4 SPEAKER: That's correct.
5 DR. APOSTOLAKIS: So among us.
6 MR. MALLICK: After lunch, we'll have some more
7 discussion on that.
8 SPEAKER: This is one that I think it's fair to
9 say an expert elicitation might have been a benefit here.
10 DR. APOSTOLAKIS: Again, you don't have to limit
11 yourself to the --
12 SPEAKER: The formal process.
13 DR. APOSTOLAKIS: -- inside people. I mean, you
14 don't have to have a very formal process and still consult
15 with outside experts. Sometimes even a phone call. It's
16 better to have information than not to have it.
17 SPEAKER: This has actually been the case with
18 this one, because this actually, in terms of -- the mean
19 correlation that was developed by the work of Ernie Leeson
20 and Bob Odette principally was sort of vetted out even in
21 the 1998 timeframe.
22 SPEAKER: But when you get an ASTM, you're
23 essentially getting a certain advantage of opinions.
24 SPEAKER: And then ASTME-10 committee has had a
25 lot of discussion, influence, et cetera, on some of the

1 direction where that's going. So that's been vetted at
2 least among industry groups and consensus codes and
3 standards folks, too.
4 DR. APOSTOLAKIS: Please don't call it mean.
5 MR. MALLICK: Best estimate.
6 DR. APOSTOLAKIS: Just nothing. There is no such
7 thing as best estimate either. That's okay. Best estimate
8 is better than mean.
9 SPEAKER: Best guess.
10 MR. MALLICK: Both in Maryland, the correlation
11 analyzes the fracture toughness and the specific material,
12 so we can see the solution to the input, and these
13 activities are using industry data to come up with the
14 distribution in terms of distribution for copper, nickel and
15 phosphorous.
16 Also, it is to get the local variability. For the
17 weld case, we have four PTS plants. In this, we have
18 something like 15 weld heats, with two nickel addition, as
19 well as 16 plate heats, and the work is virtually internal.
20 Doug Kornoski, Tammy Samples, and Lea Berser, as well as the
21 industry to get their data, a lot of data from the industry.
22 For the weld case, we have some heat distribution
23 already. They are essentially normal. And we also have
24 local variability. Welds are presented using distribution
25 of copper and nickel, as well as normal distribution for

1 phosphorous.

2 In the case of plates, the data set is somewhat

3 limited. So data is limited for the heats in the PTS

4 plants. So chemistry was taken as heat estimate and we

5 didn't have as good a distribution as we had for the weld

6 material, but the plates are much more uniformly fabricated

7 and things like that. So they were much less as it would be

8 in this case, the effect of variability, that is. So,

9 again, plates, we have limited data we obtained and we need

10 to develop a solution on that as well.

11 SPEAKER: By looking at this variation, are you

12 going to change the margin type terms that you would usually

13 use in a Reg Guide 1.99?

14 MR. MALLICK: They will go as a -- the

15 distribution will go in the analysis. We probably do not

16 have a margin.

17 SPEAKER: You'll replace the margin with this

18 distribution.

19 MR. MALLICK: Yes. The next major area we are

20 working on is the neutron fluence calculations and our

21 objective for this activity is to determine an up-to-date

22 end of life fuels map for the plants, all the four plants we

23 are looking at, using currently available cycle by cycle

24 data of the fuel loading, as well as the plant data and also

25 to have some kind of estimate for uncertainty in the fluence

1 calculation, as well.

2 And we are using draft dosimetry guide 10.53, I
3 think this will be coming soon, as well as corresponding
4 NUREG report. That staff is Billy Jones and we're getting
5 help from Brookhaven National Lab on that.

6 Plants on-line so far, all the three plants,
7 Oconee-1, Palisades and Calvert Cliffs have been analyzed.
8 We also had analyzed Robinson, but it's not in the running.
9 So we are replacing it with Beaver Valley and we are just
10 receiving the plant data from Beaver Valley, we have to look
11 at to what extent we have to perform analysis on that.

12 And Brookhaven has performed very defined grids
13 for actual circumferential, as well as the radial direction.
14 For example, here is the example given for Oconee, Palisades
15 and Calvert, actually is 218, and the corresponding
16 circumferential is 60 nodes. Similarly, we have a very
17 refined grid going in.

18 Now, Brookhaven also has calculated some kind of
19 uncertainty in the fluence calculation and for each of these
20 three plants, one sigma in fluence is about three percent of
21 the mean value.

22 And we are internally looking at do we need to
23 perform some kind of modeling interaction among these
24 various fluence parameters, such as vessel damage or nuclear
25 cross-section, they are the major contributor for the

1 uncertainty. So we're going to go look at the interaction
2 between them and that may have some effect on this number of
3 13 percent answer.
4 SPEAKER: Your comment on the non-linear
5 interaction of parameters, you mention the core inlet
6 temperature. Is that a strong parameter?
7 MR. MALLICK: Those parameters are -- it's five
8 percent of the mean or something like that is contributing
9 toward that. But I can find out more on that.
10 SPEAKER: That's the inlet.
11 MR. MALLICK: Yes.
12 SPEAKER: Okay. I will ask. In looking at these
13 parameters, have you asked yourself are there any parameters
14 -- core inlet, I guess, doesn't do it, but core outlet might
15 -- any parameters that might be significantly changed as a
16 result of things like power upgrades and so on? Is there
17 anything in here, for example, that might be dependent on
18 flow rates?
19 MR. HACKETT: I'll try and take that one. This is
20 Ed Hackett. We haven't' gotten to that level of refinement,
21 Bob, but that's a good point. Among other things that
22 haven't really been considered here that may come into play
23 in the future, that would be one, power upgrades.
24 Another thing would be the change in the neutron
25 spectra relative to higher burn-up fuels or MOX fuel

1 possibly.

2 SPEAKER: It's really a shame. You play the game

3 with your hands tied behind your back and then somebody

4 comes along with an innovative idea and suddenly all of your

5 data is kind of -- it's not all that great anymore, and it's

6 your fault.

7 MR. HACKETT: It seems like that's what happens at

8 times.

9 SPEAKER: Just from the analysis that you've done,

10 how well do these sort of refined calculations match the

11 calculations that the plants used to estimate their

12 fluences?

13 MR. MALLICK: They are very much similar, I would

14 think so, but their details are not that - they have not

15 done calculations or it's not as refined. But there is not

16 that much difference, I would think so.

17 SPEAKER: Okay. So that even though you're doing

18 a more refined calculation, there's nothing to indicate that

19 the plant calculations are unreasonable or unconservative.

20 SPEAKER: But if they use a less dense grid, then

21 they get less peaking, don't they? I mean, their integrals

22 are the same or roughly the same. So you will show higher

23 peaks in general than they will.

24 MR. MALLICK: Probably so, yes.

25 SPEAKER: I guess -- I'm trying to think of the

1 right way to come back at that one. Bill posed the question
2 of which way would this go. I think this is a level of
3 refinement that's beyond what most folks would have
4 submitted, well beyond what most folks would have submitted
5 on the PTS rule.
6 And what they would have assumed there is look at
7 the maximum asmuthal fluence and assume that that applied
8 all around the belt line. That's what was historically done
9 before. Palisades was the first time, when we did the
10 Palisades PTS evaluation, this would have been vintage
11 '96-'97, that people -- that they first got into a
12 plant-specific fluence map.
13 And then what you're looking at is the integration
14 of that around the core and that always acts in their favor,
15 related to what they had done previously.
16 SPEAKER: Because you have a huge --
17 SPEAKER: Right.
18 SPEAKER: And everybody else just took that peak
19 all the way around.
20 SPEAKER: Exactly. Now, Bob is getting to the
21 point of how well that was modeled at the peak, and I guess
22 I don't have the wherewithal to come at that one without
23 Lambrose or somebody like that being here.
24 I think what was done is they would capture,
25 however the capture it, the peak asmuthal fluence and then

1 apply that fluence around the belt line.

2 SPEAKER: Okay.

3 SPEAKER: So they could tolerate a fair amount of

4 change and still be conservative, in all likelihood.

5 SPEAKER: I'm thinking about axial now, and that's

6 where all the structure is, or a lot of it.

7 SPEAKER: Good point.

8 MR. MALLICK: The next major activity that

9 integrates all the work together is the PFM code, which is

10 being revised and implemented. This objective is to

11 implement the refined PFM methodology as well as up-to-date

12 materials data into the code and make it consistent with

13 current PRA, as well as thermal hydraulics output data, as

14 well as methodology.

15 And myself, Nathan and Lea Berser, and Oak Ridge,

16 contractor, Oak Ridge National Lab, Terry Dixon, who is

17 integrating everything together, and University of Maryland

18 in terms of uncertainties and all those things will be

19 brought into this program.

20 Brief conclusion here, concluding remarks. The

21 analysis models are being finalized, such as embrittlement

22 correlation, fracture toughness distributions, and flaw

23 distributions. Then we are also going to -- based on these

24 finalized models, we're going to do some scoping studies

25 with reality doing some, but we are going to do a formal

1 scoping study on the particular plant, such as Oconee. The
2 application for the first plant at Oconee has started and
3 PRA, as well as thermal hydraulic area, but PFM analysis to
4 start soon on the scoping analysis.
5 But once we have finalized the whole model, actual
6 work on the complete analysis will start in the March
7 timeframe, we have modified other FAVOR code.
8 And just to comment, additional primary sources
9 are being used to build rigorous uncertainty model for the
10 key variables.
11 SPEAKER: Well, I congratulate the staff. Despite
12 the best efforts of the subcommittee, they've been right on
13 schedule.
14 We'll take a break now for lunch, and be ready to
15 start at 1:00.
16 [Recess.]
17 END TAPE 2, SIDE 2.
18 TAPE 3, SIDE A
19 SPEAKER: [In progress] -- the embrittlement trend
20 curves, and Mr. Kirk is going to give us the discussion.
21 DR. KRESS: Captain Kirk?
22 SPEAKER: Captain Kirk.
23 DR. SEALE: Shall we beam him up or beam him down?
24 MR. KIRK: That's why going into the Navy was
25 never an option, because I figured I might have some luck

1 with the career up to the level of captain.

2 DR. SEALE: Oh, there you go.

3 DR. KRESS: Then that would be it.

4 MR. KIRK: Then nobody would return your calls.

5 SPEAKER: With great foresight, he has put his

6 uncertainty analysis on the last view-graph.

7 DR. KRESS: That's a good idea. He knows what

8 he's doing.

9 MR. KIRK: Okay. I've got to reverse the order of

10 my slides, because I have the second presentation first.

11 SPEAKER: Well, the question is will we notice the

12 difference?

13 MR. KIRK: Well, I don't know. How much did you

14 eat for lunch?

15 Oh, here we go.

16 Okay. That works.

17 Okay.

18 The topic of the current presentation is revision

19 of the delta-T-30. That's the shift in the 30-foot-pound

20 sharpie transition temperature embrittlement trend curves.

21 My name is Mark Kirk. I work at Hackett's branch.

22 This information sees two applications.

23 One, of course, is the project that we're here to

24 talk about today and revision of the PTS screening criteria,

25 but the project that actually has generated the information

1 you're going to see here is another project that we're
2 working on on revision to Reg. Guide 1.99.
3 It will be Revision No. 3 when it finally comes
4 out, and of course, the application of that document is in
5 both a PTS assessment methodology where plant operators
6 calculate what their reference temperature for PTS is, it
7 then compares to the screening criteria, but it also gets
8 applied in the calculation of heat-up and cool-down curves.
9 So, in the development of this information, we had
10 those sort of dual applications in mind.
11 Now, the reg. guide itself will include
12 information and guidance on things that are not needed for
13 the PTS re-evaluation.
14 I've listed here sort of the -- this is the
15 high-level discretization of the reg. guide.
16 There is the transition shift embrittlement trend
17 curve.
18 There is the uncertainty analysis of that trend
19 curve.
20 There is the through-wall attenuation function,
21 because all of these -- all these transition shifts that
22 we'll be focusing mostly on here are calculated from
23 surveillance capsule data, and of course, that's bolted
24 right to the ID of the vessel. So, they're essentially at
25 ID fluence, ID spectrum.

1 That then needs to be attenuated through the wall,
2 so that's another thing going into the reg. guide.
3 We have treatment procedures for plant-specific
4 data and how we adjust for surveillance or not, and then we
5 also have upper-shelf energy trend curves and uncertainty
6 analysis.
7 Of those, these last two just don't come into the
8 PTS re-evaluation at all. All the other parts do.
9 The work to date and what the rest of the
10 presentation reflects is that the major focus has been up
11 here in getting the embrittlement trend curve, and that's
12 sort of where we are today.
13 The work is basically completed. We're in the
14 process of writing the technical basis document, and that's
15 an activity that's going to be going on among the NRC staff
16 for probably the next three to six months.
17 The embrittlement trend curve just became
18 available, or I should say the current manifestation of the
19 embrittlement trend curve.
20 The uncertainty analysis has just begun to be
21 performed, and the current view on that is that will be done
22 sometime in the November to December timeframe, although I
23 can share with you some early results from that.
24 We're just starting to have some discussions
25 regarding what the proper through-wall attenuation function

1 is, and similarly on treatment of plant-specific data,
2 although again, you know, just to give you a perspective on
3 this, the thought is -- and I'll discuss this in more detail
4 as we go through the presentation -- that probably as we
5 move to Rev. 3, we're going to be moving away from giving as
6 much credit to the plant-specific information and instead
7 going with more of the generic chemistry-based trends.
8 SPEAKER: When you say upper-shelf energy, is that
9 the JR curve?
10 MR. KIRK: No. Upper-shelf energy --
11 SPEAKER: -- means upper-shelf energy.
12 MR. KIRK: Yes.
13 SPEAKER: What about the JR curve work? Is that
14 going to be updated, the JR curve correlation?
15 MR. KIRK: Ed, help me out here. I wasn't aware
16 JR curves were in the reg. guide.
17 SPEAKER: They're not in the reg. guide, but
18 there's a JR correlation that has a through-wall
19 attenuation.
20 SPEAKER: It's a JR-curve-based attenuation, and
21 the answer is no plans for that right now, based on the fact
22 that it was the equivalent margins analyses that were done
23 with the industry to show that basically there wasn't a need
24 for it.
25 There are -- my understanding, although I haven't

1 paid attention to this a whole lot -- I think it was
2 addressed in Ernie and Bob's NUREG in 1998 in terms of a
3 refinement, but that refinement didn't indicate that there
4 was a need to re-do any of that work.
5 So, the short answer is no, we aren't going to be
6 pursuing that.
7 SPEAKER: Just to make sure I've got this right,
8 Ed, what goes in the reg. guide is an equation that predicts
9 the drop in upper-shelf energy.
10 SPEAKER: Right.
11 SPEAKER: Wouldn't have affect the
12 heat-up/cool-down analyses?
13 SPEAKER: It does, or it could. I guess I'd put
14 it that way.
15 The difference is, I guess, based on the
16 equivalent margins analyses, that it wasn't -- didn't look
17 like it was going to be any effect on plant safety for even
18 below -- significantly below 50-foot-pounds, which is where
19 the cut-off was in the 10 CFR 50, Appendix G.
20 SPEAKER: Okay.
21 DR. KRESS: You are going to share with us what
22 your perception of a plant PRA-consistent uncertainty
23 framework is.
24 MR. KIRK: Yes, sir.
25 DR. KRESS: Is that right?

1 SPEAKER: That's the last view-graph.

2 MR. KIRK: And I'll defer all the tricky questions

3 to Nathan on that one.

4 DR. KRESS: Okay.

5 MR. KIRK: Since I see he's sitting there smiling

6 at me.

7 Okay.

8 Just as a point of reference, the trend curve in

9 the current reg. guide that we currently regulation to is

10 shown here.

11 You've got your sharpie shift is a product of two

12 different factors, a chemistry factor and a fluence factor,

13 and absorbed into the chemistry factor are all the

14 dependencies of copper and nickel and product form. Those

15 are the ones that are explicitly called out in the table

16 that gives you the chemistry factor numbers.

17 When you see it in a few slides, the form of the

18 equation has increased considerably in complexity over the

19 years.

20 Where we started with this, to develop a new shift

21 curve, is that we've got considerably more data than we had

22 that Reg. Guide 1.99, Rev. 2 was based on.

23 Rev. 2 was based on something a little bit shy of

24 200 surveillance data points. We're now up almost to 800.

25 That's the database that Ernie and Joyce used to calibrate

1 the model.

2 The other thing that's changed considerably in the
3 past, I guess now, decade-and-a-half is our understanding of
4 the underlying physical causes of the embrittlement
5 mechanisms, and that has also played a role in the
6 correlation development.

7 So, the -- just a few notes on the modeling
8 considerations that were used in developing this
9 correlation:

10 It's -- for anybody that's looked at embrittlement
11 correlations, it's pretty obvious it's going to be a
12 non-linear fit, and as a consequence, some of the fit
13 coefficients are based on the entire data set, like, say,
14 the copper coefficients and the coefficients on nickel,
15 whereas some are based only on subsets, like there's a term
16 in there that expresses the influence of flux at low times,
17 and obviously, you can't -- or at long times, I'm sorry.
18 Obviously, you can't calibrate that with short-time data.
19 So, data subsets have been used in the fit.

20 Some of our metrics for what a good fit has is, of
21 course, minimum standard error, and Ernie and Joyce did a
22 lot of looking at the residuals.

23 Of course, they were looking for an average
24 residual, zero balance plus and minus residuals, but perhaps
25 the main focus in model development was looking at trends of

1 residuals where, of course, residual is just the difference
2 between what the model is predicting and what the original
3 data said, that there's no trend in the residuals with
4 either a modeled variable or an un-modeled variable.
5 If there's a trend with a modeled variable, then
6 that suggests you don't have the functional form right. If
7 there's a trend with an un-modeled variable, well, that's a
8 suggestion that perhaps you should include it in your model.
9 In terms of statistical significance tests that we
10 apply, our understanding coming from the physics and working
11 with folks like Bob Odette gives us some guidance in how we
12 run our statistical significance tests.
13 For example, if we have a variable like
14 phosphorous where we might not understand all the in's and
15 out's of phosphorous damage in a radiation environment, but
16 we do understand enough to say, well, if there is a
17 phosphorous effect, it's going to go in the positive
18 direction, that then suggests that you do a one-tailed test,
19 whereas if you have an element or an indicator variable or
20 whatever that you don't really know, then you'll be doing a
21 two-tailed test on statistical significance.
22 Also, the stability of the model was checked
23 extensively. Since it's a non-linear model, there's not
24 just one right answer, there's an infinity of potential
25 answers.

1 So, we check the stability of the fit coefficients
2 relative to the initial estimates by just making a bunch of
3 initial guesses and making sure that we always came out with
4 the same coefficients at the end, and also, we checked the
5 stability of the model relative to the data set used to do
6 the calibration.
7 The coefficients that actually came out were based
8 on a calibration of -- came from a calibration that used all
9 of the available data, but we wanted to make sure that the
10 trend curve wasn't over-fit and wasn't just somehow specific
11 to that data set.
12 So, we ran a number of calibrations on data
13 subsets to make sure that those coefficients came out
14 statistically similar to the coefficients in the equation,
15 where we used all the data, and indeed, they did.
16 Just to give you some examples of the type of
17 information that Ernie and Joyce were looking at as they
18 developed this correlation -- and I think these are graphs
19 you can probably better see on your hand-outs than in my
20 overheads, because the print's kind of small, but the upper
21 curves show the trend of both copper -- of shift with copper
22 and shift with phosphorous, whereas the lower curves show
23 the residual, the difference between what was predicted by
24 the model and these measure data relative to the final
25 model.

1 And of course, you see what we just said was the
2 criteria for having a successful model, that the residuals
3 do, indeed, show no significant trend with the modeled
4 variables, and indeed, if you look at the next slide, there
5 are, of course, other variables that don't appear, that you
6 won't find in the equation, like flux, specifically, and
7 manganese, but there were reasons to suspect that these
8 might be important factors.
9 Of course, the justification for leaving them out
10 is that you've got a model that has zero residual, a balance
11 residual anyway, so there's no burning need to put these in
12 at this time.
13 As we got -- I should note, this is an effort in
14 terms of -- when we go back in history, this is an effort
15 that probably dates back to about 1992, where we let a
16 contract with Modeling Computing Services to start looking
17 at developing this correlation.
18 They gave us a report in 1998, and we've been
19 doing some refinements on that model ever since, some of the
20 things, as we sort of came down to the 11th hour, some of
21 the variables that we were considering.
22 So, I should say -- I guess what I want to say is
23 there were other variables, of course, like copper and
24 nickel that were already in the correlation at this point,
25 but recently we've been looking at a copper saturation

1 effect, which you saw the empirical evidence of a couple
2 slides ago, that once you get to a certain amount of copper,
3 it no longer is damaging and the amount of shift saturates,
4 phosphorous, which you saw, and interaction between flux
5 time and fluence, which is to say that fluence isn't the
6 only descriptor of irradiation damage. So, we needed to
7 include other -- or potentially needed to include other
8 terms.
9 In looking at the data and in getting some new
10 data, there was also revealed what came to be called a
11 long-time effect, where the data points sort of at the end
12 of our statistical database, above 97,000 hours, show a
13 systematically higher shift than would be predicted by any
14 of the models that we had, systematically higher shift on
15 the order of 10 degrees Fahrenheit.
16 And then there was also an effect that was
17 discovered in the process of trying to find out what was
18 going here of vessel fabricator, where it was discovered
19 that, if you looked at the shifts in the plate data, those
20 plates that were in CE-manufactured vessels had shifts that
21 were systematically under-predicted by the model, whereas
22 plates in non-CE-manufactured vessels had shifts that were
23 systematically over-predicted by the model.
24 I'm not going to delude you that we have any
25 physical understanding, at least at this stage, of why the

1 heck that is, because -- I'll say it before anybody else
2 does -- 99 percent of those plates came from Lukens.
3 Now, of course, that's not to say -- there are
4 things that happen after the steel leaves the manufacturer's
5 shop and at the fabricator.
6 So, it's not completely implausible that something
7 like that could be true, but our physical understanding of
8 it right now is non-existence. There is, however, a very
9 compelling body of statistical evidence that the effect is
10 really there.
11 As we got down to these more -- what I will call
12 more nuancy effects than those of copper, nickel, and
13 fluence, we felt it was important to impose a bit of rigor
14 on ourselves in terms of thinking about, well, what of these
15 should we let into the model and what of these should we
16 leave on the table perhaps for next time. So, we developed
17 at least a gating criteria with a lot of fuzzy words in here
18 to help calibrate ourselves.
19 We said, well, we're trying to think about this
20 both in terms of what the statistical argument is for
21 inclusion or exclusion of a term, as well as what the
22 physical -- how well understood the underlying physics are
23 of the damage mechanism.
24 So, in terms of statistical basis, we looked at
25 the situation where we could have a strong statistical

1 basis, greater than 95-percent confidence that we have a
2 trend in the model that couldn't be attributed to a
3 mis-interpretation of random error.
4 You could have a weak amount of evidence or you
5 could have something in between, and then for physical
6 rationale, you could have a damage mechanism that's well
7 accepted, like copper, for example, all the way down to
8 something where you're sort of left scratching your head,
9 and like I said, this is -- you know, I drew lines in there,
10 but of course, in our minds, there weren't any hard lines
11 drawn, but certainly if you had something that was a
12 well-accepted rationale for the degradation mechanism and
13 strong statistical basis, well, of course, you'd include it.
14 If you had something that you couldn't see in the
15 database and you didn't know why, you'd never see it anyway,
16 but you would exclude it, and in between, you'd have to
17 exercise engineering judgement, but we tried to draw this up
18 to sort of guide our thinking.
19 Now as it turned out, when we actually ran the
20 statistics on the model, all the variables, or the effects,
21 I should say, that are being considered lately -- and by
22 lately, I mean within the last year -- came up very high in
23 the statistical significance category.
24 So, the physical rationale didn't enter much into
25 it.

1 I would like to focus, at least anecdotally on the
2 next few slides -- there's been some concerns expressed both
3 within the NRC and outside, within the industry. I should
4 warp ahead to say that our current proposal, so that we can
5 move forward and do the work that needs to come next, is
6 that we suggest to Terry for inclusion in FAVOR a model that
7 includes all of these terms.
8 The rationale for making that suggestion right now
9 is as follows:
10 There are certain things that you -- in order to
11 proceed, we need to have a model to proceed with. We can't
12 do an uncertainty analysis until we have a model. We can't
13 do a regulatory impact analysis until we have a model. We
14 can't do any sensitivity studies until we have a model
15 So, we felt it was important to suggest something
16 with the recognition that, in doing all of these analyses
17 and in further working on the technical basis document, we
18 may find things that make us say, well, no, maybe not, maybe
19 we don't want that in there.
20 But certainly, in recommending this model to Terry
21 in the PTS re-evaluation project, and as you can see by the
22 fuzzy words in our matrix, we did give definite deference to
23 statistical evidence over an existing physical rationale,
24 and like I said, there has been some exception taken to that
25 by both parties in the industry, as well as parties within

1 the NRC, and I just wanted to suggest that that's not a bad
2 engineering practice and, in fact, is fairly well-founded.
3 Sort of the essence of engineering discovery is
4 that we find out things by having field failures or by doing
5 experiments, and we might not understand the physical
6 rationale for why they're happening at all, but that never
7 stopped anybody from coming up with a design curve and
8 continuing to operate structures.
9 This just happens to one of my personal favorites:
10 In the 1860s, German railway axles were failing by
11 the truckload, and a gentleman named Wohler did a very
12 famous set of fatigue experiments where he developed what
13 was, in fact, the first SN curve, showed endurance limits,
14 and then those endurance limits were passed off to
15 designers, who then designed their axles to be below them.
16 Nevertheless, the physical understanding of the
17 phenomenon of fatigue at the time was wrong. There were
18 publications in esteemed scientific journals that said the
19 metal crystallized, and so, it broke.
20 That was obviously wrong, but it didn't stop the
21 design process.
22 Similarly, just another fun example, is that, in
23 1972, ASME developed an LEFM-based K1C curve that we have
24 used in vessel integrity calculations since that time and,
25 in fact, continue to use.

1 Nevertheless, the circa 1972 physically-motivated
2 prediction of the transition fracture phenomenon in foritic
3 steels did pretty well close to the lower shelf, but as you
4 got up off lower shelf, nobody understood the mechanism at
5 the time enough to predict this very sharp upswing that was
6 well-demonstrated by the data, but that didn't stop anybody
7 from believing the statistical evidence over the physical
8 model and moving on.
9 So, having now spoken heavily in favor of
10 empirical evidence, I should say that it is certainly not
11 the staff's intention to go only with empirical evidence.
12 Understanding the physics of what's going on is
13 especially important in this field, because we find
14 ourselves in the unfortunate but necessary position of
15 always having to extrapolate our data.
16 We never have data at the fluence or material
17 conditions that we actually are trying to predict. So, we
18 need to extrapolate all these trends, and that's why, in
19 what you'll see coming out of the technical basis document,
20 there is very definitely going to be a treatment of both the
21 physics of irradiation damage as well as the statistical
22 evidence of it.
23 In terms of the correlation, I thought I'd just
24 show the basic functional form.
25 It's got three terms in it, one related to stable

1 matrix damage, one to copper-rich precipitates, and then the
2 long-time bias, and you can see on the screen the various
3 input variables that go into each one.
4 The stable matrix damage is a function of
5 phosphorous, fluence, the product form, and the coolant
6 temperature, whereas the copper-rich precipitate term is a
7 function of copper, nickel, fluence, time, product form, and
8 manufacturer, obviously a more complex relationship than we
9 had previously.
10 We've done a few calculations, just sort of a
11 start of our regulatory impact assessment to see what
12 changes we might experience in going from Reg. Guide 1.99,
13 Rev. 2 to this new proposal, and like I said, this is very
14 early information, but I just show it for your information.
15 The graphs on the lefthand side of your screen
16 show the change in shift with the -- if we go to the
17 proposed model.
18 So, here, positive values mean that the new model
19 is predicting more shift than Reg. Guide 1.99, Rev. 2,
20 negative is less, divided it up into PWRs and BWRs,
21 obviously a lot of scatter between the two correlations, but
22 on average, for the PWRs, those that didn't have -- and this
23 all -- I'm sorry -- plotted versus the old Reg. Guide 1.99,
24 Rev. 2 shift.
25 For the PWRs, if there was -- if you had a

1 material that was low-shift already, on average, it might
2 get a little bit higher. If you had a lot of shift before,
3 on average, it's going to get a little bit lower.
4 The BWRs are higher by about 13 degrees Fahrenheit
5 across the board. So, the mean shifts are somewhat higher,
6 especially for the BWRs.
7 I've also summarized in this table a comparison of
8 the fit uncertainties, the new values coming out of the new
9 correlation work by Ernie and Joyce, and then the values
10 that are currently in the regulation, and you see that, for
11 the welds, the uncertainty seems to be going down a little
12 bit, but not a whole lot.
13 Now, in terms of your previous question on a
14 PRA-consistent uncertainty framework, this is where I'm
15 wishing I was able to do the second presentation first and
16 the first second, because I talk more about this in the
17 second, but we're developing the uncertainty framework here
18 using the same methodology as we've employed to characterize
19 the RTNDT K1C uncertainty, which is the topic of my next
20 presentation, regrettably.
21 The steps in the process are basically that we've
22 assembled the data and fit the curve, and that's what I've
23 been talking about, and that was done by Modeling Computing
24 Services and University of California, Santa Barbara, under
25 contract to the NRC.

1 We're now working at understanding the nature of
2 the uncertainties and developing a framework for a
3 mathematical model using a root cause diagram approach that
4 has been developed by Dr. Nitishan at Phoenix Engineering,
5 who is an EPRI contractor, and then that information is
6 passed on to Professors Maderas and Moseley at University of
7 Maryland, who term that sort of diagrammatic understanding
8 and physical understanding into a mathematical model that
9 then gets fed into favor.
10 That process will probably be a little bit more
11 well explained in my next presentation, but here is sort of
12 the -- again, the diagrammatic representation of what will
13 become a mathematical model in FAVOR, and I really don't
14 want to get into the details here, unless anybody wants to
15 drag me in, and then I guess I'll have to go, but what I
16 want to do is to point out a couple things.
17 This just shows the information flows from right
18 to left on the diagram.
19 The input variables are circled in yellow, and
20 this is how the math would actually be represented into
21 FAVOR. So, you'd have to know who the manufacturer was, is
22 it a weld or a forging, what's the phosphorous, the coolant
23 temperature, the nickel, the end-of-license fluence. You do
24 all that and then you can use the new embrittlement trend
25 curve to calculate a shift.

1 You compare that shift with information that you
2 might have from surveillance, decide if you're going to use
3 the shift or the surveillance data, and come out with a
4 predicted shift value.
5 So, the points to make on this is that, one, the
6 root cause diagram is, in fact, just an illustration of a
7 mathematical model, and that mathematical model allows
8 uncertainties to propagate through it from input variables
9 to output, and then the third -- and I also noted here that
10 this is the new embrittlement trend curve at node 14 here,
11 which, of course, has model uncertainty in it, and perhaps
12 the most important thing, from at least my understanding --
13 and I'm getting an education on this -- from a PRA
14 perspective is to distinguish between types of
15 uncertainties, namely aleatory and epistemic.
16 This is the diagram that helps us to understand
17 that. This shows the model uncertainty in the data that
18 Eason, Wright, and Odette used to develop the embrittlement
19 correlation.
20 So, for any given -- we can sort of work it
21 backwards, just so you can see.
22 For any given sharpie shift is, of course, just a
23 simple subtraction of a 30-foot-pound transition
24 temperature, un-irradiated, and a 30-foot-pound transition
25 temperature at some fluence, and that was determined from a

1 TANH fit to a plot of sharpie V-notch energy versus test
2 temperature, and then you can start to work it all backwards
3 and it then gets down -- the sharpie V-notch energy, of
4 course, gets down to very fundamental things like, well,
5 what was the chemistry, what was the heat treatment,
6 etcetera.
7 I should very quickly point out, this isn't a
8 model that ever gets mathematically run, but it helps us to
9 understand the natures of the uncertainties involved, and
10 Dr. Nitshan has color-coded it such that the epistemic
11 contributors to uncertainty are showed with the brown slash
12 marks, whereas the aleatory are shown with the solid brown
13 coloring.
14 And this is my interpretation, and this is, of
15 course, subject to more of the expert judgements of those
16 who know, but it sort of looks like the epistemic
17 uncertainty -- the epistemic contribution has to do with
18 things that are fairly well-controlled -- the test
19 temperature, the notch acuity, the machine calibration, the
20 test method, and so on.
21 So, while there is clearly, in any delta-T-30
22 value, components of both aleatory and epistemic
23 uncertainty, it would seem to me that the epistemic
24 contributors to uncertainty -- as an old lab rat, I'd say
25 these are fairly well controlled relative to some of the

1 things in the solid brown boxes.

2 So, one might come away from this understanding

3 with the conclusion that, while delta-T-30 does include, in

4 fact, both aleatory and epistemic components, perhaps it's

5 mainly aleatory, although that's -- you know, that's just a

6 poor man's interpretation of the diagram, but that's the

7 purpose of putting this together, and that's sort of a use

8 of this type of information, is to provide the materials

9 understanding to the PRA people and provide them with a

10 commentary that that they can understand to help make these

11 sort of decisions.

12 Just got a few slides left here.

13 Treatment of surveillance data: Currently, we

14 give credit for surveillance data in the form of a factor of

15 two reduction on the uncertainty and the shift provided the

16 surveillance data is deemed to be credible, and I don't

17 think I want to go into discussion of that, but let's just

18 say it's not always clear what credibility -- credibility,

19 in general terms, means that the data are well-behaved, that

20 you don't have something at 1E19th that's a shift of 200 and

21 2E19th that's a shift of only 50. That would not be a

22 credible data set.

23 But if you have at least two credible surveillance

24 points, by our current regulations one would be permitted to

25 reduce the uncertainty in the state of knowledge about the

1 shift by a factor of two.

2 There has never been any rigorous justification or
3 documentation of why that factor reduction is appropriate.
4 That's not to say -- I mean it's certainly completely
5 appropriate to update your date of knowledge based on
6 material or case-specific data. So, I don't ever want to
7 say anything that says, well, we're not going to do that,
8 because that's, in fact, the appropriate thing to do, but
9 our current plan is just not well-based, and at this time,
10 since that plan was developed, there's not been really any
11 work to give us a better plan.

12 The work that has been done has gone mostly on
13 what you just saw, into development of the mean curve.

14 So, the current proposal that's on the table is
15 that the -- sort of the default condition for the shift for
16 a particular plant or particular material condition will be
17 calculated based on the chemistry and all the variables in
18 the equation, you'll get a shift, you'll then compare the
19 predicted shift to a measured shift, if you have it, from
20 surveillance, and as long as it's -- you know, again, I'll
21 say reasonably close, as long as it's, say, within plus or
22 minus 2 sigma, one would use the shift predicted from the
23 model that's based on 800-some data points, rather than
24 adjusting that model-based shift to correspond to two
25 measured data points.

1 You know, again, that's the current proposal
2 that's on the table. That proposal is, I suspect, going to
3 be the subject of some fairly intense discussions among the
4 staff in the coming three to six months, but you've got to
5 start somewhere or you don't know what you're talking about.
6 An even perhaps more interesting one is the
7 through-wall attenuation question.
8 Right now, in Reg. Guide 1.99, Rev. 2., we figure
9 out what the fluence is at a particular thickness location
10 from the ID-X, where X is measured in inches from the ID by
11 taking the ID fluence and decaying it by this negative
12 exponential with the .24 coefficient.
13 Really, the only -- and I should say that there
14 hasn't been a whole lot of work since this equation was
15 developed that would give us a basis to do anything else.
16 There have been a very few test reactor studies where
17 basically a whole bunch of steel samples were machined,
18 blocked together, and then irradiated, so it simulated like
19 they were at different positions in the wall.
20 There was one study done like that which we'll be
21 looking at, and to my knowledge, that's -- I can't ever
22 pronounce it -- the Gundrumagin vessel. Those are really
23 the only data available that say anything to attenuation.
24 There's also the question of what the appropriate
25 damage -- radiation damage function is to use, should one be

1 using DPA or fluence to attenuate through the vessel wall.
2 So, there is some new information available that
3 the staff will be looking at. There's not a whole lot,
4 because quite frankly, it hasn't been an area of focus, but
5 there is a very practical impact that we need to look at in
6 that, with the old embrittlement trend curve, everything was
7 a function of fluence.
8 So, when you attenuated the fluence, you
9 attenuated the shift in direct proportion, according to this
10 relationship, whereas with the new equation, it's got terms
11 -- with the new equation, there are two terms. There's a
12 time term and there's a bias that don't depend on fluence at
13 all.
14 So, if you believe -- and now, this is a good
15 question, and as I said, again, I'm sure it will be the
16 focus of some interesting discussion over the next few
17 months. If you believe that this is really attenuating
18 fluence -- although when you look at Randall's basis
19 document, you decide that it might not really be attenuating
20 fluence. It's an engineering approximation.
21 Anyway, if you attenuate the fluence in the new
22 function according to that form and apply it only to the
23 fluence, then you certainly don't attenuate that and you
24 don't attenuate time, because time just marches boldly
25 forward.

1 Well, for some vessels, that's not going to matter
2 at all, because they're at such a high fluence anyway, the
3 contribution of that is nil, and so, you're giving up a
4 fractional degree, but for things like BWRs that tend to be
5 at lower fluence, it can be quite a significant impact.
6 It's going to be very important to -- like I said,
7 we don't have a lot of new information, but it's going to be
8 very important to consider the regulatory impact of this on
9 BWRs, especially for heat-up and cool-down, where we
10 attenuate the quarter-T and three-quarter-T to do our
11 calculations.
12 For PWRs and PTS calculations, the recommendation
13 that we've made to Terry right now is that, for right now,
14 pending further thought and information, use the Reg. Guide,
15 Rev. 2 function to attenuate the fluence in the new
16 embrittlement trend curve, it's not so much a problem in the
17 calculations that Terry is doing, because if a flaw is
18 deeper into the vessel than an eighth of a T, it's not going
19 to matter anyway.
20 So, this plot shows the impact of that
21 recommendation on the horizontal axis, is the old
22 attenuation at an eighth of a T.
23 So, this is how much less shift you had at an
24 eighth of a T than at the ID using Reg. Guide 1.99, Rev. 2.
25 This is how much less shift you have using the new

1 correlation but the old attenuation function, and what you
2 see is your have some situations, the heavy triangles or PTS
3 plants -- the worst it gets is you might have had one
4 material in one plant where it was previously attenuated by
5 15 degrees, now it's only attenuated by seven.
6 Again, the focus here -- I don't know if this has
7 come out earlier -- has been to get off the dime with the
8 calculations and get Terry something to use, with the
9 recognition that we might need to come back and change it
10 later.
11 It doesn't seem to be as significant an influence
12 here as it could be, certainly in this case. For the reg.
13 guide, it's going to be something that we have to very
14 carefully consider, because the impacts can be quite
15 incredible, up to 100 degrees Fahrenheit.
16 And I think that's basically it, just a discussion
17 of ongoing steps now.
18 SPEAKER: Doing that -- is that basically
19 equivalent to saying there's an aging effect that's
20 independent of irradiation?
21 MR. KIRK: Yes.
22 SPEAKER: And have we seen that -- you know,
23 except for when you dump a lot of philosophers into here, I
24 mean is there any --
25 MR. KIRK: That's a good question. Professor

1 Odette, in fact, just provided us with a report, which I
2 understand includes some of that information, but that, I
3 think, is one of the open questions that needs to be looked
4 at.
5 Of course, the difficulty being the availability
6 of material that's been cooked for that amount of time is
7 pretty low.
8 My understanding of what Bob's told me on the
9 phone -- and unfortunately, we just got the report last week
10 and I haven't had a chance to go through the details -- is
11 there is some information from hydro-cracker service of
12 similar materials at somewhat higher temperatures, but you
13 get into some pretty dicey cases of knowing when you're
14 extrapolating beyond the bounds of where you should be
15 extrapolating.
16 So, that's an open question, and in fact, of all
17 the terms in the equation -- and again, just a personal view
18 -- for my money -- well, this is probably the one that's got
19 people scratching their heads the most. It's like how the
20 hell did that happen? Bad luck.
21 I'm thinking that the procurement agent at CE was,
22 well, perhaps not as nice to the steel mill folks as they
23 were at the vendors, but that's just my theory.
24 But this is the one -- this term in here seems to
25 be the one that's the most theoretically contentious,

1 because some of the physical theories seem pretty good, but
2 getting the evidence to back them up in terms of what you
3 just pointed out, long-time data, is just very hard to do.
4 But as I pointed out by that graph, it has some
5 very significant practical implications in the heat-up and
6 cool-down mode.
7 SPEAKER: Now, I assume that Ernie has scrubbed
8 this looking for a phosphorous dependence, which would be
9 the -- you know, everybody's first --
10 MR. KIRK: I'm sorry. Scrubbed the long-time?
11 SPEAKER: Yeah.
12 MR. KIRK: That's a good question. I honestly
13 don't know for sure. That work sort of predated my
14 involvement. But that would certainly be a good question to
15 ask. I know he's scrubbed it every which way from Sunday,
16 but I can't swear to you that he's specifically looked at
17 that. You mean just looking for heavier incidents of tramp
18 elements in those.
19 SPEAKER: Right. Is there a reason an element
20 like that would be the prime candidate for just an aging
21 effect without irradiation?
22 MR. KIRK: Yeah. Of course, the feeling is that's
23 also showing up here.
24 SPEAKER: Right.
25 MR. KIRK: See, the thing is this got very

1 evolutionary.

2 This term came along first, in the historical

3 development of the model. There was the so-called flux time

4 term, and there was significant contention about that, and

5 we looked and looked and found more data, and then this one

6 popped up in trying to understand that.

7 This one actually exists independently of this,

8 because this is driven by data at low fluence, long-time,

9 BWRs, is what's driving the existence of this term. But in

10 collecting more data, we got -- of course, as time goes on,

11 you get more long-time data, and we found that, beyond

12 100,000 hours, the data points beyond 100,000 hours were

13 systematically under-predicted by the model on the order of

14 10 degrees Fahrenheit.

15 SPEAKER: These are very low fluences for kind of

16 an irradiation-assisted segregation, but --

17 MR. KIRK: True. Yeah, if you're looking for a

18 synergistic effect, you might want more atoms going through

19 it.

20 So, we found this looking for that, and then, in

21 saying, well, now, this really isn't making a lot of sense,

22 what's going on, this one popped up.

23 SPEAKER: That one's really tough.

24 MR. KIRK: But like I said, I can say to you with

25 confidence that -- I've worked enough with Ernie to know

1 that, if he says they're statistically significant, they
2 are, and the other thing that I perhaps should note is that
3 the industry group, EPRI and Sam Rizinski, contracted with
4 Dan Naman, who's a professor of statistics at Johns Hopkins
5 University, to take an independent look at this, and
6 Professor Naman came up with this quite independently of
7 Ernie, because we weren't letting Ernie talk at that time,
8 and Dan found it all by himself.
9 So, it's really there. I mean it frustrates
10 people, but it is, indeed, really there.
11 But in terms of where we're going on from here,
12 we're going the uncertainty analysis. Like I said, that
13 just got started, and we were able to turn over the
14 information to Dr. Natashan and Professor Medarez in August,
15 so they've sort of just started on that, probably looking
16 for seeing something out of that sometime in the November
17 timeframe.
18 We're working here on doing the regulatory impact
19 analysis and also having discussions about how surveillance
20 data should be treated, and of course, we're going to have
21 to get Ernie involved in those discussions, discussions
22 about through-wall attenuation, and we're in the process of
23 drafting the tech basis document for review.
24 And of course, the PTS project is going to be
25 continually updated, you know, on where we're going, and

1 we'll have to work with Shaw to see how that best slots in,
2 but what we did, I guess it was basically last month, is
3 gave Shaw and Terry our current best guess of, you know,
4 okay, if you hold a gun to our heads and say give me
5 something today, well, here you go, and what we've tried to
6 do is not just say here you go but tried to identify the
7 warts in it, so that nobody is misled that, well, you know,
8 this is true for all time. Well, it might not be.
9 But we also need to make very sure that we sync
10 the information that's in the reg. guide with the
11 information that's included in the PTS re-analysis, because
12 of course, we want both of those to be self-consistent and
13 supportive.
14 Any questions on that?
15 [No response.]
16 MR. KIRK: Okay.
17 Then my next -- should I go ahead?
18 SPEAKER: Yeah.
19 MR. KIRK: Okay.
20 The next set of slides is on fracture toughness
21 distributions and uncertainty analysis.
22 What I'd like to work through with you is talk
23 about our goal in doing this work and the folks that have
24 participated in what's become a fairly extensive cooperative
25 effort, talk about our approach, what new data we collected,

1 the uncertainty framework, show you some of the current
2 results, and then talk about where we're going next.
3 As I just suggested, there have been quite a few
4 people involved in this particular piece of work, and I
5 think to very good effect, because we've got a diversity of
6 experience and perspectives here that most projects have --
7 indeed, this is a fairly small-scale effort -- don't
8 normally enjoy.
9 I should say the goal here is to characterize
10 toughness for input into FAVOR in a way that's consistent
11 with current PRA methodologies, which is to say a proper
12 treatment of uncertainties.
13 At the NRC, I've sort of been coordinating this,
14 and Shaw and Nathan have both been involved.
15 At the University of Maryland, we've been working
16 with Professor Medarez to do the uncertainty work. His
17 graduate student is Faye Lee, and his associate is Allie
18 Moseley.
19 And at Oak Ridge, they've been involved in various
20 aspects of this work, both in collecting the K1C data and
21 developing a statistical curve, as well as more recently, in
22 looking at RTNDT model uncertainty. That includes Paul
23 Williams, Kenny Bowman, Terry Dixon, John Murkle, Richard
24 Bass, and Randy Nanstead.
25 And then we've also had significant support from

1 EPRI. Stan Rizinski is the project sponsor there, and he's
2 been kind enough to allow us to involve Marjorie Natashan of
3 Phoenix Engineering, and she's been doing the root cause
4 diagram work and interfacing directly with Professor
5 Medarez.
6 And what I'm presenting here is really the
7 amalgamated work of all those folks.
8 So, the goal I've already stated. The three boxes
9 below the goal show you the process that we've gone through.
10 We started off at Oak Ridge, and this probably goes over a
11 year ago now, assembling all the available valid K1C and K1A
12 data and developing a purely statistical fit to that. We
13 then moved on and involved University of Maryland and PAI to
14 establish sources of uncertainty using the root cause
15 diagram analysis to allow us to distinguish epistemic from
16 aleatory uncertainties and give us a procedure to treat both
17 parameter and model uncertainties, and then, coming out of
18 this, of course, our goal is a description of K1C and K1A
19 with uncertainties that we can plug into FAVOR.
20 This slide summarizes the work that was done by
21 Oak Ridge, now something over a year ago.
22 On the lefthand side, you have the K1C data;
23 righthand side, K1A.
24 The numbers in reverse video show you how the data
25 set size increased relative to that which was used to

1 establish the original K1C and K1A curve.

2 So, originally, we had 171. We wound up with 254.

3 The K1A database had a more substantial percentage increase.

4 The black specks on each of the diagrams is, of

5 course, the data itself.

6 The red curves on your screen are the way we used

7 to model the scatter in the data based on the ASME K1C curve

8 and moving that up and down by a sigma, whereas the black

9 curves are the new Oak Ridge model which is based on a Wible

10 formulation, and the same thing are shown over here.

11 One thing, just sort of looking at this and

12 saying, well, so what, that you come away with is you come

13 away with the immediate impression that the old scatter

14 bounds that we used in FAVOR were too narrow, especially for

15 K1A.

16 The consequence of that, the effect on the

17 calculated probability of vessel failure, of course, depends

18 upon the transients considered.

19 Terry did a nice little study of that probably a

20 little bit less than a year ago now, found in some cases it

21 mattered a whole lot, in some cases it doesn't matter quite

22 so much, depending on if you have late re-pressurizations,

23 whether arrest is important, and things like that.

24 Of course, this all needs to be considered in the

25 context of everything else that's going on.

1 The uncertainty analysis -- we started off with
2 the root cause analysis to identify the sources of
3 uncertainties, appealed to a physical model, so that we
4 could try to understand where the uncertainties came from
5 and distinguish -- Dr. Natashan and Professor Medarez worked
6 a lot together in terms of her trying to express the
7 physical understanding and the test lab understanding of
8 where these uncertainties come from to Professor Medarez,
9 who was working on the mathematical model.
10 So, they worked that out, developed a mathematical
11 model, which then Professor Medarez and Terry Dixon have
12 been working on to get it implemented into an actual FAVOR
13 programming structure.
14 The root cause diagrams -- and this is sort of
15 like talking about the horse after it got out of the barn,
16 because I've already done a couple of these.
17 It's just a way to diagram mathematical
18 relationship, show how uncertainties move from one place to
19 the next, but I do want to point out that the big change in
20 this way of doing things relative to the way we've coded
21 uncertainties in FAVOR before is that here we input
22 uncertainties and parameters back here and then propagate
23 those into uncertainties and output variables in a way
24 that's very systematic and critiqueable because you can see
25 it and say, no, that box doesn't belong here, it belongs

1 over there, rather than the margins being prescribed to the
2 analysis a priori, which is exactly what we used to do.
3 So, this is a very integrated and systematic
4 approach, and it actually works very nicely when you need to
5 get input from a whole lot of people in that you can lay it
6 out and explain it to them and they can see where -- how the
7 various pieces interact very easily.
8 So, it's worked out, actually, quite well.
9 Just to look at the diagram at its highest level,
10 for K1C RTNDT, of course, at the end, we want to get out the
11 uncertainty in K1C.
12 Going into that is the uncertainty bounds on the
13 fracture toughness data that I showed you previously coming
14 out of the statistical analysis of the data, but of course,
15 that's an index to an irradiated RTNDT value to position the
16 data in temperature space.
17 The RTNDT irradiated value itself is a function of
18 both an un-irradiated value and a shift, and of course,
19 there's a whole lot more that are in the detailed reports
20 but aren't shown here.
21 But again, similar to the last time, I do want to
22 make a couple of points here about some of the new or
23 significant features coming out of this analysis.
24 This diagram is just an expansion upon the one I
25 just showed you, and it even flows off on to other diagrams,

1 but one point is that we've got a process that matches or
2 models, I should say, the current regulatory framework for
3 how we determine RTNDT irradiated, and we're putting this
4 into the code, I should say, right for the first time. So,
5 that's a good thing.
6 We've got a statistical representation of
7 toughness that I already told you about, and that plugs in
8 here, and then, I guess the newest of the new things is a
9 recognition that there is a -- I shouldn't use the word
10 "systematic," because it's not always the same -- there's
11 always a bias in RTNDT. It's just simply not the right
12 value to use.
13 I can illustrate that to you -- and I should say
14 that's going to be taken account of in the calculations. I
15 can illustrate that to you just by putting up data from two
16 different heats of steel.
17 This is an A533B plate, HSST plate, are two tested
18 by Marsden back in '87 -- I'm sorry -- reported by Marsden,
19 tested long before that. This was the basis of the original
20 K1C curve.
21 So, you've got the K1C data and a K1C curve
22 indexed to RTNDT having absolutely no relationship to the
23 data other than the RTNDT value, was determined from
24 specimens cut from the same plate, and you see that, in this
25 case, RTNDT does a pretty good job of putting the curve

1 where you wanted it to go.

2 You can look at other data sets, like the

3 Midland-Beltline weld in the un-irradiated condition test by

4 McCabe in '94 and find out that RTNDT, in this case, is not

5 doing as good a job as you want it.

6 This is not at all unexpected. In fact, it is

7 expected, since RTNDT was designed to be a bounding, an

8 upper bounding estimate of fracture toughness transition

9 temperature.

10 So, we expect this to be the case, but it's highly

11 inconsistent with a PRA approach that's based on best

12 estimates.

13 We've got a parameter here that we use to figure

14 out where we go into our K1C distribution that we know is

15 always off, and it could be off anywhere from, say, zero

16 degrees to 150 degrees, and some accounting needs to be

17 taken of that.

18 Now, how that's going to be done, I can't tell

19 you, because we haven't quite figured that out yet, but will

20 it be accounted for, I think I can state unequivocally, yes.

21 We're still having some discussions between all of

22 the parties that I mentioned before regarding what the

23 correction function should be -- well, the correction

24 function being the probability distribution that relates

25 RTNDT to truth, however truth might be defined, and we're

1 arguing about what truth is, so I'm hesitant to put a
2 timeframe on that, and then -- that's perhaps a more sticky
3 question, and then we're also having some discussions,
4 mainly between Professor Medarez and the folks at Oak Ridge,
5 regarding what the proper mathematical procedure is to
6 create the correction once we know what truth is, and I'd be
7 the wrong one to talk about that.
8 But having said that, I think we're making
9 progress. We seem to be -- I think we're converging. But
10 we don't have an answer quite yet.
11 And Bill looks like he wants to ask a question.
12 SPEAKER: Well, I'm trying to figure out how I
13 know truth when I see it. What do I need to know to know
14 truth?
15 MR. KIRK: I could make a suggestion. I think --
16 this is going to really reveal my biases. I think the data
17 is truth. I mean you've got -- do you believe that linear
18 elastic fracture toughness characterizes the fracture
19 resistance of the material in an appropriate way for this
20 calculation?
21 If you can answer yes to that question, then you
22 say, okay, well, then truth is my K1C data for a particular
23 heat of steel, because that's what we need to characterize
24 to FAVOR, is the fracture toughness of the material on a
25 heat-by-heat basis.

1 So, then, if you can agree with those things, then
2 I think truth is some -- well, if truth is the data, then
3 the data is there, and the measure of how untrue RTNDT is is
4 just the distribution of -- for heat one of the steel, it
5 was off by 5 degrees; for heat two of the steel, it was off
6 by 100 degrees; for heat three of the steel, it was off by
7 50 degrees.
8 SPEAKER: Now, was this RTNDT determined from a
9 sharpie specimen of the same material as the K1C?
10 MR. KIRK: Yes.
11 SPEAKER: I'm not depending on a correlation to
12 get RTNDT.
13 MR. KIRK: No.
14 All these RTNDTs are, for what it's worth,
15 credible MB2331 RTNDTs determined on the same material, yes.
16 SPEAKER: Okay.
17 MR. KIRK: So, no, that's not in there making the
18 situation worse.
19 SPEAKER: Now, is it the same material seen under
20 the same flux, the fluence?
21 MR. KIRK: With very few exceptions, all of the
22 RTNDTs are on un-irradiated materials. There is only --
23 END OF TAPE 3, SIDE A; BEGIN TAPE 3, SIDE B
24 MR. KIRK: [In progress] -- four materials I think
25 we have a real RTNDT value on in an irradiated condition,

1 because quite frankly, most people don't irradiated NDT
2 specimens.
3 What I could tell you -- I don't have this graph
4 with me, but the -- really, what we're arguing over, the
5 distribution of the shifts, you know, what's the smallest
6 shift to what's the lowest shift, or how wrong can wrong be,
7 is always on the order of 125 to 150 degrees Fahrenheit.
8 What we're arguing over -- and this is where the
9 physics of it comes in -- what we're arguing over is where
10 this is positioned, but what I can share with you is that
11 we've made plots before of the various data points for all
12 the un-irradiated materials, and of course, we've got a much
13 larger number then that we do the irradiated.
14 The irradiated seemed to follow very closely to
15 the same trend, and I wouldn't -- I think the reason there's
16 a difference here is it's a test procedure problem, and it's
17 a stress state problem within the -- the differences in
18 stress state between the sharpies and the NDTs and the
19 fracture toughness.
20 The irradiation really isn't changing that
21 dynamic. I don't expect there to be a different
22 distribution. I can't demonstrate that to you very
23 convincingly with data, because I've only got four data
24 points, but I don't really expect there to be a difference.
25 But in answer to your question, I mean I think

1 here, you know, we've sort of -- well, in doing these
2 calculations, we premise truth on -- you know, that K1C is
3 an appropriate failure criteria, you know, for this material
4 under this application.
5 If we're going to question that, well, Pandora's
6 Box.
7 For me, I think the data is truth, and we need to
8 find out how far the RTNDT prediction is from the data. If
9 we don't believe the data, we've got bigger problems.
10 MR. HACKETT: This is Ed Hackett. I think I'd
11 just like to add sort of a tone commentary here.
12 A lot of this discussion sort of feels like we're
13 running down RTNDT, and of course, that was the basis of a
14 lot of good work that went into sections 3 and 11 of the
15 ASME code by a lot of folks who preceded us.
16 I think what Mark says is correct, but don't want
17 to leave anyone with the impression, because we've said we
18 don't maybe think it's a good indicator of the exact or more
19 accurate behavior of what we think we might see in a vessel.
20 However, it's worked pretty well for the ASME code in terms
21 of demonstrating in a convincing way safety assessments of
22 boilers and nuclear vessels and so on. Just don't want to
23 leave anyone with the impression that that's a problem, that
24 the current framework is a sound framework from that
25 perspective.

1 This would hopefully be an iteration on improving
2 the accuracy.
3 MR. KIRK: Yeah, and it works because it's been --
4 it's doing what it was designed to do. It was designed to
5 be conservative, and lo and behold, it is, you know, good
6 job, but that -- you know, again, my understanding, in
7 working with Mohammed and Nathan is that that doesn't really
8 fit very well into this approach, so we've got to do
9 something to try to take this -- you know, this being what
10 we understand it to be and what, in fact, it is and turn it
11 into a best estimate in our simulations, or at least correct
12 for the fact that it's not. I'm not sure if I'm saying that
13 quite the right way.
14 DR. KRESS: Well, you expect to do it on a
15 heat-by-heat basis?
16 MR. KIRK: Yeah, that's what you would be doing.
17 DR. KRESS: And then have a series of curves,
18 depending on the heat?
19 MR. KIRK: No.
20 DR. KRESS: You'd have one mean curve for all the
21 heats?
22 MR. KIRK: No, the idea would be, if you pick any
23 of these correction functions, just for purpose of
24 illustration, it doesn't matter which one, but you go
25 through the simulation and you decide, for a particular

1 region, I've got a particular set of material properties.
2 In a particular sub-region, that set of material properties
3 has a fluence associated with it.
4 DR. KRESS: Right.
5 MR. KIRK: I go through all the calculations and I
6 get a RTNDT irradiated, and then I go into a hat and I pick
7 up a number, and that's a number between zero and one, and
8 based on what that number is -- say it's .6, and let's say
9 I'm using this red one.
10 I would then take that number and reduce it by 80
11 degrees Fahrenheit, but I might go through the simulation
12 the next time, come up with exactly the same number here --
13 I'm sorry -- exactly the same estimate of irradiated RTNDT,
14 go into my hat, and this time pick up a .2 and decide that
15 I'm only going to reduce that number by 20.
16 What we're saying is this is our best state of
17 knowledge about how far off RTNDT could be, and since you
18 don't have any other information, you don't have the
19 fracture toughness data in this case, all you know is that
20 it's off by somewhere between this and that, and that, of
21 course, adds uncertainty to the analysis.
22 It also -- well, depending upon what -- it adds
23 uncertainty to the analysis, but it also adds a pretty hefty
24 mean shift.
25 DR. KRESS: Isn't that the same thing as drawing

1 the mean line through all the data and putting a
2 distribution around that line?
3 MR. KIRK: I'm afraid I don't understand what
4 you're saying.
5 DR. KRESS: That's all right.
6 MR. KIRK: Okay.
7 Just to summarize, what we've completed so far is
8 the statistical model of transition fracture toughness. At
9 Oak Ridge, they collected the data and made a fit to that
10 data.
11 In the development of PRA uncertainty framework,
12 we understood the current process that we use to calculate
13 an irradiated RTNDT using the root cause diagram approach
14 and develop mathematical models of that. Details of
15 implementing those models in FAVOR were discussed and
16 clarified between Mohammed and Terry, and ongoing work --
17 we're working on finalizing that mathematical model and
18 resolving the issue that we've just been talking about for
19 the past few minutes, the RTNDT bias, and also as ongoing
20 work, we're still working on assembling input data to run
21 all these models, and that's all I had prepared.
22 Are there questions?
23 SPEAKER: Does the uncertainty in RTNDT mean --
24 should you also go back -- the way you're accounting for
25 this uncertainty -- should that also have been included when

1 you did the fit to the K data?

2 MR. KIRK: Okay. That's one of the questions

3 we're considering under what the correction procedure is.

4 One proposal was the way I described it, which is to go

5 through, simulate an RTNDT irradiated in FAVOR, pick a

6 correction value, and get a corrected RTNDT.

7 Proposal 2, or 2(a) -- I've lost track -- is to do

8 exactly what you said, which is essentially to apply this to

9 the data and re-fit the data, take the consideration and the

10 uncertainty outside of FAVOR and allow it to be treated as

11 input data.

12 DR. KRESS: I think that's what I was saying.

13 MR. KIRK: Okay. I'm sorry. I didn't understand

14 it that way.

15 SPEAKER: It really puts it where it belongs,

16 because you don't know what RTNDT is when you're measuring

17 K.

18 MR. KIRK: True. And I think, Mohammed, would it

19 be true to say that's sort of the way the wind's blowing

20 now?

21 MR. MEDAREZ: I'm Mohammed Medarez from the

22 University of Maryland.

23 I think it's right. What we are trying to do now

24 is -- Oak Ridge is using a methodology, a bootstrap

25 methodology to shift the data by this correction, actually

1 the 256 or so data points that we have, and basically shift
2 it according to this curve that you have on the left.
3 There about about four or five ways of doing that,
4 and each of them have different implications.
5 We are in the process of doing that, and also, my
6 belief actually is that the two methodologies would yield
7 the same answer, although we are seeing some differences,
8 but I think we know what the differences are, why we are
9 getting those differences.
10 I agree, also, that it's cleaner to go and correct
11 the data, as opposed to, as you mentioned, actually go back
12 and calculate an RTNDT which is biased and then try to
13 correct it afterwards, but we have to understand exactly the
14 process here. We are not still there.
15 I think it will be about a month or two. Next
16 time, we should be able to propose a definitive process for
17 computing this error here.
18 MR. KIRK: Okay. Thank you.
19 DR. KRESS: You know, among everything else that's
20 here, I must say these materials guys have come up with the
21 sexiest slides produced in the last year-and-a-half.
22 SPEAKER: Break for 15 minutes.
23 [Recess.]
24 END OF TAPE 3, SIDE B; BEGIN TAPE 4, SIDE A
25 MR. DIXON: The title of this presentation is the

1 status of the FAVOR code development. I'm Terry Dixon, and
2 I'd like to acknowledge Richard Bass and Paul Williams, two
3 of my colleagues that work with me that helped me put this
4 presentation together, and the intent here of this
5 presentation is to describe the evolution of an advanced
6 computational tool for reactor pressure vessel integrity
7 evaluations, namely FAVOR, and basically, this presentation
8 is sort of broken up into five different categories.
9 The first one is going to talk about how FAVOR is
10 applied in the PTS reevaluation.
11 The second one is the integration of evolving
12 technology into FAVOR, the FAVOR structure, PRA methodology,
13 and the last one, which I'm sorry that Professor Apostolakis
14 left -- the very thing he was talking about, kind of
15 stepping through a calculation, was my intent here, assuming
16 that we have time.
17 Okay.
18 Someone asked this morning or alluded to this
19 morning, how would the results be used that comes out of
20 FAVOR, and this is an attempt to sort of answer that
21 question. So, application of FAVOR to this particular
22 effort, PTS reevaluation, addresses the following two
23 questions.
24 Here's a graph that shows frequency of vessel
25 failure as a function of effective full-power years.

1 Now, the abscissa here could just as easily be
2 RTNDT. It could be neutron fluence. In other words, you
3 could have this, different variables, but most people can
4 relate pretty well to effective full-power years.
5 But anyway, the two things that will be addressed:
6 at one time in the operating life does the frequency of
7 vessel failure exceed an acceptable value, which currently,
8 in the current regulations, is 5 times 10 to the minus 6.
9 However, someone presented this morning that this number is
10 probably going to change to 1 times 10 to the minus 6.
11 DR. KRESS: Look what that does to you on the
12 graph.
13 MR. DIXON: Yes. It could be dramatic.
14 Now, these curves, by the way, aren't -- these
15 don't correspond to a particular plant. This is just an
16 illustration.
17 DR. KRESS: But it could be a plant.
18 MR. DIXON: Obviously.
19 And then the second question is how does the
20 integration and application of the advanced technology
21 affect the calculated result, and by that, what we're
22 talking about here is -- say that, you know, you have a
23 model and you do the analysis, and at some time in the
24 operating life of the plant, say 32 years, shows that you --
25 that's how long you can operate your vessel and be in

1 compliance with the screening criteria to come back -- if
2 you improve your model, which is what we're trying to do --
3 this whole effort is to try to improve our computational
4 models, and you re-do it and you get a reduced value,
5 essentially what you've done is you have increased the time,
6 the period of time that you can operate your vessel and
7 still be in compliance with the screening criteria.
8 DR. KRESS: I presume, with that improved model
9 result, you make some guesses of what the changes would be
10 in the various parts of your model to get a different
11 result? I mean you kept everything the same, except you
12 looked at the -- for example, the K1C, you probably made it
13 less bounding and things like that?
14 MR. DIXON: We haven't done too much of this yet,
15 because as you've heard today, a lot of these models are
16 still being developed, but there was a paper that was
17 published.
18 DR. KRESS: We have a copy of that. I remember
19 it.
20 MR. DIXON: That was an attempt, as of about two
21 years, to do exactly what you're talking about.
22 DR. KRESS: Just to see if it's worthwhile to
23 continue.
24 MR. DIXON: Yes. It was like taking several
25 elements and saying, okay, if you change this to this,

1 what's the effect, and then what's the cumulative effect,
2 and that was sort of what kick-started this whole effort,
3 that that study showed that there was a potential, at that
4 time, for this type of -- in other words, to get additional
5 time in compliance.
6 DR. KRESS: If I were to look at the curve and it
7 was the only information I had and if I were to really
8 believe that the new acceptance criteria were going to be 1
9 times 10 to the minus 6, I might conclude that all this
10 effort is not worthwhile, if that were the acceptance
11 criteria, because you're not changing things much in a year
12 or two.
13 MR. DIXON: I couldn't say that until -- sometimes
14 you got to go down that road to know.
15 DR. KRESS: Yeah, you really do, I think.
16 MR. DIXON: You know, I couldn't make that
17 statement right now until we actually do this effort.
18 DR. KRESS: But it seems like it's pretty
19 important to pin down this acceptance criteria pretty early
20 in the game.
21 MR. DIXON: Right. But another thing that I would
22 like to point out here -- and it's referring back to the
23 question this morning.
24 Notice, this is just one line here. So, you can
25 think of this as being the mean value.

1 Now, every time that you execute the FAVOR code,
2 you get one point on this line.
3 In other words, you execute the FAVOR code at a
4 snapshot in the operating life of the vessel, in other words
5 corresponding to a particular fluence map that -- you know,
6 15 years, 30 years, 60 years, whatever.
7 So, you would run FAVOR at several times in the
8 life of the plant, and actually, you would get a
9 distribution.
10 Now, this doesn't show that, this just shows a
11 line, but actually, there is some uncertainty. We've
12 propagated the uncertainty through the model. So, this line
13 actually has a band around it.
14 DR. KRESS: So, my question earlier on was, once
15 you get that, what are you going to do with that?
16 MR. DIXON: Well, that's a good question, and I
17 don't know that we have that answer yet. I will just say
18 that that kind of gets into interpretation and regulation.
19 DR. KRESS: That's not your area.
20 MR. DIXON: Right. I'm not real sure that anybody
21 knows the answer to that just yet.
22 The schedule has been sort of sliding, but the
23 latest schedule decision is that, you know, the FAVOR code
24 will be ready for reevaluation analysis by around March 1 of
25 next year.

1 Now, in the meantime, models are being finalized.
2 You've heard discussion this morning about several of the
3 models. Then these finalized models have to be implemented
4 into the FAVOR code. Some of them are, some of them aren't,
5 and in the meantime, there's going to be scoping studies
6 performed specifically for Oconee, I believe it is, because
7 as Dave Besette said this morning, the Oconee thermal
8 hydraulics is essentially ready. I believe the PRA is close
9 to ready. We need the flaw data that was discussed.
10 So, all the input data, maybe not in a finalized
11 form but at least enough for us to kind of start cranking
12 some numbers.
13 Also, there was some discussion this morning about
14 kind of the history of FAVOR, how did it come about, and the
15 development was initiated in the early 1990s by combining
16 the best attributes of OCA and VISA with evolving
17 technology.
18 So, we show OCA-1, OCA-2, OCA-P -- all of these
19 were developed at ORNL in the early 1980s, and VISA was --
20 in the same timeframe, was developed primarily -- first at
21 the NRC and then later at PNL, and then there was lessons
22 learned from IPTS and a lot of lessons learned from the
23 Yankee Rowe experience, and Mike Mayfield was in Oak Ridge
24 at one time for a meeting, and I remember him making the
25 statement that the NRC was no longer going to support two

1 codes, VISA and OCA-P. He said I want a completely new
2 code, I want a new name, and I want it to combine the best
3 attributes of -- basically to do this.
4 So, that's what we've attempted to do.
5 There was public releases of FAVOR in 1994 and
6 1995, and then there was a limited release in 1999, a
7 limited release insofar as this group of NRC staff, industry
8 representatives and contractors, anybody that came to those
9 meetings got a copy of the code, and as I said, the current
10 development version is -- the plan right now is to be fixed
11 in March of next year for the PTS evaluation.
12 Now, of course, as you've seen, this is somewhat
13 dependent on other people feeding stuff into FAVOR. So,
14 this date is as good as the schedule that people feed things
15 in.
16 DR. KRESS: What kind of language is the code in?
17 MR. DIXON: FORTRAN.
18 DR. KRESS: Does it work on a PC?
19 MR. DIXON: Yeah.
20 Okay.
21 Kind of the second part of this presentation is
22 kind of the integration of evolving technology into FAVOR.
23 This is kind of schematic to show how elements of
24 updated technology are currently being integrated into the
25 FAVOR computer code to reexamine the current PTS

1 regulations, and this just shows kind of several blocks of
2 things that are done better now than they were done back in
3 the days of the IPTS and SECY-8265.
4 Detailed neutron fluence maps -- you've heard a
5 little about that. You'll hear a little more.
6 Flaw characterizations -- plates and welds --
7 you've heard a considerable amount about that.
8 Embrittlement -- new and better embrittlement
9 correlation that Mark Kirk talked about.
10 Thermal hydraulics -- the APEX experiments --
11 hopefully, RELAP, this latest version, confirmation through
12 experiments -- hopefully, we're getting better thermal
13 hydraulics data than we were 15 years ago.
14 PRA -- that's just kind of a generic term to talk
15 about kind of the overall methodology that I will talk about
16 in a moment.
17 RVID is the reactor vessel integrity database that
18 was created and is maintained by the Nuclear Regulatory
19 Commission that sort of, I guess, holds the official data
20 for every vessel.
21 If you wanted to know what the accepted chemistry
22 was for a particular weld or plate in a particular plant,
23 this is where you would go.
24 Extended K1C and K1A database -- the statistical
25 representations are -- I believe it's Professor Apostalakis

1 -- he said don't refer it to that way -- the uncertainty
2 representations of the K1C and K1A database. Again, Mark
3 talked about this. I'll talk a little bit more about it.
4 Fracture mechanics -- the FAVOR code itself -- in
5 other words, all of these are going to feed in what we would
6 say updated technology and we're going to apply this to the
7 four plants, which has been discussed, and then plot curves
8 like I showed a moment ago, and where are we, you know,
9 where are we when we do that?
10 DR. KRESS: Does FAVOR have the thermal hydraulics
11 built into it? Do you have to calculate the temperature
12 distribution through the wall?
13 MR. DIXON: Yeah. You're just one step ahead of
14 me, but FAVOR doesn't do thermal hydraulics. FAVOR accepts
15 thermal hydraulics as input.
16 In other words, output from RELAP becomes input to
17 FAVOR.
18 DR. KRESS: Yeah, but don't you have to translate
19 that into temperature distribution through the wall itself?
20 MR. DIXON: Yes.
21 DR. KRESS: But that doesn't come from RELAP.
22 MR. DIXON: No. RELAP gives you the coolant
23 temperature on the inside surface of the wall as a function
24 of time.
25 We'll talk about that, a little more detail about

1 that in just a moment.

2 DR. KRESS: Okay.

3 MR. DIXON: Okay.

4 This is getting a little bit redundant, I suppose,
5 but advanced technology is integrated into FAVOR to support
6 possible revision of PTS regulation, and again, this is just
7 sort of saying in words what we just said -- new flaw
8 characterizations, detailed fluence maps, improved
9 correlations, embrittlement correlations, reactor vessel
10 integrity database, better fracture toughness models.

11 Now, here is one that is very significant. FAVOR
12 will now be able to handle surface breaking as well as
13 embedded flaws, whereas previous versions of FAVOR, as well
14 as OCA, VISA did surface breaking flaws only, because all
15 the current regulations were derived from analysis that
16 assumed all flaws were on the inner surface.

17 Now, we include through-wall weld residual stress,
18 and then there's a lot to talk about in new methodology.

19 Certainly -- I referred -- Ed Hackett referred
20 this morning -- I referred already to the study we did in
21 1999 that showed a lot of potential existed for the
22 relaxation of the current PTS regulations, and the one
23 single thing -- Tom asked did we do sensitivities with
24 respect to different elements, and the answer is yes, and
25 the one that had the biggest impact was this significant

1 improvement in the flaw characterizations, when they
2 actually went and started cutting up -- non-destructive
3 examination as well as destructive examination of the P.V.
4 Roth, as well as Shoreham and other vessels, because the
5 current regulations, the current PTS screening criteria, as
6 well as Regulatory Guide 1.154, all your flaws are
7 surface-breaking flaws.
8 They took the Marshall distribution, even though
9 the data that Marshall distribution was derived from, the
10 flaws were, in fact, embedded, they said we'll still put
11 them on the inner surface. It was conservative.
12 But when they actually start cutting up the
13 specimen material, what they find is that there's a higher
14 number of flaws than what was postulated in the PFM analysis
15 from which the current regulations were derived.
16 However, all flaws detected so far are embedded.
17 In fact, Lee had some numbers up there this morning. When
18 you take the PV rough flaw densities and apply them to a
19 commercial PWR, you get about 3,500 flaws in the first
20 three-eighths thickness of the RPV vessel.
21 So, you're talking about considerably more flaws,
22 but none of them are on the surface, they're embedded, and
23 the impact of that was that you get considerably reduced
24 failure probabilities.
25 So, this, more than any single other thing,

1 element, showed the potential existed for impact in the
2 current regulations.
3 I pointed out lessons learned from IPTS and
4 lessons learned from Yankee Rowe.
5 One of them was that what we're dealing here with
6 -- we're dealing with an entire beltline, you know, and
7 typically we consider the beltline to be from one foot below
8 the core to one foot above the core, and the older codes,
9 OCA-P and VISA -- they would allow you to put, you know, one
10 chemistry, one neutron fluence.
11 So, you'd have to take kind of the worst case and
12 apply it everywhere.
13 But the current version of FAVOR now utilizes a
14 methodology that allows the beltline to be discretized in
15 the sub-regions, each with its own distinguishing
16 embrittlement-related parameters such as copper and nickel,
17 phosphorous, neutron fluence.
18 So, this accommodates the chemistries from RVID
19 and the detail neutron fluence map.
20 This just shows how, you know, you can break the
21 vessel up into different sub-regions, each with its own
22 embrittlement characteristics, each with its own number of
23 flaws, and so forth.
24 So, this was a pretty big step forward from the
25 older version codes to version codes that we have now, and

1 Brookhaven National Laboratory is generating very detailed
2 neutron fluence maps.
3 Shaw Malletshow talked about the number of points,
4 literally thousands. I mean they're talking about breaking
5 that vessel up into thousands of points, if you desire, and
6 this just shows some of the gradients.
7 Here's asmuthal location, and this is at mid-core.
8 So, this is 72 inches above the bottom of the core.
9 So, this is kind of the highest, and this shows
10 the asmuthal location at the mid-core, this shows it 13
11 inches above the bottom of the core, and this shows it, you
12 know, at the extreme top and bottom.
13 So, you see there's dramatic gradients here,
14 asmuthal gradients, as well as axial gradients. This shows,
15 as a function of your axial location, at core flats, and
16 this shows at some various other angular locations.
17 The point here is that there's dramatic gradients
18 and fluence that need to be accounted for.
19 DR. KRESS: That was a question I was going to
20 ask. Why do they need to be accounted for? Why don't you
21 just use the location that has your highest fluence and use
22 that as your -- that's where it's going to fail, right?
23 MR. DIXON: Well, I'll refer back to the figure
24 where I showed the two curves, where one is an improved
25 model. By discretizing -- it's guaranteed that when you

1 discretize and put in the map that includes these values, as
2 well as this, you're going to get smaller failure
3 probabilities. What you're talking about doing is doing a
4 bounding analysis, taking the highest value and applying it
5 everywhere.
6 DR. KRESS: That's because your flaws are
7 density-per-unit volume.
8 MR. DIXON: You will have just as many flaws here,
9 probably, as you do at this level.
10 DR. KRESS: Okay. How come the ones at that level
11 up there aren't the ones that fail, then?
12 MR. DIXON: They may be, but not necessarily.
13 SPEAKER: [Inaudible.]
14 DR. KRESS: That's the answer.
15 SPEAKER: [Inaudible.]
16 MR. DIXON: He said it better than probably
17 anything else I say. You've got to distribute everything.
18 DR. KRESS: That's the right answer, yeah. I
19 understand that.
20 MR. DIXON: Right.
21 So, think in terms of overlaying those fluence
22 maps, you know, those type fluence maps onto here, and you
23 know -- and you'll have flaws distributed over these
24 regions.
25 DR. KRESS: The question is what's the probability

1 of a flaw of given characteristics being at the same spot
2 that the high fluence is.
3 MR. DIXON: Right. By doing a Monte Carlo over
4 all of these permutations of possibilities, we feel you're
5 getting closer to reality.
6 SPEAKER: Why does that circ weld sit on that
7 axial plot?
8 MR. DIXON: Well, that would vary, I think, from
9 plant to plant, but I'm familiar with one -- I won't call
10 its name, but I believe the center line of this weld might
11 be about one foot above here, and a lot of plants, by the
12 way, will have an upper circ weld that falls into this
13 category. This actually corresponds to a plant, and I won't
14 call its name, but the whole idea here is you have one, two,
15 three intermediate axial welds, three lower axial welds, a
16 circ weld, you've got six plates, that when you went to the
17 RVID database, that's how much chemistry you would have.
18 So, I would call those major regions, you know.
19 This would have a different chemistry, and the
20 RVID -- it won't tell you that you had a chemistry here and
21 a chemistry here. It will just say this weld has a certain
22 chemistry.
23 The same with this plate and this plate, but it's
24 when you start overlaying the neutron fluence map onto those
25 chemistries that you get what I would call the embrittlement

1 map.

2 And again, why did we do this? Because when we

3 were doing -- when we were in the Yankee Row analysis,

4 evaluation and analysis, this was certainly a question.

5 People said, well, why can't you account for fluence

6 gradients? Well, the computational tools that we had at

7 that time just didn't. Nobody had taken the time to put

8 that in.

9 This is redundant. Mark Kirk's already discussed

10 this.

11 I'm just going to say that I'm talking about

12 things that are already into FAVOR code.

13 These new statistical models, statistical

14 representations, uncertainty models, whatever you want to

15 call them, for enhanced plane strain, static initiation and

16 arrest, fracture toughness, have been implemented into

17 FAVOR, and this just shows our 254 valid LEFM points, and

18 this shows the WIBLE distribution.

19 This is like the .001 percent curve, the 99.9999

20 percent curve, this is the median curve, and this very

21 lowest curve here is what, in the Wible distribution, is

22 called the location parameter.

23 There's three parameters -- A, B, and C. The

24 parameter A is the location parameter, and this is a plot of

25 that, and basically, that is the lowest possible predictive

1 value of K1C that you could ever have, okay?

2 Again, I guess if we were to get 10 more data

3 points, everything would change, but right now, that's where

4 we're at, and here it is for K1A.

5 Now, this was -- the old EPRI database, I believe,

6 was 171 points. We went to 254. I believe this was 50 or

7 54 data points. This one almost doubled. So, we've got

8 extended databases, and we've got much better uncertainty

9 representation of that data.

10 So, this is -- we feel this is a significant step

11 forward.

12 Okay.

13 Again, I've already alluded to this. This just

14 shows an inner surface breaking flaw, as opposed to an

15 embedded flaw, and as I mentioned earlier, the current PTS

16 regulations and reg. guides all deal with this guy, but what

17 is being found when they go out and do NDE and destructive

18 examination of vessel material -- they don't find these,

19 they find these.

20 So, if we want a better model, better

21 representation of what's out there, we have to be able to

22 model both inner surface breaking and/or embedded flaws.

23 So, the current version of FAVOR now -- it will

24 handle both, I mean at the same time. You can have a

25 combination of surface breaking and embedded.

1 Even though they haven't found any
2 surface-breaking flaws yet, it's my understanding that there
3 will be probably some surface-breaking flaws in the
4 characterization that goes into these analyses, because
5 perhaps they've looked at one-tenth of 1 percent of the
6 vessel material, and I don't think you would want to
7 conclude that, because you haven't found on there, doesn't
8 mean that there might not be one out there, and it becomes a
9 problem of statistics, and Lee Abramson is working on that.
10 Okay.
11 Just one slide here about the structure of FAVOR.
12 Maybe it helps. People that are code developers or code
13 users can relate to this.
14 When you talk about the FAVOR code, it's not like
15 just one module. It's actually broken down into three
16 modules, three completely separate modules.
17 The first one is what I'll call the load
18 generator, okay? And this top line of data is input data.
19 This middle yellow line -- that's the actual codes, the
20 executables. And this bottom line of data is output data
21 from each of the modules.
22 So, this module -- this first module is the load
23 generator, and the input to it is like the thermal elastic
24 material properties of the clad in base, the vessel
25 geometry, and the thermal hydraulic boundary conditions, or

1 in other words, the output from RELAP.

2 Now, the output from RELAP is going to be time

3 histories, coolant temperature, pressure, heat transfer

4 coefficient that's imposed on the inner surface of the

5 vessel, and FAVOR will allow you to give 1,000 pairs,

6 time-history pairs for each of those three for each of the

7 transients, and you can do 30 transients in one run of

8 FAVOR.

9 So, you can see this becomes a bookkeeping thing,

10 too. You're literally talking hundreds of thousands of

11 points.

12 Dave Bessette said this morning, for Oconnee, he

13 was going to give me 27 transients. Each one of those has

14 the three traces. So, 27 times 3 is 81, each one with

15 1,000.

16 We're talking 81,000 data points or time-history

17 pairs. So, we're talking about a lot of data.

18 DR. KRESS: Is that automated? You don't do that

19 by hand.

20 MR. DIXON: No. He gives me a disk.

21 DR. KRESS: He gives you the input curves?

22 MR. DIXON: He doesn't give me curves. I have to

23 make sure it's in the correct format, but that's relatively

24 simple.

25 But anyway, you feed this in -- and I'll talk a

1 little more about this in a minute -- you feed this in to --
2 basically, this is a finite element program, and out comes
3 your -- this is what you were asking, Tom, a moment ago.
4 You do get your space and time-dependent
5 temperature through the wall, how that gradient through the
6 wall at each location is changing as a function of time, the
7 same with regard to axial stress and hoop stress, and the
8 same for stress intensity factors for inner surface breaking
9 flaws, for different flaw geometries at different times.
10 Okay.
11 So, you run that module by itself. You run that,
12 and you get this output file, and it's just a lot of
13 numbers, but they're formatted in such a way that this
14 module, the PFM module, knows that format, and it can read
15 them in accordingly.
16 So, when you run the PFM module, you input the
17 flaw data, the beltline embrittlement data, all those
18 sub-regions and corresponding chemistries and fluence maps,
19 with all the flaw data, and also all of this load data for
20 each of the transients.
21 All that is used as input into the PFM module, and
22 out of that comes distributions for conditional probability
23 of initiation, conditional probability of failure for each
24 transient.
25 Now, it should be said that conditional

1 probability of initiation is dealing only with cleavage or
2 fast fracture. There is no EFPM. Somebody mentioned a
3 moment ago about JR curves. Okay. There is no ductile
4 tearing considerations going on.
5 This is a cleavage fracture, LEFM cleavage
6 fracture analysis only at this point.
7 Okay.
8 Then the third module is the post processor.
9 Actually, this only exists in my head right now, but I know
10 what to do, and the input to that is the transient
11 initiating frequency distributions, which comes from the PRA
12 people. Okay.
13 So, that's input, as well as these distributions
14 that you got from the PFM module. All that goes in the post
15 processor, and out of that comes the bottom line of an
16 analysis, and the bottom line is the frequency of
17 initiation. This is kind of a mismatch. It's the frequency
18 of RPV fracture, which is CPI, and the frequency of RPV
19 failure. So, the distribution -- that distribution would
20 have a mean value associated with it.
21 So, the mean value of this distribution would be
22 what was plotted in that figure I showed earlier, because
23 remember, I'm doing this at a moment in time, because
24 there's one fluence map here.
25 SPEAKER: Fracture in this case means initiation,

1 and failure means failure.

2 MR. DIXON: Good point. Initiation means fracture

3 occurs.

4 Now, whether that flaw propagates through the wall

5 is another question, and frankly, that's something we're

6 still working on, and I'll talk about that in a moment.

7 In fact, now we're going to shift gears and talk a

8 little bit kind of about, before we get too lost in the PFM,

9 probabilistic fracture mechanics detail, let's step back and

10 kind of talk about the overall PRA methodology.

11 This is a pretty busy slide, but this is just

12 showing that on the last -- on the slide a moment ago, I

13 showed the load generator. This is just showing the load

14 generator again.

15 But first, let me read this caption, because I

16 think this is important.

17 The FAVOR analyses incorporate the uncertainty

18 associated with the thermal hydraulics by including variants

19 for each of the transients, okay?

20 This shows RELAP generating a lot of output data,

21 okay, and major transients. Transient one might be a

22 small-break LOCA. Transient two might be a stuck turbine

23 bypass valve. Transient three, something else, dot, dot,

24 dot, transient N.

25 Okay.

1 Now, within each one of those major transients,
2 there's variance.
3 The way that a small-break LOCA comes down, it
4 could be this, could be this, could be this, could be this.
5 So, if you want to consider all those
6 possibilities, each one of these is three -- represents the
7 three time histories, each one of these errors. Maybe this
8 is a small-break LOCA, one possibility.
9 Here's the temperature, pressures, heat transfer
10 coefficient for that.
11 So, all of that goes in in one run of the load
12 generator, which performs a one-dimensional, axi-semetric,
13 finite element analysis to calculate the loads for each
14 transient, and again, this is redundant, temperature,
15 circumferential axial stresses, stress intensity factors,
16 tremendous amount of data here, big bookkeeping exercise
17 right here.
18 Okay.
19 The other module was the PFM module, and what it
20 does, it generates these arrays for the conditional
21 probability initiation -- I call that PFM-I -- and failure,
22 PFM-F, for vessel J subjected to transient I. It's starting
23 to get a little bit esoteric here, but think of this as
24 being a two-dimensional array, where each row in this array
25 corresponds to a particular transient -- in other words, one

1 of those representations that was shown on a previous slide,
2 and each column in this array corresponds to a vessel, and
3 the entry that goes into a particular I-J entry into that
4 array is the conditional probability of initiation that that
5 vessel fractured when subjected to that transient.
6 Same thing for failure, okay? And this module --
7 this is redundant. This is just another way of showing what
8 I showed a moment ago, where the loads, all the stresses,
9 temperatures, and everything that was done in the finite
10 element analysis is input into here, as well as the flaw
11 characterization files, which Lee and Debbie will provide,
12 for weld material, plate material; the PFM input, the
13 embrittlement maps for all those various sub-regions, along
14 with probabilistic input such as what's the one standard
15 deviation, you know, a lot of things like that.
16 I think I've about talked that one out.
17 A third module, if you recall, is a
18 post-processor, and the objective of the post-processor is
19 to integrate the uncertainties of the transient initiation
20 frequencies with the PFM-I and PFM arrays to generate
21 distributions for the frequencies of RPV fracture and RPV
22 failure.
23 This just shows the initiating frequency for
24 transient one, the distribution of initiating frequency for
25 transient one, two, dot, dot, N, okay? And these are shown

1 in histogram form, because it actually comes into the
2 program numerically. You don't say this is gaussian, this
3 is beta, because then you've got to create a whole library
4 of the possible distributions. So, we just said just do it
5 numerically.
6 So, that's the way that it's going to be done.
7 Also, the arrays that I showed a moment ago, the
8 PFM-I array, where the IJ entry, you remember, is the
9 conditional probability that that vessel will fail when
10 subjected to that transient, as well as the PFM-F comes into
11 here, and the output is the distribution of whichever one
12 you're doing, the initiation or the failure, okay?
13 So, you get a distribution, and this shows that
14 this distribution is, I guess, what statisticians like to
15 call bi-modal.
16 It will have -- typically, it will have a big
17 value, kind of a skyscraper here at zero, because hopefully
18 most of these were zero, and then you'll have some other
19 kind of distribution.
20 So, the mean of this distribution is not here.
21 It's going to be way over here.
22 So, it's going to be a very unsymmetrical
23 distribution.
24 Okay.
25 Now, the process to get here, what goes on in this

1 post-processor is that, for each vessel -- in other words,
2 for each column in one of those arrays, you sample the
3 initiating frequencies.
4 So, you have -- I like to think of it -- you'd
5 have a row vector of initiating frequencies, you know, one
6 value for each of the transients. Then you combine that
7 with like the PFM-I array, which I like to think of that as
8 a column vector.
9 So, if you multiply a row vector times a column
10 vector, you get a number, get a scaler.
11 So, that would be one value that would be the
12 frequency of initiation or, if you were doing failure, the
13 frequency of failure.
14 So, that would give you one value.
15 Well, if you do this, say, 100,000 times, you've
16 got 100,000 values.
17 So, you sort those, arrange them into a
18 distribution, then you calculate the mean and standard
19 deviation.
20 So, that's the bottom line right there.
21 In going back to that picture that I showed
22 earlier, you could take the mean of that, plot it for that
23 time, then you'd go do another analysis for another time in
24 the life of the vessel, and of course, what I didn't show --
25 and I'm being redundant -- what I didn't show on that first

1 slide was the amount of uncertainty, but we will know it.
2 Okay.
3 That could stop right there and that be the end of
4 the presentation, but we'll now try to talk a little bit
5 about some of the details of the PFM analysis. That was
6 just -- in other words, I'll try to talk about some of the
7 details of how you get a number into that PFM-I array, okay?
8 All I'm going to talk about here is how do you get
9 a number into the PFM-I array?
10 Now, I'm going to digress here just a moment,
11 because you asked a very good question this morning, Dr.
12 Shack, about -- you said you weren't sure if we were riding
13 one curve down or what, and I'm going to talk in more
14 detail, but now's a good time to interject that what I
15 showed a moment ago, in each IJ entry of that PFM-I array,
16 it's a number between zero and one.
17 Each entry has -- it's a probability, with the way
18 that we do it now.
19 The way we used to do it, which is what you said,
20 grab a curve, sample, ride it down, and either it's a
21 yes/no. It either breaks or it either doesn't. And that
22 was the old way of doing it.
23 In that case, it was a zero or a one. It's kind
24 of digital. It was either broke or it either wasn't broke.
25 But now, with our new methodology, you can have something

1 between a zero and a one.

2 Anyway, that will sort of lead in.

3 This is a terrible slide, and I'm going to maybe

4 try this a little differently. Instead of showing that --

5 that's even worse.

6 I'll try this, and like I said a moment ago, I

7 could have stopped, but we're going to jump off into some

8 details now.

9 The name of this section is PFM details.

10 Actually, I was hoping that it would be time for

11 people to go catch planes and stuff by the time I got to

12 here, but looks like not.

13 The idea here is -- remember, I said that I'm

14 talking about how you get a number into those arrays, okay?

15 I've showed you what you do with them after you get them.

16 How do you get a number? Okay.

17 I told you we're going to do many vessels. So,

18 let's let our outer loop be vessels, vessel equal vessel

19 plus one.

20 Then we know that all the vessels are going to

21 have multiple flaws. You saw Lee's presentation this

22 morning, and I had a slide here that showed that they have

23 around three or four thousand flaws, every vessel. So,

24 you're going to increment your vessels.

25 Okay.

1 Now, that particular flaw -- where on that
2 beltline region is it? Is it in a plate? Is it in a weld?
3 You choose that.
4 You sample and determine that. You place the flaw
5 on the beltline region, and in that beltline region, there's
6 a certain copper, nickel, phosphorous, neutron fluence, all
7 the embrittlement properties in there.
8 So, here, you've got a flaw located on the
9 beltline, with its embrittlement properties.
10 Now, we're going to sample the flaw
11 characteristics. How big is the flaw? Where is the flaw in
12 the wall? Is it a surface flaw? Where is it embedded?
13 So, now, we know enough to calculate the RTNDT of
14 the cracked tip. We know where the cracked tip is. We know
15 all the things that goes into the correlation that Mark was
16 showing, the chemistries, the neutron fluence. So, you get
17 an RTNDT.
18 So, at this point, we've got a flaw with a tip
19 located somewhere that's got a certain RTNDT.
20 Now, the next loop is going to be transients.
21 We're going to subject that to the various transients.
22 Okay. And the next loop is time, transient time.
23 So, we're going to step through here this time
24 loop, calculating the conditional probability of initiation
25 and failure for each one of these flaws.

1 SPEAKER: Let me ask my question here.

2 MR. DIXON: Okay.

3 SPEAKER: I've just calculated RTNDT. Why don't I
4 calculate a toughness?

5 MR. DIXON: Well, you do. You can see that this
6 was already pretty busy. This is high-level. That's the
7 next couple of slides of how we do that.

8 SPEAKER: Yes, but doesn't it make a difference
9 whether I compute the -- I pick that curve sort of outside
10 the time loop or I sample --

11 MR. DIXON: No.

12 SPEAKER: I guess this is my riding down versus --

13 MR. DIXON: No, either way. RTNDT is not a
14 function of transient time.

15 To calculate K1C, it's T -- it's a function of T
16 minus RTNDT.

17 T is transient time dependent.

18 So, I can calculate my RTNDT outside of even my
19 transient loop or my time loop, but you're right, once I get
20 into this time-loop, I'm going to be saying T minus RTNDT, T
21 minus RTNDT, and it doesn't matter if I'm moving down a
22 curve or moving across a distribution, my RTNDT is not going
23 to change.

24 It's the same RTNDT at that crack tip throughout
25 not only this transient but all the other transients, as

1 well, okay? And you're right, there's a lot going on in
2 here that I don't show, but there's some slides coming up in
3 a moment that attempts to address that.
4 But basically, you do this until all the time's
5 over, all the transients are over, you've done it for all
6 the flaws, okay, and then you have to go through this whole
7 multiple flaw thing. I'll talk a little bit about that. At
8 this point, you would have a value for one flaw, and then
9 you have to do kind of some algebra to combine the effects
10 of multiple flaws for that vessel, and we'll talk about that
11 in a moment.
12 And then the last -- you close your last loop,
13 which is vessel.
14 So, you set there, you got these four loops going
15 on, but physically, I like to think of it -- you know, you
16 take vessel one, you locate a flaw somewhere on that
17 beltline, you get an embrittlement, and then you set there
18 and hit that flaw with all the transients, okay, and then
19 you go to the next flaw, and you do that until all the flaws
20 are exhausted for that vessel, at which point you have an
21 entry into your PFM-I and PFM-F array.
22 I know that's a very busy slide, but it also
23 contains a lot -- what Dr. Apostolakis was asking this
24 morning. He would like to see you step through one
25 iteration. There it is. There's one iteration.

1 MR. HACKETT: Terry, let me add a comment while
2 you have that up there. This is Ed Hackett.
3 I think another thing that's come up in some
4 previous discussions with the committee is that it's
5 important to note that these are done -- as far as I
6 understand it, they're done randomly and independently. So,
7 there's no linkage, for instance, between an area that's
8 high in copper with some kind of idea that that would be
9 inherently more flawed than some other area.
10 Those are going to be, you know, in separate
11 loops, as much as something like that could exist. We're
12 not modeling that kind of thing.
13 DR. KRESS: But you did say you attempted to model
14 multiple flaws some way.
15 MR. DIXON: Yeah.
16 DR. KRESS: These are, you know, one flaw there by
17 itself.
18 MR. DIXON: Yeah.
19 DR. KRESS: And you're saying that there might be
20 another one close by and they link up or something like
21 that?
22 MR. DIXON: No. Yes, but right now, let me just
23 say -- maybe I'll just say this. Right now, there is no --
24 right now, there's an assumption that every flaw is
25 independent from every other flaw as far as fracture. The

1 presence of one flaw does not influence the fracture
2 response of another flaw.
3 However, at the PVP conference in Seattle this
4 past July, a professor from the university of Ottawa
5 presented a paper that I went to, and he had done some work.
6 So, I think -- I've read his paper.
7 I actually think -- I don't know if we want to,
8 but I was going to discuss it with NRC staff at some point
9 in the future.
10 He's got curves that you could use to sample that,
11 but I'm not sure that we want to go there. I don't know.
12 His work was kind of the first, I think, in this area.
13 Right now, the answer to your question is every
14 flaw is independent of every other flaw.
15 SPEAKER: How long does it take for a single run
16 from vessel equal vessel, from the first vessel that's
17 chosen to the end point?
18 MR. DIXON: Okay. That's a good question. It
19 depends on a lot of things.
20 I've got a machine that's a 533-megahertz machine,
21 and to run it for, say, 100,000 vessels, for a single
22 transient, 100,000 vessels, where each vessel has around
23 3,500 flaws, it's about -- like I'll start it when I leave
24 work, like at five o'clock, and I'll come back the next
25 morning and I'll see where it finished at 2:30 in the

1 morning or something.

2 So, it's eight, nine hours on a 533-megahertz

3 machine for one transient, and Bessette said this morning

4 that he's going to give me 27 transients for Oconee.

5 So, I can already see that we may have to -- I

6 know, right now, you can buy 800-megahertz machines for the

7 same thing that you could buy this one for last February.

8 So, I think we may have to -- maybe by next March,

9 when we get ready to do this, we may go buy us a couple

10 giga-flop machines, which will probably be out there for

11 what we bought the 533 for last year.

12 So, I mean you can see that this is pretty

13 computationally intensive.

14 And remember, at the end of the day, when you do

15 that, that's just one point on your curve.

16 Okay.

17 I told you that I would try to -- between that

18 transient time loop -- I just stepped over it. Now I'm

19 going to try to address that a little bit here.

20 Here's a transient. In fact, this is taken from

21 the IPTS studies.

22 This is designated in the IPTS studies as Calvert

23 Cliffs transient 8.3, and it has a distinguishing

24 characteristic that was a distinguishing characteristic of

25 most of what was called the dominant transients in the IPTS,

1 those that contributed most significantly to the vessel
2 failure, and that is this late re-pressurization.
3 You know, your temperature is here. It's a pretty
4 sudden cool-down down to about 150. No, it's not very
5 sudden. It's pretty gradual. Over a period of two hours,
6 it cools from 5.10, I believe, to around 150.
7 Pressure drops suddenly, stays low. Get over here
8 about 95 minutes, boom, you spike back up to full pressure.
9 Bad news transient.
10 But anyway, I'm going to use this transient to
11 illustrate this new methodology of calculating the
12 conditional probability of initiation, as opposed to the old
13 way of going up and getting a curve, picking a curve and
14 riding it down, and either the vessel breaks or it either
15 doesn't.
16 Okay.
17 This is a lot of words. I'll read it.
18 The conditional probability of initiation is
19 calculated by solving the Wible K1C cumulative distribution
20 function for the fractional part, percentile, of the
21 distribution that corresponds to the applied K1 as a
22 function of T, a lot of words, but what that means -- what
23 this is an attempt to illustrate is here's your Wible
24 location parameter. I showed earlier, that's the lowest
25 value of K1C you could every have, okay? And I chosen an

1 arbitrary flaw. I said let me take a half-inch-deep flaw
2 that's embedded, that's located such that it's inner cracked
3 tip is one-half-inch away from the RPV inner surface.
4 So, I've got a flaw that's a half-inch,
5 through-wall, located a half-inch from the inner surface of
6 the vessel, and I subject that to this transient, and here
7 is the K1.
8 Now, this is T minus RTNDT. So, time is going
9 this way, okay?
10 This shows the applied K1, this K1 as a function
11 of T, moving this way, and you notice that it never breaks
12 into the -- it never penetrates the K1C space until the
13 re-pressurization.
14 At 95 minutes, about 95 minutes, boom, it spikes
15 up here, and at that point, that is the 6.35-percent curve,
16 okay, or the .0635, which you solve if you put the K1 into
17 the Wible cumulative distribution function along with A, B,
18 and C, which are functions of T minus RTNDT, you get the
19 conditional probability of initiation for this transient at
20 this time for this flaw, okay?
21 So, this is pretty fundamental right here of
22 what's happening down at the innermost kernel of this
23 algorithm, okay?
24 Now, here's another -- here's an attempt to show
25 that same thing another way.

1 In the illustrative example problem, the Calvert
2 Cliffs, 8.3, at the time of re-pressurization, K1 is greater
3 than .0635 of the Wible distribution at this particular
4 vertical T minus RTNDT.
5 So, at that moment in time, when you spike up
6 below that lowest value, the question is how far did you get
7 up into that K1C space, which I showed how you solve for
8 that, but all you're doing is you're just solving for what
9 part of that total distribution is applied K1 greater than,
10 okay?
11 Now, if you want to ask questions, this is a good
12 time to do it, because this is new. This is new PFM
13 methodology that -- basically working with the University of
14 Maryland, and it's my understanding that this includes the
15 aleatory uncertainty that we used to didn't include.
16 When we used to get up and ride a curve all the
17 way down and it was either a zero or a one, that did not
18 include the aleatory uncertainty, whereas this method does.
19 SPEAKER: But it says that that variation in K is
20 all aleatory.
21 MR. DIXON: There's no variation in K. K is only
22 as a function of time.
23 SPEAKER: K1C.
24 MR. DIXON: Right.
25 SPEAKER: Somehow, I would pick that as families

1 of curves for a given material.

2 MR. DIXON: It is families of curves. It is, in

3 fact, families of curves. You can think of it that way.

4 SPEAKER: But once I've picked the material, I

5 have a curve, with perhaps some scatter around it.

6 MR. DIXON: You're right. Once you pick RTNDT,

7 you have -- I'll tell you what. Maybe this will help.

8 Maybe it won't. We can go back to that slide.

9 This is an attempt to show -- this is showing it

10 as a function of time. Now, you know, we're moving this

11 way. This is a different situation. This is not that

12 transient 8.3. This is a different case, a different flaw.

13 But this shows how the Wible location parameter changes as a

14 function of RTNDT. As RTNDT increased, that Wible location

15 parameter gets lower.

16 Now, here comes this -- in time, here comes the

17 applied K1 in time.

18 So, the question is, how much does this applied

19 K1, if at all, how much does it penetrate the K1C space, you

20 know? That's the question that we're asking when we do this

21 particular computation, and the little dots correspond to

22 the discrete times that we're analyzing it at.

23 Now, this is a plot of the instantaneous

24 conditional probability of initiation; in other words,

25 solving -- as I showed a moment ago, solving the Wible

1 cumulative distribution function as a function of time, or
2 in other words, as a function of applied K1.
3 You can see that, at 325 degrees, RTNDT, which is
4 pretty high -- I did it just for a good example -- how far
5 is it above this line, and for 275, how far is it above this
6 line, and this answers those questions.
7 This shows the conditional probability of
8 initiation as a function of time.
9 I don't know if that helps or not.
10 SPEAKER: Let me just take a more simple-minded
11 approach.
12 MR. DIXON: Okay.
13 SPEAKER: If I went back and, you know, I plotted
14 that data, all my 274 data points --
15 MR. DIXON: Yeah.
16 SPEAKER: -- for the K1C, and I have all the data
17 for a single material, you know, where I've made all the
18 samples, will those sort of occur randomly within that band,
19 or will the material for a given sit somewhere either at the
20 top, bottom, or middle of that band?
21 MR. DIXON: I don't know. Mark could probably
22 answer that better, and he stepped out.
23 SPEAKER: Could you give that one more time, Bill?
24 I'm not sure I followed that.
25 SPEAKER: If I take my 254 data points, and those

1 are multiple heats of material, and I look at a single heat
2 of material, will I find it uniformly scattered up and down
3 that band, or if I look at single heat of material, will I
4 find it sitting somewhere in the middle of that data as I
5 move from RTNDT?
6 SPEAKER: Looking at a single heat, I'd be
7 inclined -- I guess I can't answer for the current
8 situation. I think previously I know -- I can say the way
9 we addressed Pallisades, it would have been uniform, is that
10 way we've done it previously, and I don't know if that
11 carries through to where Terry is now.
12 SPEAKER: Yeah. He's saying you can go anywhere
13 from the top to the bottom.
14 SPEAKER: Then that's a random choice.
15 SPEAKER: That's a random choice, whereas, you
16 know, I'm sort of -- I would have argued that maybe that
17 band really indicated that some materials are tougher than
18 others, and therefore, you pick a material and you would
19 have had some aleatory distribution, but it would have been
20 a much narrower aleatory distribution.
21 SPEAKER: I see what you're saying now. I think I
22 understand now.
23 That would be the intent of the new methodology,
24 would be what you just said there.
25 SPEAKER: No, I think the new methodology says I

1 go up and down the whole damn curve.

2 SPEAKER: Yeah.

3 SPEAKER: See, I thought it was more the -- you

4 know, this is going to depend on how these uncertainties,

5 you know, cascade into this, but I would have thought it

6 would be more what you just said. Maybe I've got the wrong

7 impression.

8 MR. DIXON: Going back to our K1C database --

9 END OF TAPE 4, SIDE A; BEGIN TAPE 4, SIDE B

10 MR. DIXON: [In progress] -- a vertical slide

11 through there at a given value of T minus RTNDT.

12 Now, I don't know if what I'm fixing to say

13 addresses your question. I may not get this exactly right,

14 but you'll get the idea.

15 That 254 data points -- I believe there was 16

16 groups, okay, 16 groupings of various T minus RTNDT, okay,

17 you know, plate, HSST, one four plate, HSST, 02, dot, dot,

18 dot, and so, they were grouped by heat, but the Wible

19 distribution that is derived from that does not include

20 those considerations. It's just data.

21 SPEAKER: Right. That's okay if the data for all

22 those plates sort of falls up and down that thing uniformly,

23 but if they were all colored and I saw all green balls down

24 at the bottom and I saw all red balls up at the top, then

25 doing my Wible -- I can't answer my question until I know

1 where the balls lie.

2 DR. KRESS: Are you going to be able to know which

3 heat a given vessel --

4 SPEAKER: No, but then I would sample -- I don't

5 know where the curve is, and so, I would sample -- you know,

6 what I would think of as families of curves and pick a

7 curve.

8 DR. KRESS: Yeah, but on what basis would you pick

9 that curve?

10 SPEAKER: Because it would be some material, and I

11 would pick it at random, but once I picked that, I would say

12 -- the material never changes through the whole transient.

13 Every time he goes to a time step, he goes up and down that

14 whole distribution, and I would say no, once I've picked my

15 material, I've sort of got a tough material --

16 MR. DIXON: No, no, no. What you just said is not

17 correct.

18 SPEAKER: It's not?

19 MR. DIXON: What you just said is misleading.

20 Keep that picture in your mind.

21 Now, let me see. Let's go here.

22 We're not bouncing up and down. The question is,

23 the way I like to think of it -- I don't know which picture

24 is best.

25 We're not bouncing up and down anywhere. The

1 question at any time is what percentage of the Wible
2 distribution is the K1 greater than? That's not bouncing up
3 and down.
4 In other words, if I was to -- in fact, one of my
5 back-up slides may do this. No, it will just confuse it.
6 In other words, if you were to go at this time, 10
7 minutes later in the transient, you don't come over here and
8 completely re-sample. You're not sampling. There's no
9 sampling going on here.
10 The question is, you've got this K1C space
11 defined, between here and here.
12 Now, the question is, when I bring my K1 as a
13 function of T into play, how does it penetrate that space,
14 if at all? That's the question.
15 There's no sampling involved.
16 DR. KRESS: But you're saying if you define that
17 curve a little finer, with the different colors, you could
18 have sampled it.
19 SPEAKER: If I can interject here, I want to point
20 out a couple of things.
21 One, the curves that Terry is showing here are
22 certainly necessary for us getting on with the work and
23 formulate things, but I don't think this is the final word.
24 This was based on the statistical analysis of the data set.
25 If you go back to Terry's slide showing the Wible

1 equation, he mentioned the parameters A, B, and C. One can
2 develop different distributions for those parameters.
3 That's where the epistemic comes in, what's the value of A,
4 B, and C, and if you segregate the data based on different
5 characteristics -- and I'm way beyond my depth now, but
6 conceptually, what you would do is, if you identified
7 different classes for which you have different families of
8 values for A, B, and C, that's how you would enter that
9 process.
10 So, that would be the same thing as what you're
11 talking about, selecting the curve. In this case, you'd be
12 selecting A, B, and C, and then, once you have that now --
13 SPEAKER: It depends on whether you're doing that
14 inside the delta time group or outside the delta time group.
15 SPEAKER: That's right, and the epistemic loop is
16 outside, by definition. The inside is when you're dealing
17 with the aleatory component, because now you're dealing with
18 a transient and the response on a time step by time step
19 basis.
20 SPEAKER: When I say bouncing every time, Terry,
21 at every delta-T, you're sampling a K1C.
22 MR. DIXON: No.
23 SPEAKER: Where do you determine the K1C? That's
24 outside the delta time group?
25 MR. DIXON: There is no sampling of K1C. Once

1 you've got your -- you've got your K1C space defined by the
2 Wible statistical representation.
3 Now, the question is -- I'm going to put the K1
4 into that function, and what I get out of that is the
5 percentile K1C curve or which one of those family of curves,
6 if you wish to look at that way, does that K1 correspond to?
7 Let me try it this way.
8 This is the Wible cumulative distribution function
9 that, if you had K1C in here, if you had K1C in here, it
10 would tell you which one of those families -- in other
11 words, which percentile K1C curve is that, as a function of
12 K1C, A, B, and C, but when I plug K1 in instead of K1C, the
13 question that I'm answering is what -- I mean, right there,
14 that shows -- that's the 6.35-percent K1C curve.
15 So, I'm not sampling K1C. I'm asking the
16 question, how far does my K1 penetrate into K1C space?
17 MR. KIRK: Mark Kirk, NRC.
18 Can I say it maybe a different way, relative to
19 Terry's ugly slide? Maybe we've found a use for that.
20 Could you put it back up?
21 MR. DIXON: Okay.
22 MR. KIRK: Terry's certainly right in what he's
23 saying, he's not sampling K1C, but the material properties
24 for any given -- if you look at the loop that says calculate
25 RTNDT at cracked tip, that's outside the time-loop.

1 So, at that point, I guess the way I'd think of
2 it, once he's calculated RTNDT at the cracked tip, at that
3 point, he's determined where the K1C curve is for that
4 material. That's then fixed on a toughness versus
5 temperature plot.
6 He then goes and runs the time loop, and that's
7 what the illustration -- if you go to your slide 23 -- so,
8 once he's determined RTNDT at the crack tip, he's determined
9 where the K1C curve is for the whole time loop.
10 He then runs the time loop, I think, as he said,
11 from right to left, and that's the applied K1 changing with
12 time, and how it winds up with in the K1C curve gives you
13 your final probability of failure -- of initiation, I'm
14 sorry. But once you get inside the time loop, the material
15 characterization has been fixed. It's not re-evaluated each
16 and every time.
17 SPEAKER: I see what he's doing now.
18 MR. KIRK: Is that a correct interpretation,
19 Terry?
20 MR. DIXON: Yeah.
21 Notice, at these points down here, you can
22 positively say the conditional probability of initiation is
23 zero. It does not get equal to or above this lowest
24 possible value of K1C, the location parameter.
25 You can positively say, you know, with a

1 confidence interval very high, that the probability here is
2 zero, until you re-pressurize.
3 SPEAKER: [Inaudible.]
4 MR. DIXON: Yes. In other words, any time the K1
5 is above this location parameter, you've got a non-zero
6 value of conditional probability of initiation.
7 SPEAKER: Could you put that other slide back up,
8 Terry, the schematic again? I just want to see if I'm clear
9 on where Bill was coming from.
10 MR. DIXON: This one?
11 SPEAKER: No, the methodology.
12 MR. DIXON: Oh.
13 SPEAKER: Because I was wondering -- maybe I'll
14 pose it as a question, Bill.
15 I was wondering if you were on the third box down
16 where we're looking at sampling sub-regions and where that
17 relates to the generation of the K values in terms of maybe
18 compartmentalizing the K1C or that type of generation,
19 because obviously, we are looking at different values for
20 the different sub-regions, but that also, by Terry's chart
21 here, is fixed outside the loop, outside the transient loop.
22 I don't know if that helps at all, but I was
23 wondering if that might be where you were coming from.
24 MR. DIXON: The only material property that's
25 varying in here is K1C, and it's varying because temperature

1 is varying. RTNDT is fixed.

2 In this loop right here, your temperature is

3 changing. Therefore, T minus RTNDT is changing.

4 Mohammed?

5 MR. MEDAREZ: Mohammed Medarez. Maybe if I can

6 show you --

7 MR. DIXON: Sure.

8 MR. MEDAREZ: This one view-graph -- maybe it

9 explains this a little bit better.

10 If you're looking at it, here's the K1C

11 distribution, and as time goes by, the distribution will

12 have different shapes.

13 It slightly changes, because as time goes by, the

14 temperature changes slightly.

15 Typically, if you take a sample of this as a

16 percentile here and if this is your K1, this shows the time

17 that it exceeds, okay?

18 If I take many of these samples, I can build a

19 distribution here of the time that I initiate that flaw.

20 Everything inside a flaw, flaw is fixed, and I'm just going

21 over time now, okay?

22 So, I take -- typically, I think this is what you

23 do. You take a sample here, and this is a sample of the

24 percentile. From the old time, he had only a bounding

25 value. Now he has a distribution of these, because he has a

1 variability, and therefore, he gets a distribution of the
2 time to initiation of the flaw.
3 So, for instance, the probability that he would
4 have any initiation between this time and this time in this
5 area which is hatched, which is also equal to that area.
6 So, that's the difference from the last time of
7 operation.
8 Essentially, he used a bounding line, and now he
9 is taking a percentile of this curve, but he stays constant.
10 Once he takes that, he stays constant over that line, and
11 finds what time the crack starts to initiate.
12 So that's the process.
13 SPEAKER: Why is your cumulative probability on
14 the bottom -- why doesn't that go out to where your K1T
15 crosses your bottom line again?
16 MR. MEDAREZ: This one, why it goes down?
17 SPEAKER: Your probability that you're
18 accumulating the probability of failure.
19 MR. MEDAREZ: Because physically, if you start in
20 here, you started right here, if it goes down, it has
21 already started. So, you don't start it again. That's why.
22 If it goes up and down, it can only start one
23 time, and that's it.
24 So, that's why you have, actually -- once you
25 reach the maximum, you trap it out completely. There is

1 nothing else after that.

2 MR. DIXON: I don't know if this will help, but
3 Mohammed basically is saying, okay, given this applied K1 as
4 a function of time, you could set here and do a Monte Carlo
5 analysis on this flaw and sample this Wible K1C distribution
6 and come down here and get a distribution.

7 What I'm saying -- and we have verified this, he
8 at the University of Maryland, as well as I at Oak Ridge --
9 you get exactly the same answer as if you go ahead and
10 algebraically solve the cumulative distribution function.
11 It's the same thing, because if you do this Monte Carlo,
12 which becomes computationally prohibitive, because now
13 you're doing a Monte Carlo within a Monte Carlo, and that
14 gets a little bit crazy, but what you're really asking is,
15 you know, what's the percentile of your K1 space that you
16 penetrated? That's the way it comes easiest for me to
17 understand.

18 SPEAKER: I don't think we should get too hung up
19 on the -- I mean there is a difference between the mechanism
20 used to do the computation, and we can use sampling or we
21 can use quadrature, we can do lots of things, and then the
22 basic model as to where the variability is coming in, as a
23 function of time, and where the epistemic uncertainty and
24 how that's treated, and clearly, we need to do a better job
25 of explaining that.

1 So, I think, in the upcoming meeting, we will
2 certainly put together a better story as to how your issue
3 is being addressed, because we understand the question.
4 SPEAKER: Okay.
5 MR. MEDAREZ: And right now, of course, we're
6 treating it as aleatory, but we recognize that that may not
7 be correct.
8 SPEAKER: There are components that are epistemic.
9 You're not seeing that right now in this curve.
10 MR. MEDAREZ: But right now, we basically carry
11 the whole uncertainty through, and what we're calculating is
12 the probability of vessel failure, which is all aleatory, in
13 that case.
14 SPEAKER: I guess what I missed was the fact that
15 you're really looking at these cumulative curves.
16 MR. DIXON: Shaw, did you tell me that you
17 distributed to these guys a copy of that IAEA paper that we
18 wrote?
19 MR. MEDAREZ: Yes.
20 MR. DIXON: It's called updated probabilistic
21 something. It's a paper Shaw and I wrote for the IAEA
22 conference.
23 That says in words what I'm getting tongue-tied
24 trying to say up here. In other words, that problem with
25 that re-pressurization -- there's a narrative that describes

1 that in that paper that probably says it better than I'm
2 trying to say up here right now.
3 I can write better than I can speak.
4 SPEAKER: I'm not sure I completely understand
5 everything, but now I understand what you're doing.
6 MR. DIXON: Until now. And this is a very
7 complicated looking slide, but -- and I probably made this
8 more complicated than I had to.
9 But this whole thing about accounting for multiple
10 flaws -- remember, each vessel may have three, four, five
11 thousand flaws, and you go through that loop and you get
12 values of conditional probability of initiation for flaw
13 number one, flaw number two. Actually, the way it seems to
14 turn out, maybe out of that 3,500, maybe four or five of
15 them will be non-zero, okay?
16 So, the question is now, for that vessel, what's
17 the probability of initiation, and I'm not going to go
18 through all this equation-looking stuff, other than to say,
19 if CPI is the conditional probability of initiation, one
20 minus CPI is the probability of non-initiation, and then, if
21 you -- for two flaws, if you take one minus CPI for the
22 first flaw and multiply it times one minus CPI for the
23 second flaw, what you have is the probability that neither
24 one of those flaws initiated, you have a joint probability
25 that neither one of those flaws initiated, right, and if you

1 have 3,000 flaws, it's still just one minus the CPI times
2 one minus the CPI all the way out to however many flaws you
3 had.
4 So, at the end of that, that's the probability
5 that none of those flaws initiated. Then, if you subtract
6 that from one, it's the probability that at least one of
7 them did initiate it.
8 That's the value -- that's what this is an attempt
9 to show. That's the value that goes into your PFM-I array
10 for that vessel transient, that IJ entry in your PFM-I
11 array.
12 So, you go through that business about how did K1
13 penetrate K1C space, you get a value of CPI for that flaw,
14 you do it for many, many flaws.
15 Then you do this and you get a value to go into
16 your PFM-I matrix.
17 One other little -- this max in here -- you do it
18 for the maximum value as a function of time for each flaw.
19 In other words, take the peak value.
20 So, for this particular flaw, you know, let's say
21 this was the case.
22 We would come out here and we would take that
23 value for flaw number one, and then if, you know, we had
24 another non-zero, we would do the one minus that time one
25 minus that to get the value that goes into the PFM-I array.

1 DR. KRESS: Multiply that probability times the
2 time?
3 MR. DIXON: Not times the time. That's the
4 conditional -- each one of these is instantaneous, but if
5 you think about it -- that's a good question. This value
6 here really is the cumulative value of everything that's
7 gone before.
8 DR. KRESS: I'm trying to get a probability
9 density function integrated over time, but I don't see how
10 to do it.
11 MR. DIXON: That's not what's going on here. I
12 know it's a lot to get your fingers around at one time.
13 I'll just conclude with, you know, one that I
14 showed earlier. You know, the goal is to have the code
15 ready to go by March 1, 2000. This assumes, you know, that
16 all the models are finalized according to schedule.
17 In the interim period, we're going to finalize
18 some models, implement models in the FAVOR, and perform
19 scoping studies, and it looks like Oconee will be the unit
20 that's the guinea pig for the scoping studies, because the
21 thermal hydraulics and the PRA are going to be finished.
22 That's it. That concludes everything that I have.
23 SPEAKER: [Inaudible.] Pieces of this don't break
24 off all that easily.
25 DR. KRESS: No, it doesn't seem to.

1 SPEAKER: What do you think is important for the
2 rest of the committee to hear out of this, to let them know
3 where the staff is, possibly raise questions about the
4 recommendations on where they should go?
5 SPEAKER: George seemed very concerned about the
6 uncertainty analysis in the K1A.
7 DR. KRESS: Terry walking through that thing would
8 bring that out, I think, would be one of the things.
9 SPEAKER: That might be my candidate.
10 DR. KRESS: Yeah. I was about to say that would
11 be my candidate.
12 SPEAKER: And hold off on the flaw distribution
13 until they're ready with a final report, although I would
14 have thought it was going to go the other way around.
15 DR. SEALE: I think something about how they plan
16 to integrate the PRA data into FAVOR -- that is, the PRA
17 process -- what they expect to have as a communication
18 vehicle in order to get the risk-based output.
19 DR. KRESS: Terry had one slide on that which
20 would cover it, I think.
21 SPEAKER: I really think these two pieces are the
22 ones that maybe --
23 DR. KRESS: Which is that?
24 SPEAKER: This fracture toughness uncertainty with
25 the RTNDT.

1 DR. KRESS: Yeah.

2 SPEAKER: Because it sort of puts those pieces

3 together.

4 SPEAKER: That's with an understanding that there

5 will be a more detailed, updated meeting on the

6 uncertainties?

7 SPEAKER: Certainly, the whole uncertainties, but

8 at least to give us the chance to go through the mechanics

9 of what we're doing.

10 DR. KRESS: I'm quite interested in this risk

11 acceptance criteria, 1 times 10 to the minus 6, but I can't

12 see that there's anything they can present to us at the next

13 meeting for that. I mean somebody is working on that and

14 thinking about it. We didn't hear anything today about it.

15 SPEAKER: I guess I'd agree with Dr. Kress. I

16 don't think we're ready to talk about it. My understanding

17 is there's some work going on there, but we won't be ready

18 for that.

19 I guess I'd agree with Bill on those two pieces,

20 with one caveat, I guess.

21 I know Nolan, Nathan, and I were talking

22 separately that to do the meeting that I think Professor

23 Apostolakis was asking for, we may not be quite ready for

24 that till maybe December timeframe, to really spend a day on

25 uncertainty and track through that, but I think we could do

1 a reprise of those -- you know, Terry's and Mark's
2 presentations, maybe trying to articulate some --
3 SPEAKER: I sort of realized you weren't going to
4 be ready to do the full uncertainty. It was just a question
5 of what we could do sort of leading up to that and, I think,
6 highlighting some places where it seemed especially
7 uncertain how to handle the uncertainty.
8 SPEAKER: Yeah, and I guess our reluctance, a bit,
9 is because this is work in progress.
10 SPEAKER: That is the problem here, that
11 everything is work in progress.
12 SPEAKER: Right.
13 DR. SEALE: Not that we don't like to be able to
14 put our finger in the soup while it's still fresh.
15 SPEAKER: No doubt.
16 SPEAKER: You know, I am a little concerned, you
17 know, with Tom's question that, you know, we're raising a
18 fairly fundamental issue about the acceptance criteria, you
19 know, can we work from the LERF goal in 1.174.
20 Do we need to formally somehow get that raised for
21 staff consideration, or do we consider it raised at this
22 point?
23 SPEAKER: It's certainly been raised. I mean I
24 believe the SECY paper recognized that this was an issue
25 that had to be dealt with.

1 We said that we were going to do a scoping study
2 that would --
3 SPEAKER: But the SECY paper really started with
4 the 1.174 criteria as the ultimate acceptance criteria.
5 SPEAKER: That may be. I was under the
6 impression, speaking with Mark, that there were still
7 questions about that. That was certainly a model of how
8 we're going to proceed. It was not necessarily the only
9 model that we were going to look at.
10 I thought that that was part of the discussion on
11 -- once we apply -- we tried to apply some of the latest
12 thoughts on how we're doing the risk-informed applications,
13 whether or not we'd come back to PTS and say, okay, now we
14 need to look at things a little bit differently now. I
15 thought that was open under the SECY.
16 Anyway, if the SECY didn't say that, we're not
17 saying that's necessarily the ultimate goal.
18 DR. SEALE: Certainly, the one size fits all is
19 not the right way to go because of this question of the
20 containment and issues like the spent fuel fire and so on.
21 DR. KRESS: It's the same issue.
22 DR. SEALE: It's the same issue, but it shows up
23 in very specific examples.
24 SPEAKER: Understood.
25 SPEAKER: That may be a judgement call, but that

1 may be worth some more discussion. We had a meeting for the
2 RES division directors, for Farouk and Tom King and Mike
3 Mayfield, where we talked about, you know, fleshing out this
4 issue of the containment integrity in LERF.
5 Obviously, the committee has weighed in on that
6 already once and, I think, weighed in on the side of we'd
7 like to see the staff take that on, is what I recall.
8 SPEAKER: I'm not sure Tom's issue came up in that
9 discussion.
10 DR. KRESS: I doubt if it came up then.
11 SPEAKER: What we don't want to do is raise this
12 six months from now. I just want to make sure that it gets
13 -- you know, the notion that, you know, the source term that
14 was used to generate that LERF may not be the right source
15 term for the PTS.
16 DR. SEALE: We may need to highlight it.
17 SPEAKER: Widely different situations.
18 SPEAKER: Does that address your concerns that we,
19 you know, somehow have to get that into a letter or a formal
20 presentation of the committee?
21 SPEAKER: I think the committee needs to think
22 about what message and what way they're going to transmit
23 it.
24 SPEAKER: And we haven't really raised this issue
25 with the full committee either.

1 DR. KRESS: We can't do it as a subcommittee. It
2 has to be the full committee. That may be a subject we
3 might want on the full committee agenda, even though they're
4 not ready to talk about it.
5 SPEAKER: You can just have a few minutes to raise
6 that concern.
7 DR. KRESS: Okay. Let's do it that way. I'll
8 raise the concern.
9 SPEAKER: The staff is not ready to address it,
10 but you know, it's a concern that we've raised.
11 DR. KRESS: That way we'll raise it to the level.
12 SPEAKER: So, you're not looking for a staff
13 presentation on that.
14 SPEAKER: No.
15 SPEAKER: Unless you're ready.
16 SPEAKER: At least philosophically, just to go
17 around sort of what the division directors were talking
18 about the other day, I believe Farouk or Dave Bessette have
19 talked about they've tasked Professor Diafanis with looking
20 at containment pressurization and any failures that may
21 result from containment pressurization due to PRS, and then
22 Mike Mayfield chimed in with the thing we talked about at
23 the beginning here, that I'm not overly worried about
24 containment pressurization, I'm worried about this
25 displacement of the vessel.

1 SPEAKER: But see, that all relates to containment
2 failure, and Tom's concern is, once the containment fails,
3 you know, what's an acceptable probability that you have a
4 different consequence.
5 SPEAKER: And again, I think a number of folks
6 have raised different issues, and different people on the
7 staff have different opinions as to what's going to happen
8 or how this will be addressed, and we're clearly not ready
9 to talk about that in any consistent way.
10 SPEAKER: If the committee has some
11 recommendations on how to proceed, I think it would be
12 worthwhile hearing.
13 DR. KRESS: Well, I can maybe suggest something,
14 but what I'll plan on doing is articulating the concern to
15 the full committee, and that will raise it.
16 SPEAKER: So, we'll have the presentations, then,
17 on the -- the two presentations.
18 SPEAKER: What do we have, two hours, Noel?
19 SPEAKER: Two hours. We don't need to use the
20 whole amount.
21 SPEAKER: Okay. We'll try and come in with
22 shortened versions of these.
23 DR. SEALE: Dana will figure out what to do with
24 anything you give the committee.
25 SPEAKER: Somehow, I suspect, with Professor

1 Apostalokis, I wouldn't count on shortening it too much.
2 DR. KRESS: I'd shorten it, but I wouldn't count
3 on shortening it two hours. I'd shorten the presentation.
4 SPEAKER: I'd shorten the presentation, but I
5 wouldn't take too much of the time back.
6 DR. KRESS: That's right.
7 SPEAKER: Okay. Sounds good.
8 SPEAKER: Thank you.
9 DR. KRESS: As usual, a very professional
10 presentation. We appreciate it.
11 SPEAKER: Could we get a copy of the most recent
12 version of the generalized flaw distribution paper, since
13 the one we have seems to be a somewhat out of date version?
14 SPEAKER: Yeah, I guess I should have summarized,
15 because I knew George had asked for the P.D. Ruff NUREGs,
16 basically, volumes one and two are available publicly now,
17 and also the reports on Prodigal. So, Debbie took an action
18 to get those, and I guess we can get them.
19 SPEAKER: I have those, but I don't know whether I
20 get those as ACRS or UC-5. You never know how they're
21 coming in.
22 [Inaudible conversation.]
23 END OF TAPE 4, SIDE B
24
25

CERTIFICATE

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

Name of Proceeding: ACRS MEETING: MATERIALS & METALLURGY SUBCOMMITTEE

Case Number:

Place of Proceeding: Rockville, Maryland

were held as herein appears, and that this is the original transcript thereof for the file of the United States Nuclear Regulatory Commission transcribed by me from recorded tapes provided by the Nuclear Regulatory Commission, and that the transcript is a true and accurate record of the foregoing proceedings to the best of my belief and ability.

Tamara Shipp

Tamara Shipp

Transcriber

Ann Riley & Associates, Ltd.

INTRODUCTORY STATEMENT BY THE CHAIRMAN OF THE
MATERIALS AND METALLURGY SUBCOMMITTEE
11545 ROCKVILLE PIKE, ROOM T-2B3
ROCKVILLE, MARYLAND
SEPTEMBER 21, 2000

The meeting will now come to order. This is a meeting of the ACRS Subcommittee on Materials and Metallurgy. I am Dr. William Shack, Chairman of the Subcommittee.

ACRS Members in attendance are: Drs. George Apostolakis, Thomas Kress, and Robert Seale.

The purpose of this meeting is for the Subcommittee to hear staff presentations on the status of the Pressurized Thermal Shock (PTS) Technical Basis Reevaluation Project activities associated with PTS thermal hydraulic experiments, flaw distribution, fracture toughness distributions and model uncertainties, embrittlement correlations, and the FAVOR probabilistic fracture mechanics code. The Subcommittee will gather information, analyze relevant issues and facts, and formulate proposed positions and actions, as appropriate, for deliberation by the full Committee. Mr. 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 September 5, 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.

The staff briefed this Subcommittee on March 16 and April 27, 2000, concerning the status of the PTS Technical Basis Reevaluation Project. At the May 2000 ACRS meeting, the staff presented a draft Commission paper that described potential options and approaches for revising the PTS acceptance criteria. Today we will hear presentations about the results from some of the ongoing activities associated with the Reevaluation Project.

We will now proceed with the meeting and I call upon Mr. Edwin Hackett, Assistant Chief of the Materials Engineering Branch, to begin.

PRESSURIZED THERMAL SHOCK RE-EVALUATION PROJECT

Ed Hackett, Assistant Chief,
Materials Engineering Branch
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission

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

Rockville, MD
September 21, 2000

E-Mail: EMH1@NRC.GOV

USNRC/INDUSTRY PTS RE-EVALUATION PROJECT

Background/Impetus

- "Encouraging" materials integrity developments drive need for re-evaluation of PTS rule
  - Improved flaw distributions
  - Revised embrittlement correlations
  - Improved fracture mechanics methods
  - Dickson/Malik ASME PVP Paper (1999) shows potential for significant burden reduction

- Additional developments in thermal hydraulics and PRA
  - Improvements in T-H codes
  - Testing at APEX facility (flow stagnation)
  - Context for PRA (RG 1.174)
  - Explicit consideration of uncertainties

USNRC/INDUSTRY PTS RE-EVALUATION PROJECT

- Initiated in April, 1999 with original planned completion in December, 2001

- Fully participatory with input from stakeholders:
  - NRC (RES, NRR, Contractors)
  - Industry (MRP, EPRI, Vendors)
  - Public
  - ACRS reviews (2/99, 7/99, 3/00, 5/00 ...)

- Four full scale plants being analyzed:
  - Oconee-1
  - Calvert Cliffs-1
  - Palisades
  - Beaver Valley-1 (replacing H.B. Robinson)

USNRC/INDUSTRY PTS RE-EVALUATION PROJECT

Current Status

- Work progressing in major technical areas, schedule issues being addressed

- Finalization of materials inputs for revised PFM code (FAVOR) and initiation of FAVOR runs for four plants - Oct/Nov, 2000

- T-H Code validation through testing in APEX facility (4th Q, 2000)
  - Conditions for flow stagnation/mixing

- Progress in PRA aspects includes:
  - Process for explicit consideration of uncertainty in key inputs
  - Completion of Commission Paper on acceptance criteria (July, 2000)

- ACRS Meetings in March/May, 2000
  - Risk approach similar to RG 1.174
  - Likely re-set of risk criteria to 1E-6
  - Containment integrity could be considered to set criteria lower

USNRC/INDUSTRY PTS RE-EVALUATION PROJECT

Summary/Conclusions

- First major application of new risk-informed methodology to revise an adequate protection rule
- Good progress thus far. Schedule impacts currently being assessed
- Consideration of LERF and containment integrity is a major departure from current PTS framework
- Although initial indications pointed toward relaxation of current criteria, the final outcome is not yet clear
- Near-term scoping study for Oconee should complete in December 2000 - Initial indication of probable outcome.

United States
Nuclear Regulatory Commission

PRA for PTS Rule Revision

H. Woods, N. Siu, E. Thornsbury

Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission

Presentation to the ACRS Subcommittee on Reactor Safeguards, Materials and Metallurgy
September 21, 2000

PRA Objective

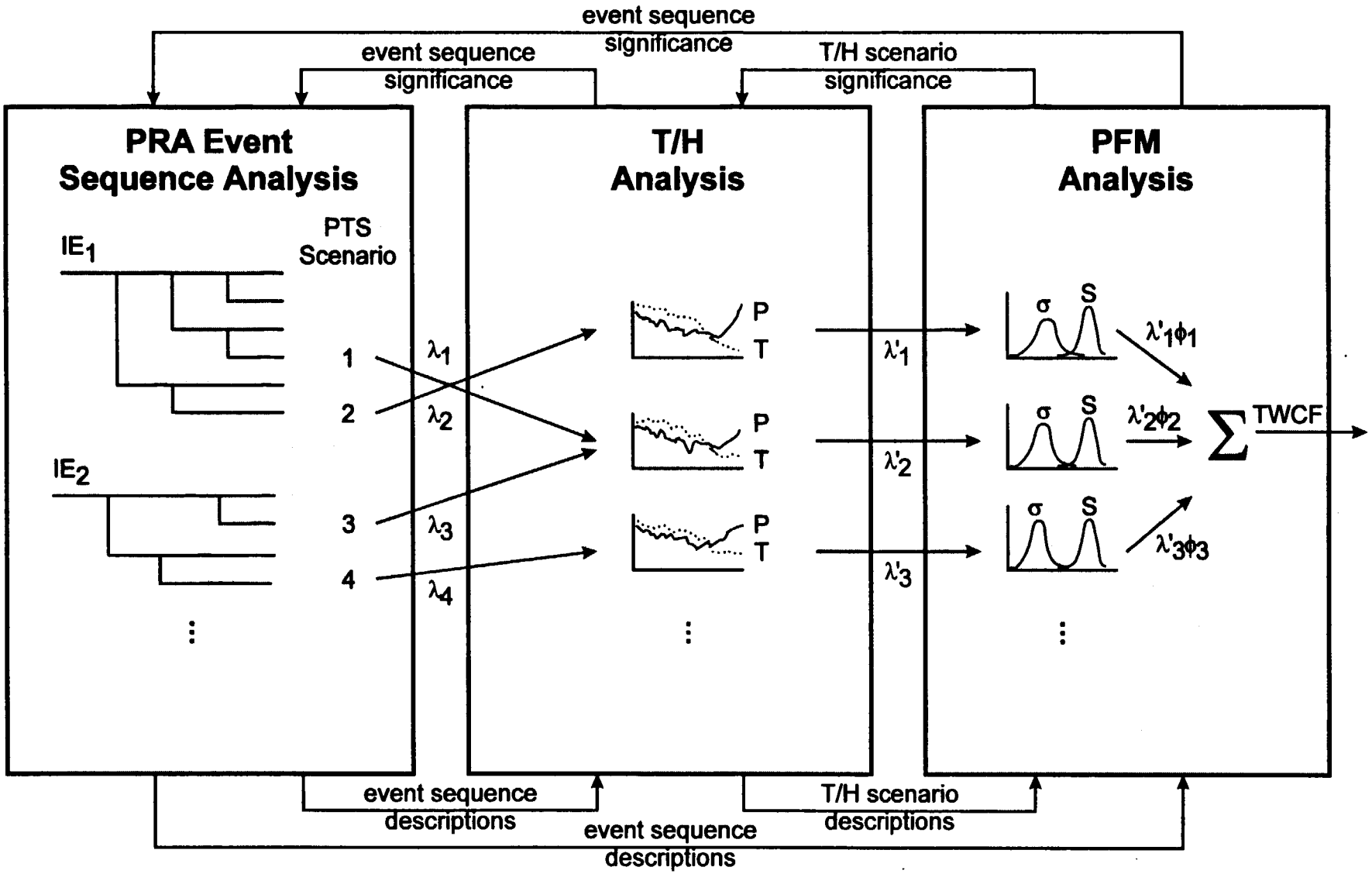
Support development of technical basis for revised rule

- **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**

- **Update IPTS PTS/PRA studies**
  - **Reflect changes to IPTS plants**
  - **Reflect changes to PRA state of the art, knowledge base**
  - **Address other plants**

Overall Analysis Framework

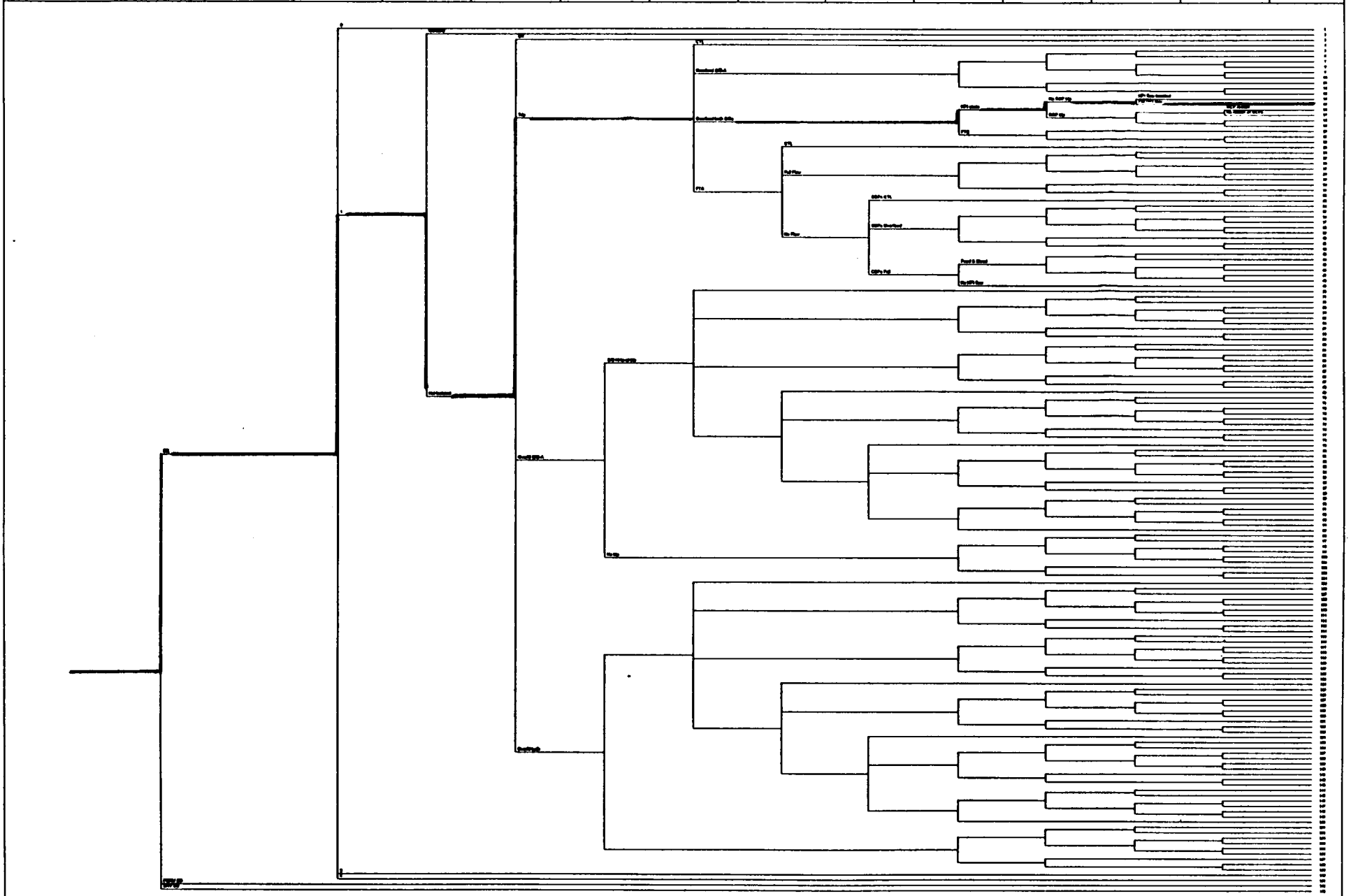


PTS/PRA Analysis - Status

- Oconee and Beaver Valley PTS Scenario Models
  - Event trees developed starting from IPTS studies
  - Generic initiating event frequencies and top event "split fractions" (developed from industry data) used to focus model development, support interactions with T/H and PFM
  - Some fault trees developed from Oconee PRA
  - Potential human failure events developed using ATHEANA
  - Quantification ongoing

- Palisades and Calvert Cliffs - Information Collection & Assessment Underway, No Substantial Review to Date

Rx Trip with TurbineTrip	PORV or SRV Stuck Open	Stuck Open PORV Isolated	TBV or MS-SRV Stuck Open	Stuck Open TBV Isolated	MFW Response to IE	MFW Fails to trip on S/G HI-L	EFW Response to MFW trip	Fail to Recover from EFW-FTS	Condensate Booster Pumps Fail	HPI/FAB Response	RCP Trip (i.e., loss of RCS subcooling)	Fail to Throttle HPI Flow	Fail to Restart RCPs	
RTTT	PORV_SRV_SO	PORV_ISO_F	TBV_SO	TBV_ISO_F	MFW_F	MFW_TRIP_F	EFW_F	EFW_REC_F	CBP_F	HPI_STARTS_F	RCP_TRIP	HPI_THROTTLED_F	RCP_RESTART_F	0



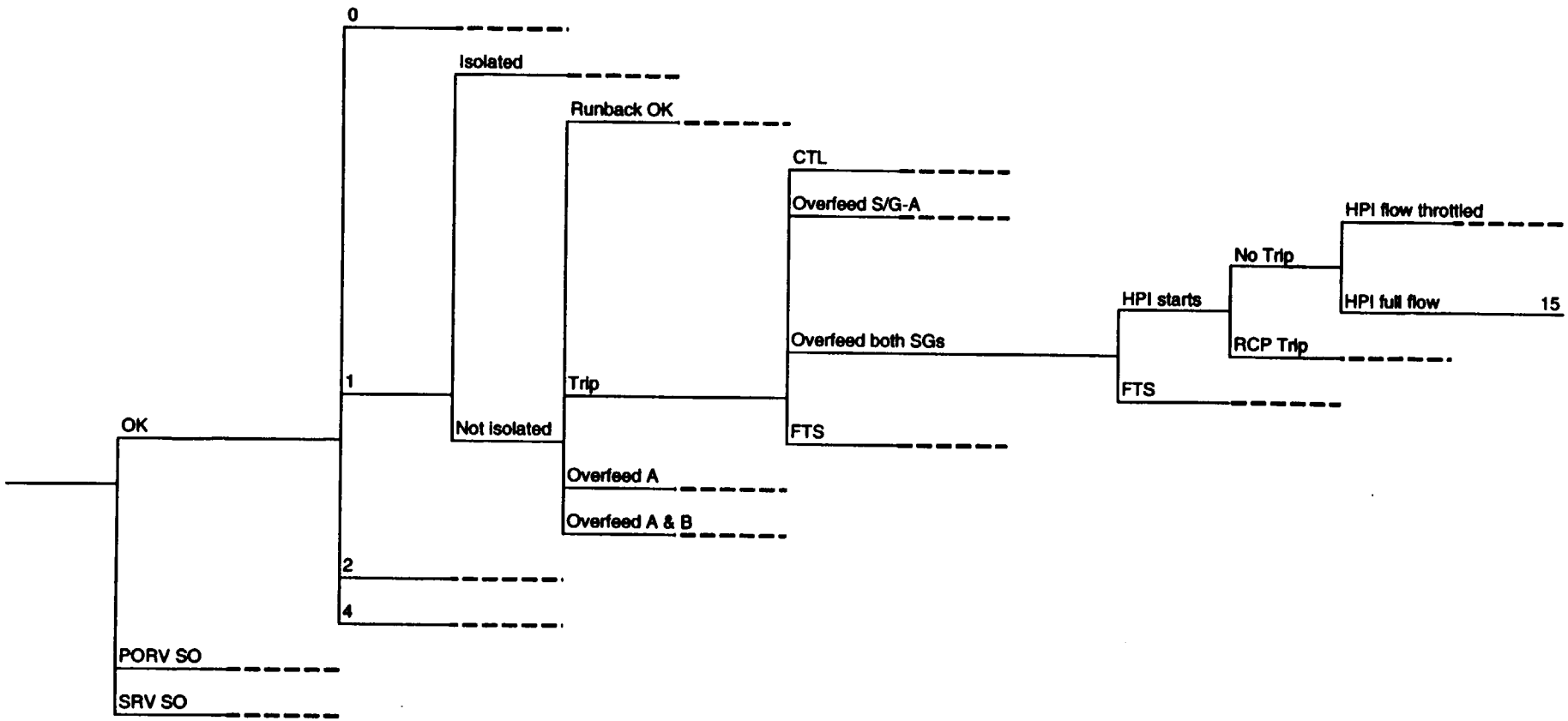
ONS-PTS-RT2 - Oconee PTS Rx-Trip with 1 TBV or MS-SRV Stuck Open

2000/09/12

A Representative Scenario

- **PTS Rx-Trip with 1 TBV or MS-SRV Stuck Open: Sequence #15**

Rx Trip with Turbine Trip	PORV or SRV Stuck Open	Stuck Open PORV Isolated	TBV or MS-SRV Stuck Open	Stuck Open TBV Isolated	MFW Response to IE (Runback)	MFW Fails to trip on S/G Hi-L	EFW Response to MFW trip	Fail to Recover from EFW-FTS	Condensate Booster Pumps Fail	HPI/F&B Response	RCP Trip (i.e., loss of RCS subcooling)	Fail to Throttle HPI Flow	Fail to Restart RCPs
RTTT	PORV_SRV_SO	PORV_ISO_F	TBV_SO	TBV_ISO_F	MFW_F	MFW_TRIP_F	EFW_F	EFW_REC_F	CBP_F	HPI_STARTS_F	RCP_TRIP	HPI_THROTTLED_F	RCP_RESTART_F



A Representative Scenario

- Initiating Event: Reactor Trip [Initiating Event Study]
- PORV or SRV Stuck Open: OK [Industry + Oconee experience]
  - Either not demanded or demanded and reclosed properly
- Stuck Open PORV Isolated: Pass
- TBV or MS-SRV Stuck Open: 1 [Oconee data]
  - TBV normally opens on Rx trip - fails to reclose
- Stuck Open TBV Isolated: Not Isolated [ATHEANA]
  - Identification and diagnosis of stuck open TBV
- MFW Response to IE (Runback): Tripped [Industry data]
  - Either as part of IE or other failure
- MFW Fails to trip on S/G Hi-L: Pass
- EFW Response to MFW trip: Overfeed both SGs
  - I&C Failure [Screening value]
  - Failure of operator control [ATHEANA]
- Fail to Recover from EFW-PTS: Pass

- **Condensate Booster Pumps Fail: Pass**
- **HPI/F&B Response: HPI Starts [HPI Reliability Study]**
  - **Cooldown causes primary pressure drop below 1600 psi**
- **RCP Trip: No Trip [Screening value]**
  - **Subcooling is not lost - RCPs do not need to be tripped**
- **Fail to Throttle HPI Flow: HPI full flow [ATHEANA]**
  - **Concurrent secondary side anomaly**

- **NOTES**
  - **Dependencies between HFEs still under investigation**
  - **Timing of HFEs is important**

Information Used in Analysis (BV Example)

- The BV IPE
- BV P&IDs, FSAR Sections, and Plant Operations Manual Sections for Equipment Related to PTS Events (e.g., CVCS, SI, MStm, FW)
- EOPs (and Their "Bases" Documentation) Related to PTS Events
- Selected AOPs (human actions for some PTS initiators)
- BV TH and PFM Calculations/Summaries Relevant to PTS
- Training Provided to the Operators Related to PTS Events
- BV's PRA Model and Supporting Documentation
- Specific Severe Accident Management Guides (SAMGs)
- Specific Technical Specifications (e.g., MSSVs, MSIVs)
- Specific WCAP Reports (e.g., HBR PTS, Generic PTS, BV PTS)
- BV Operating Experience (e.g., Prim. PORVs and SRVs, Sec. SRVs and SDVs, MSIVs)

What's New

- Use of Increased Operating Experience ⇒ More Realistic Event Frequencies and Failure Probabilities

- Use of Current Plant Design and Operating Procedures (some specifically to avoid overcooling events)

- Provision of Better Coupling Between Event Sequences and TH Analyses

- Use of Better PRA and HRA tools and methods allows:
  - more explicit modeling of sequences (less collapsing)
  - more integrated modeling of the sequence of events (facilitates performing sensitivity calculations)

What's New (cont'd)

- **Identification of Contextual Factors Affecting Operator Performance of Specific Actions**

- **Consideration of New Errors of Commission (e.g., "operator trips RCPs when not required to do so," and "operator isolates wrong SG")**

- **Allowance of More Credit for Recovery Actions (e.g., "operator throttles or terminates SI when SI operation is not desirable")**

Concluding Remarks

- PRA/TH/PFM interactions are leading to analysis improvements
  - Screening of event sequences
  - Better characterization of event sequences [especially important with Oconee - are reducing size of "Other" bin]
  - PRA/TH link [specification of TH runs]
  - Improved treatment of uncertainties

- Issues
  - External events
  - Inconsistencies and generalizations
  - Acceptance criteria

Status of the FAVOR Code Development

Terry Dickson, Richard Bass and Paul Williams
Heavy-Section Steel Technology Program
Oak Ridge National Laboratory

Advisory Committee on Reactor Safeguards
Meeting of the Materials and Metallurgy Subcommittee
Pressurized Thermal Shock Screening Criterion Re-evaluation

September 21, 2000
Nuclear Regulatory Commission
Rockville, Maryland

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This Presentation Describes the Evolution of an Advanced Computational Tool for RPV Integrity Evaluations : FAVOR

1/ How FAVOR is Applied in PTS Re-evaluation

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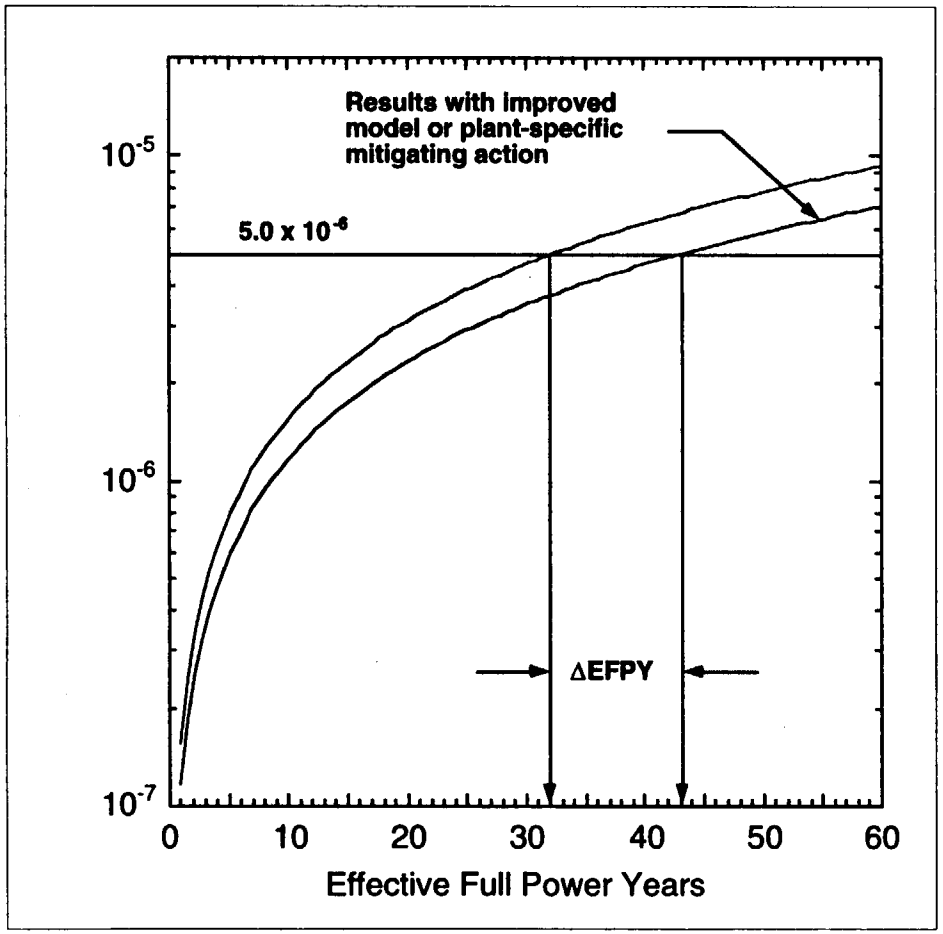
4/ Overall PRA Methodology

5/ PFM Details

Application of FAVOR to PTS Re-evaluation Addresses the Following Two Questions



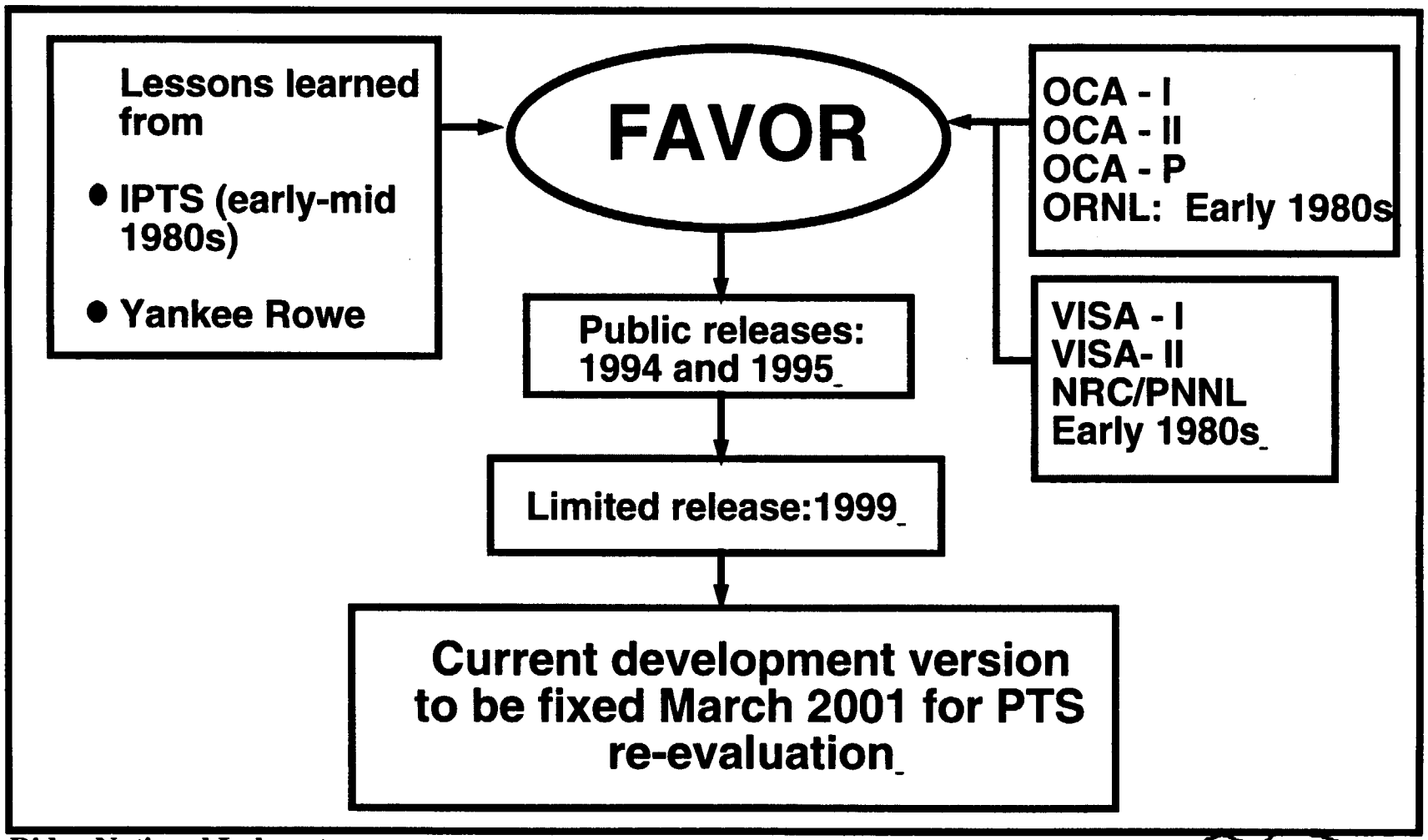
- At what time in operating life does frequency of RPV failure exceed acceptable value (currently 5 x 10e-06)?
- How does integration and application of advanced technology affect the calculated result?

Near-Term Schedule for Development of the FAVOR Code has been Defined

- Current schedule specifies FAVOR to be ready for PTS re-evaluation analyses on March 1, 2001

- In the interim period:
  - models are being finalized
  - finalized models are being implemented
  - scoping studies are being performed

Development of the FAVOR Code was Initiated in Early 1990s by Combining Best Attributes of OCA/VISA with Evolving Technology



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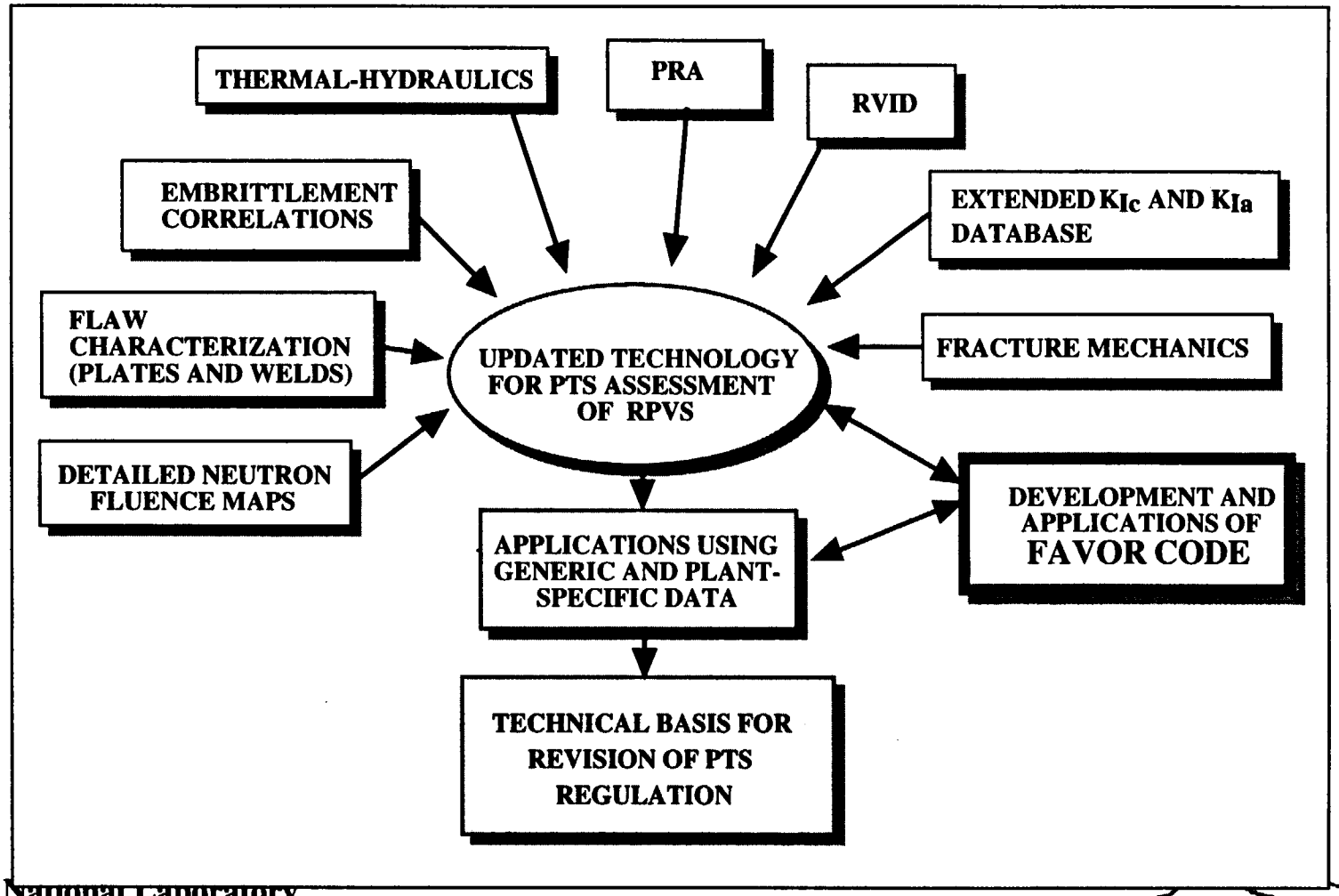
Elements of updated technology are currently being integrated into the FAVOR computer code to re-examine the current PTS regulations*

(Fracture Analysis of Vessels: Oak Ridge)



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
- New PFM methodology

A Significant Improvement Since the Derivation of Current PTS Regulations is Flaw Characterization*

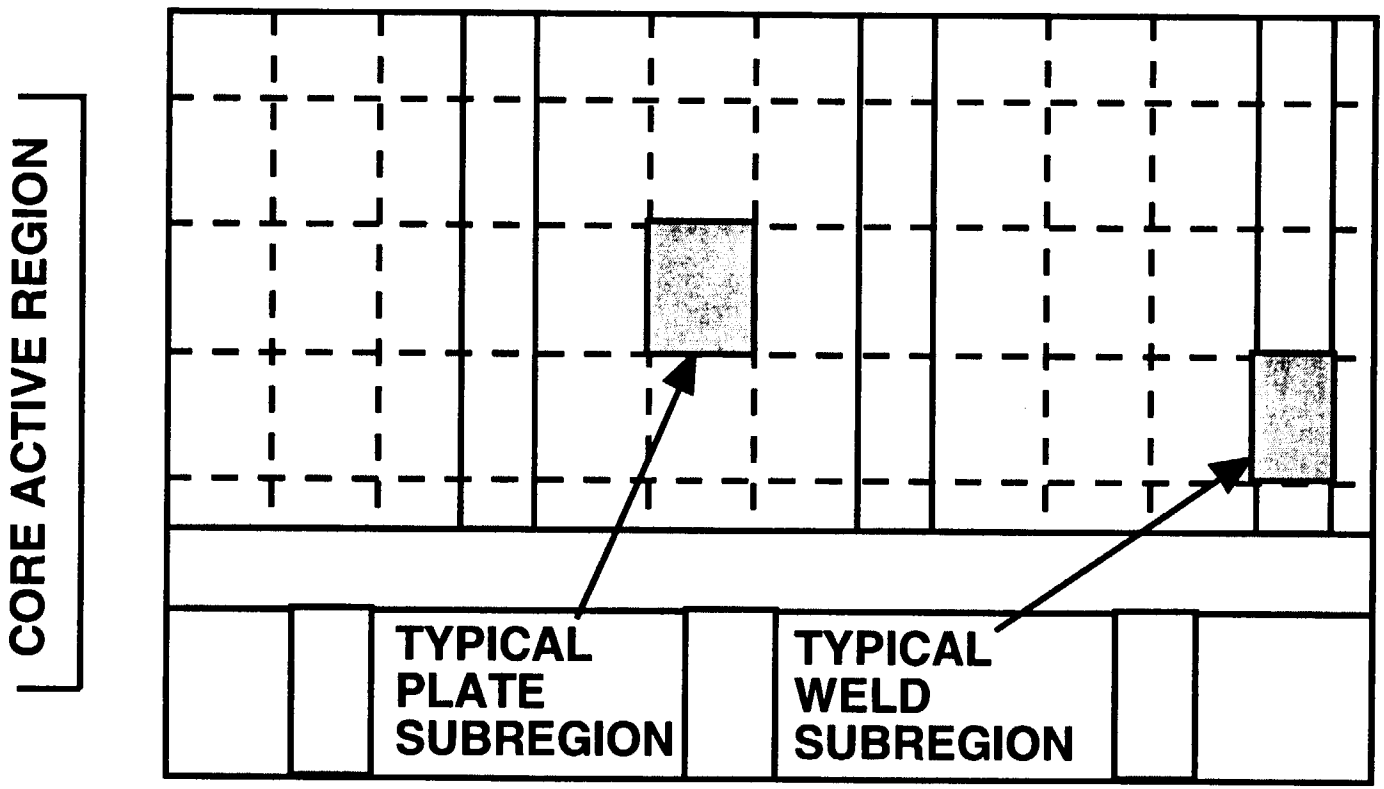
**** analyses assumed all flaws were inner-surface breaking flaws***

- **Recent NDE and DE of RPV material at PNNL has established an improved technical basis for flaw-related data used as input for PFM analyses**

- **A significantly higher number of flaws were found than was postulated in PFM analyses from which current PTS regulations were derived; however, all flaws detected thus far are embedded**

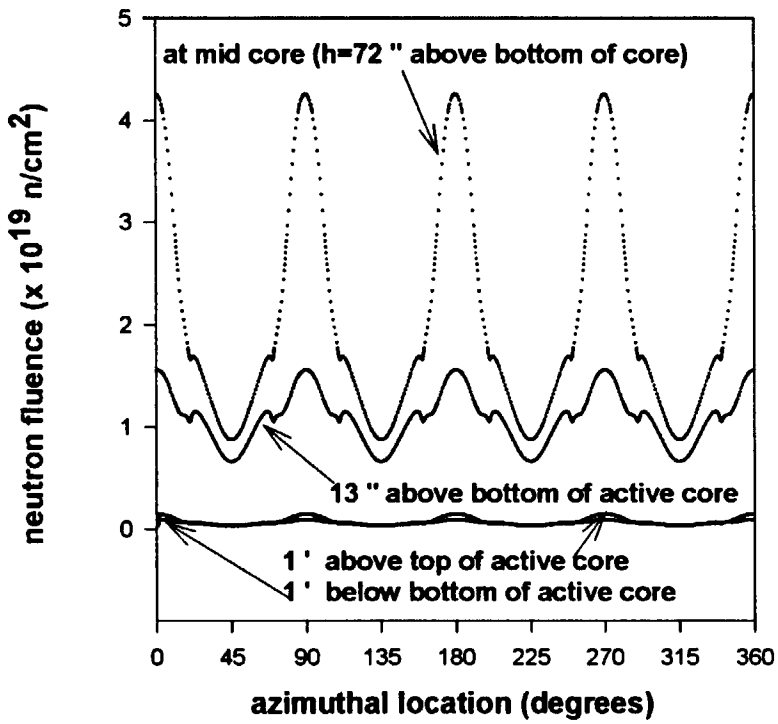
- **Application of PVRUF flaw densities to commercial PWR results in over 3500 flaws in 1st 3/8 thickness of RPV wall**

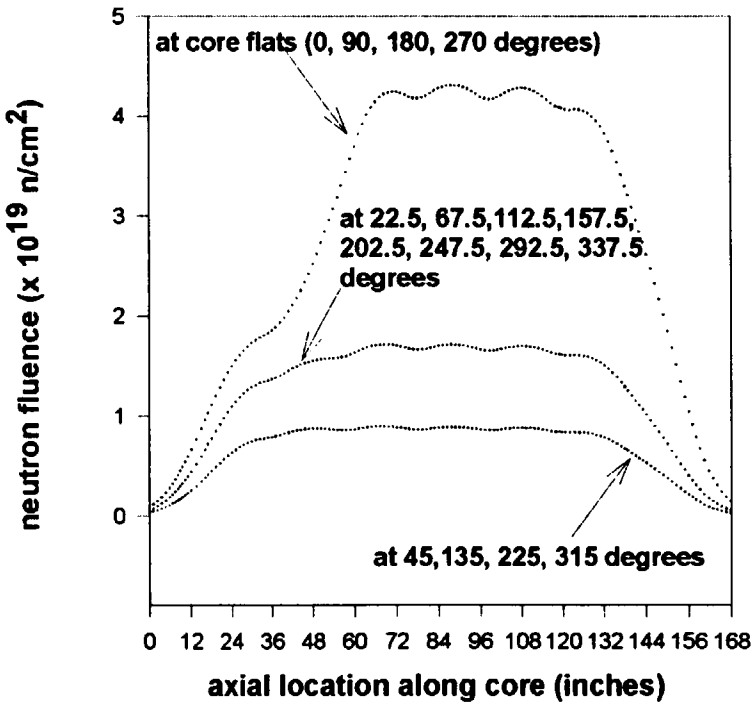
FAVOR utilizes a methodology that allows the RPV beltline to be discretized into sub-regions, each with its own distinguishing embrittlement-related parameters. This accommodates chemistries from the RVID and detailed neutron fluence maps



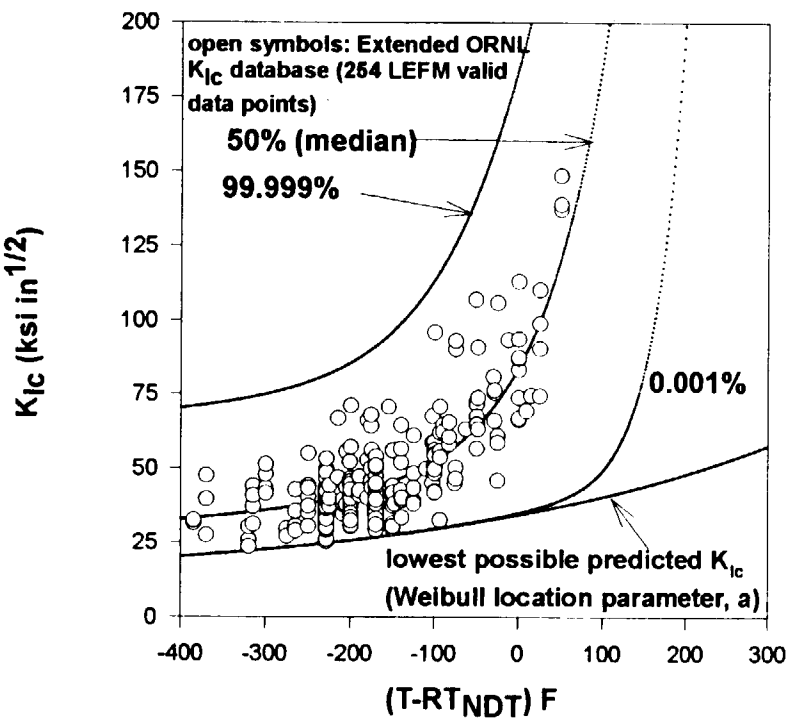
TYPICAL VESSEL BELTLINE LAYOUT

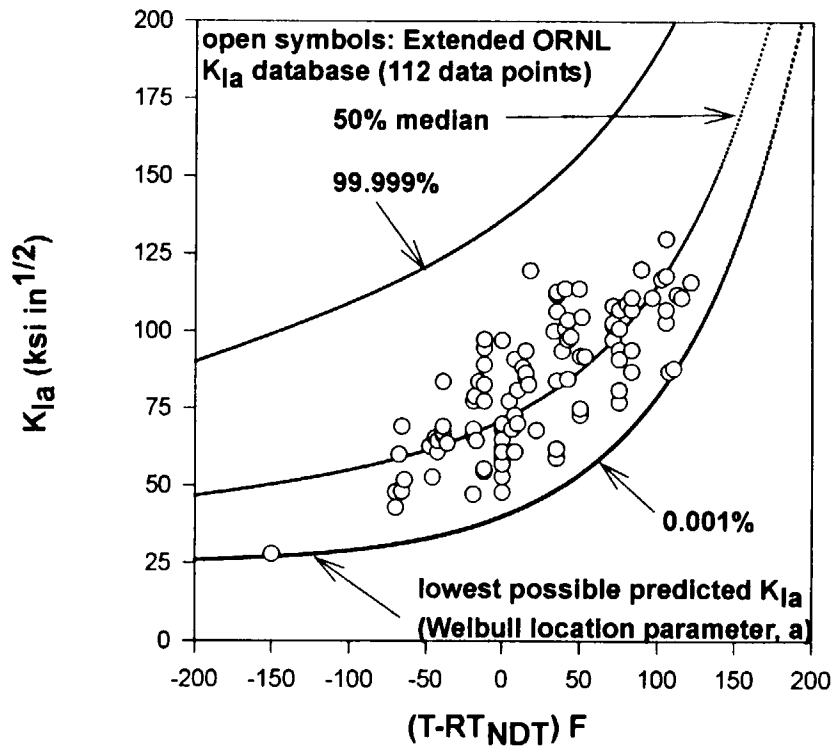
Brookhaven National Laboratory is generating very detailed neutron fluence maps for selected PWRs corresponding to 32 EFPY and 40 EFPY



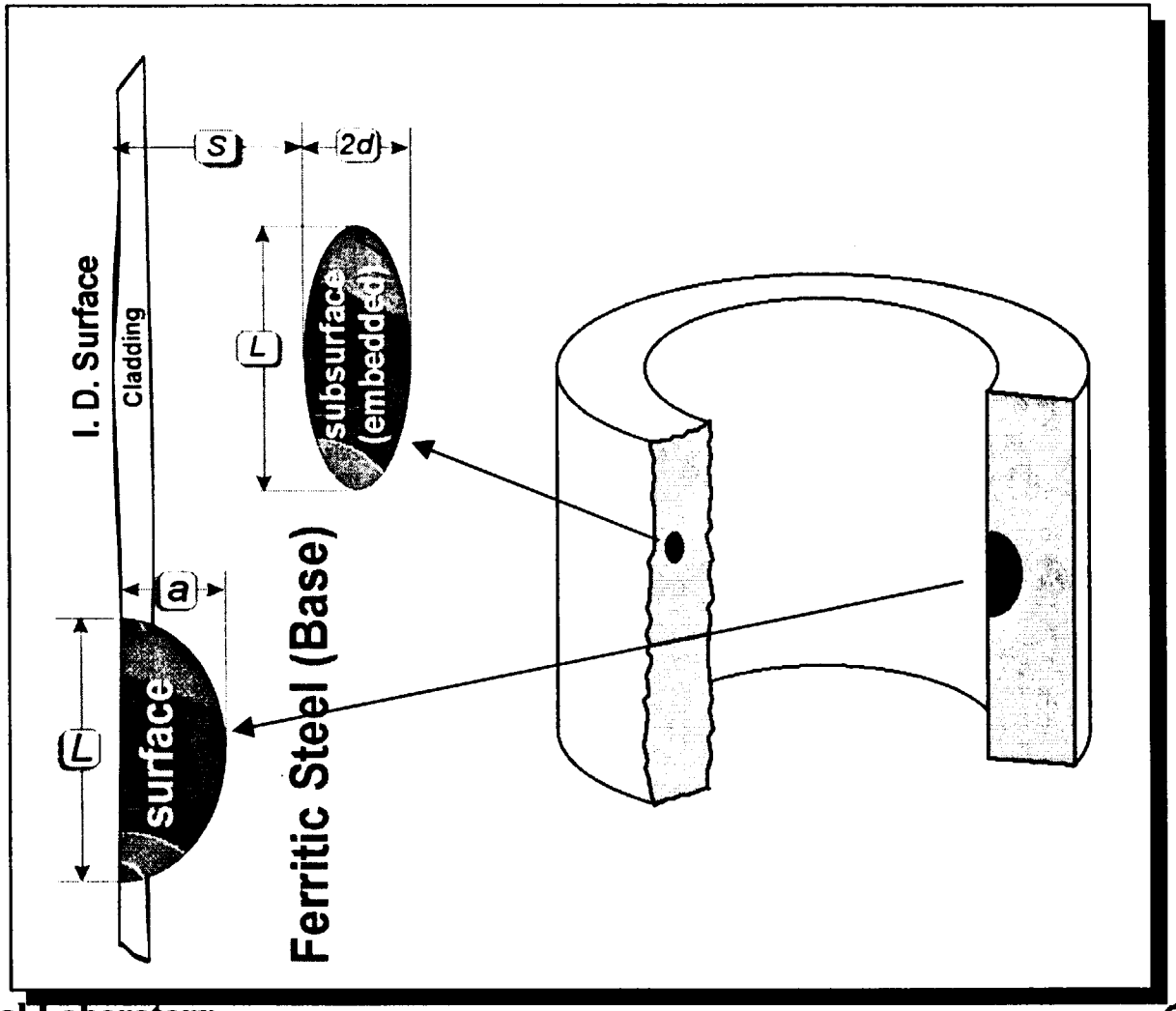


New Statistical Models for Enhanced Plane-Strain Static Initiation (K_{Ic}) and Arrest (K_{Ia}) Fracture Toughness Data Bases were Implemented into FAVOR





The FAVOR PFM Model Now Includes Inner Surface-Breaking and/or Embedded Flaws



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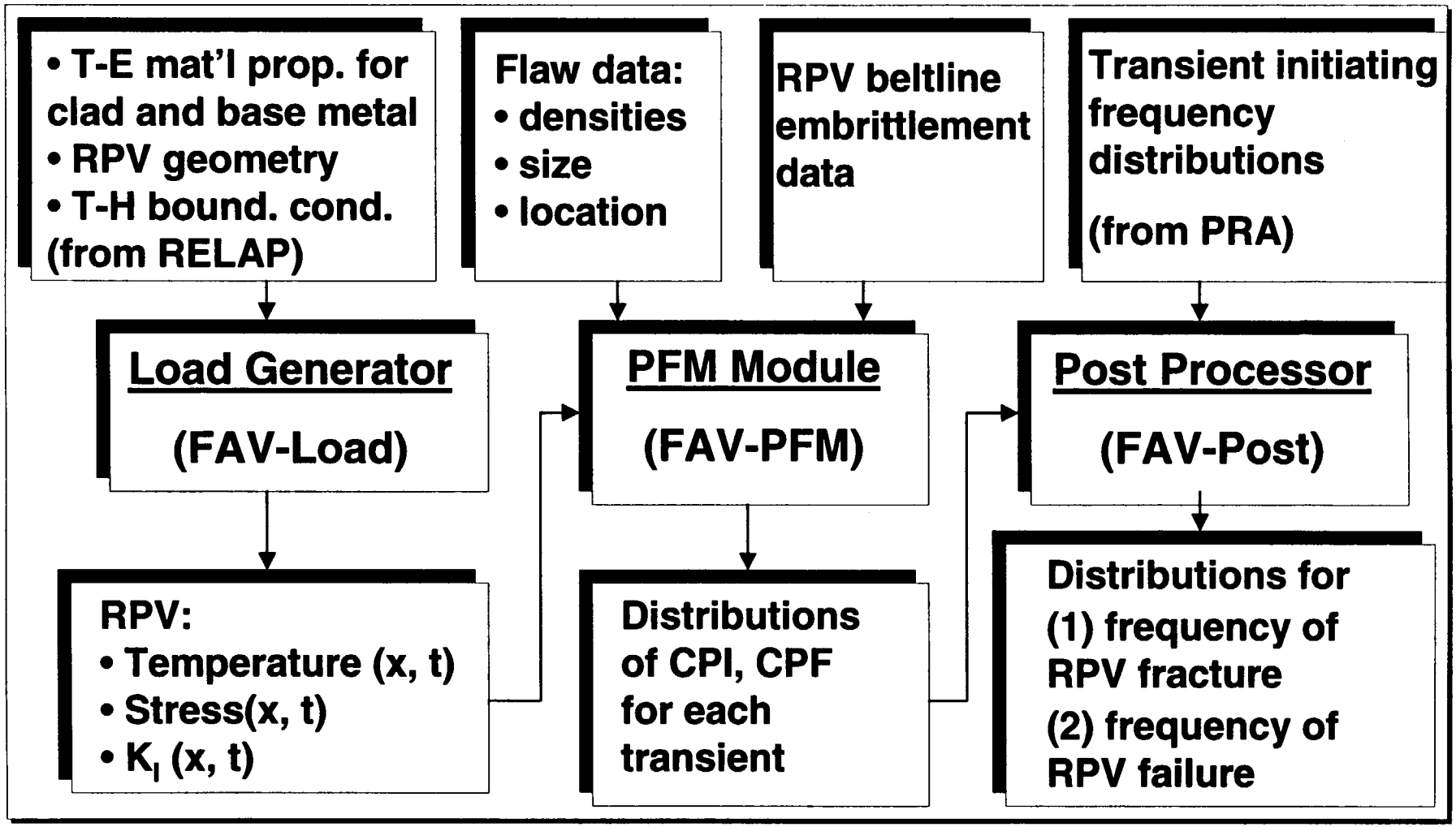
The Current FAVOR Code Consists of Three Separate Modules



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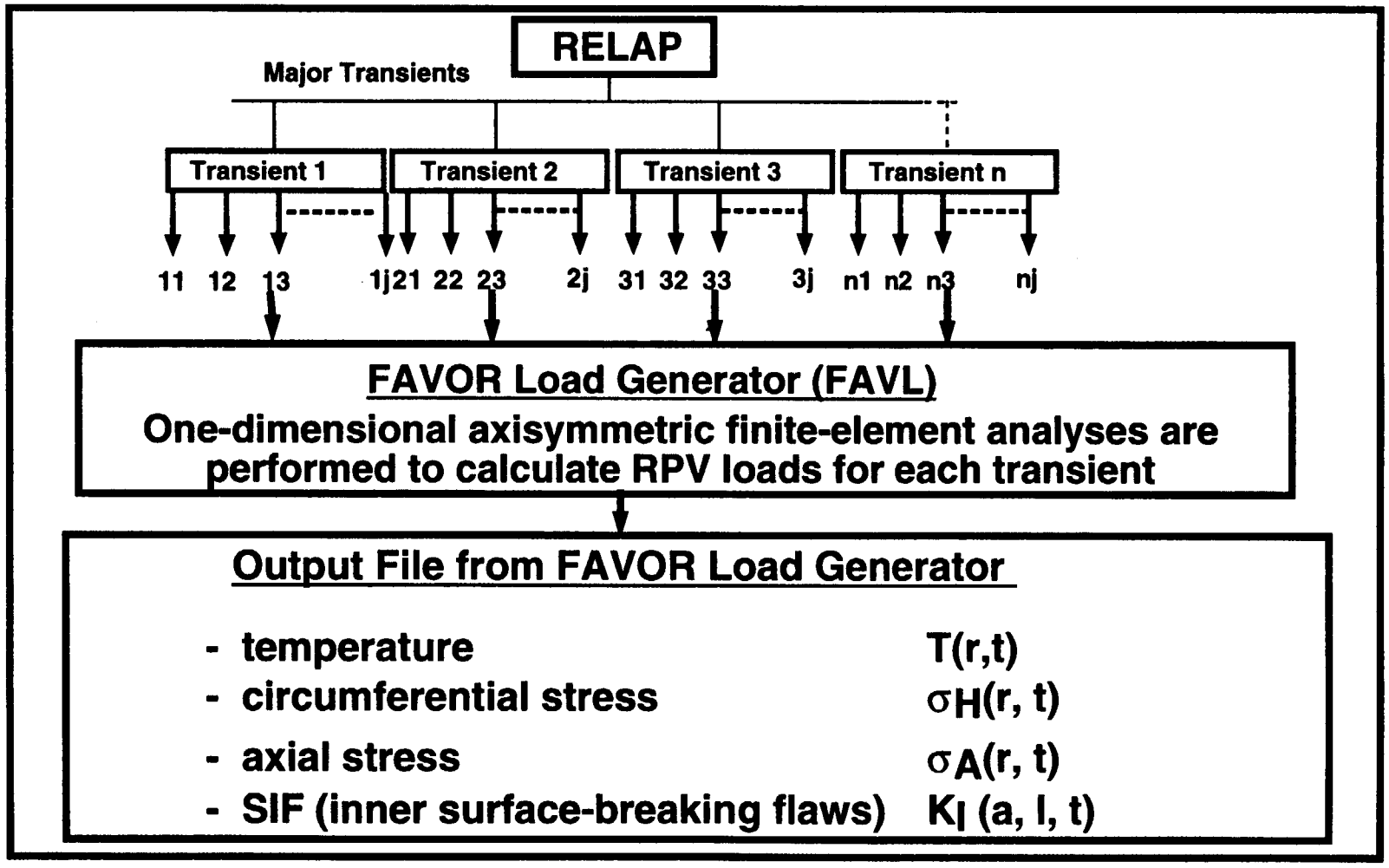
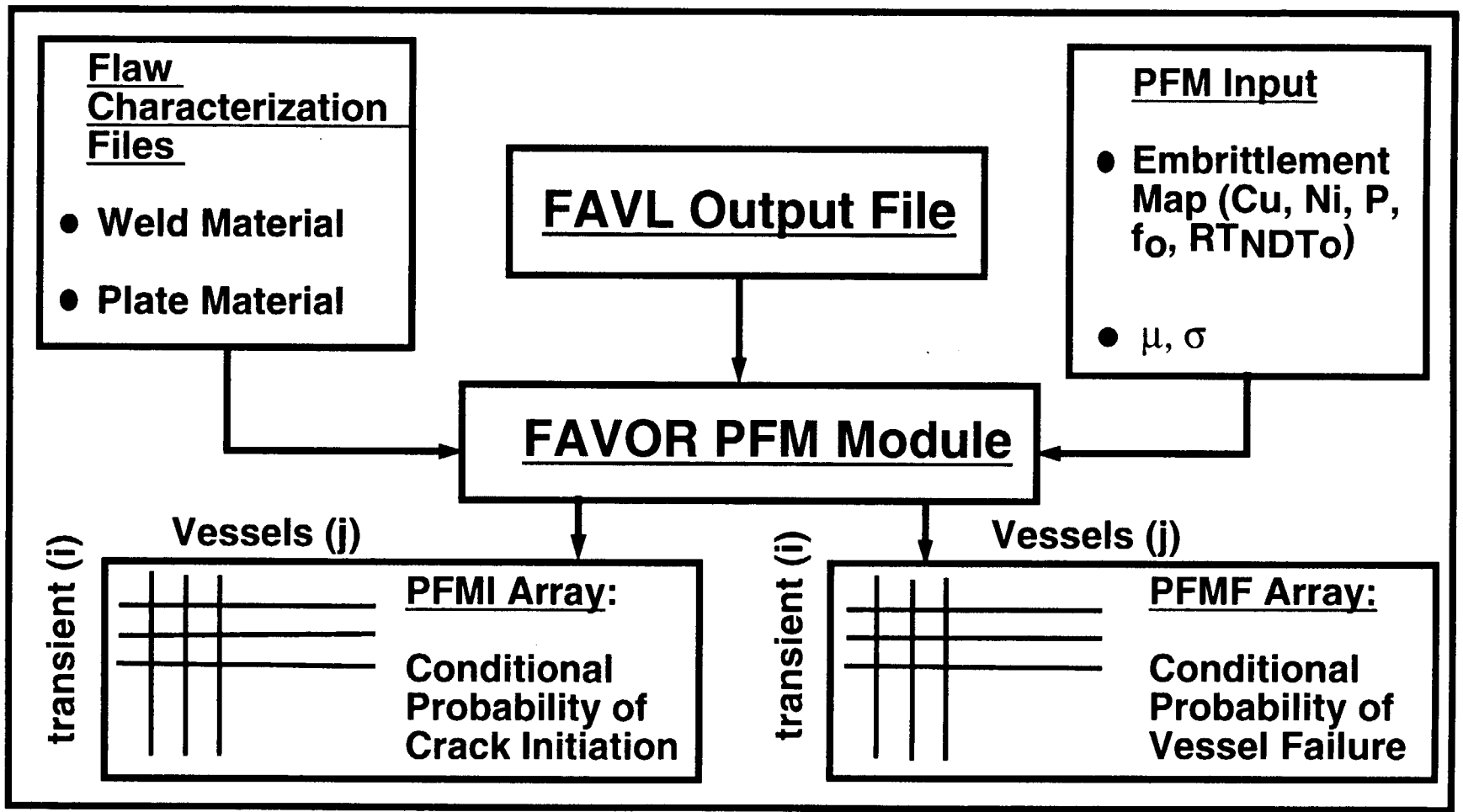
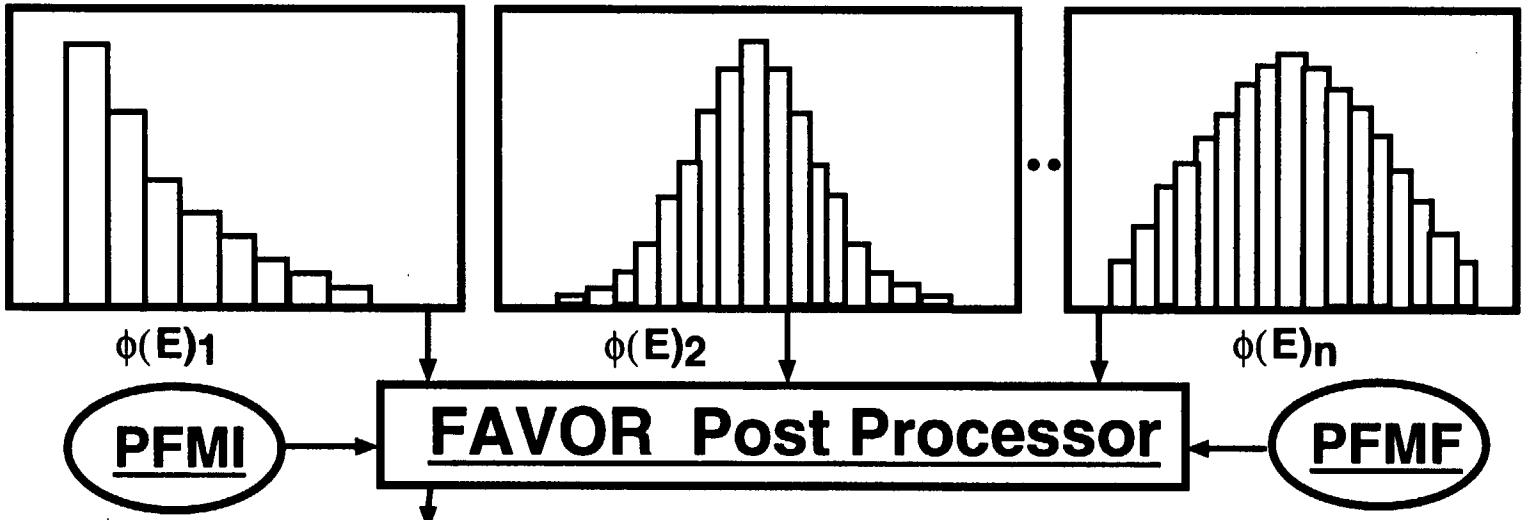
FAVOR Analyses Incorporate Uncertainty Associated with Thermal Hydraulics by Including Variants for Each of the Transients

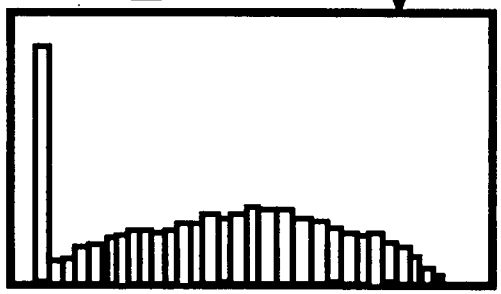


The FAVOR PFM Analysis Module Generates Arrays Containing Conditional Probabilities of Initiation (PFMI) and Failure (PFMF) for Vessel(j) Subjected to Transient(i)



The FAVOR Postprocessor Module Integrates the Uncertainties of the Transient Initiating Frequencies with the PFMI and PFMF Arrays to Generate Distributions for the Frequencies of RPV Fracture and RPV Failure





$\phi(F)$ (Frequencies of RPV fracture/failure)

For each vessel:

1. Sample initiating frequencies, $\phi(E)_1, \ldots \phi(E)_n$
2. Combine $\phi(E)$ with PFM results, $\phi(F)_i = \Sigma\phi(E)_T \cdot P_{FM}(T,V)$
3. Generate histogram for $\phi(F)$ from resulting array of $\phi(F)_i$

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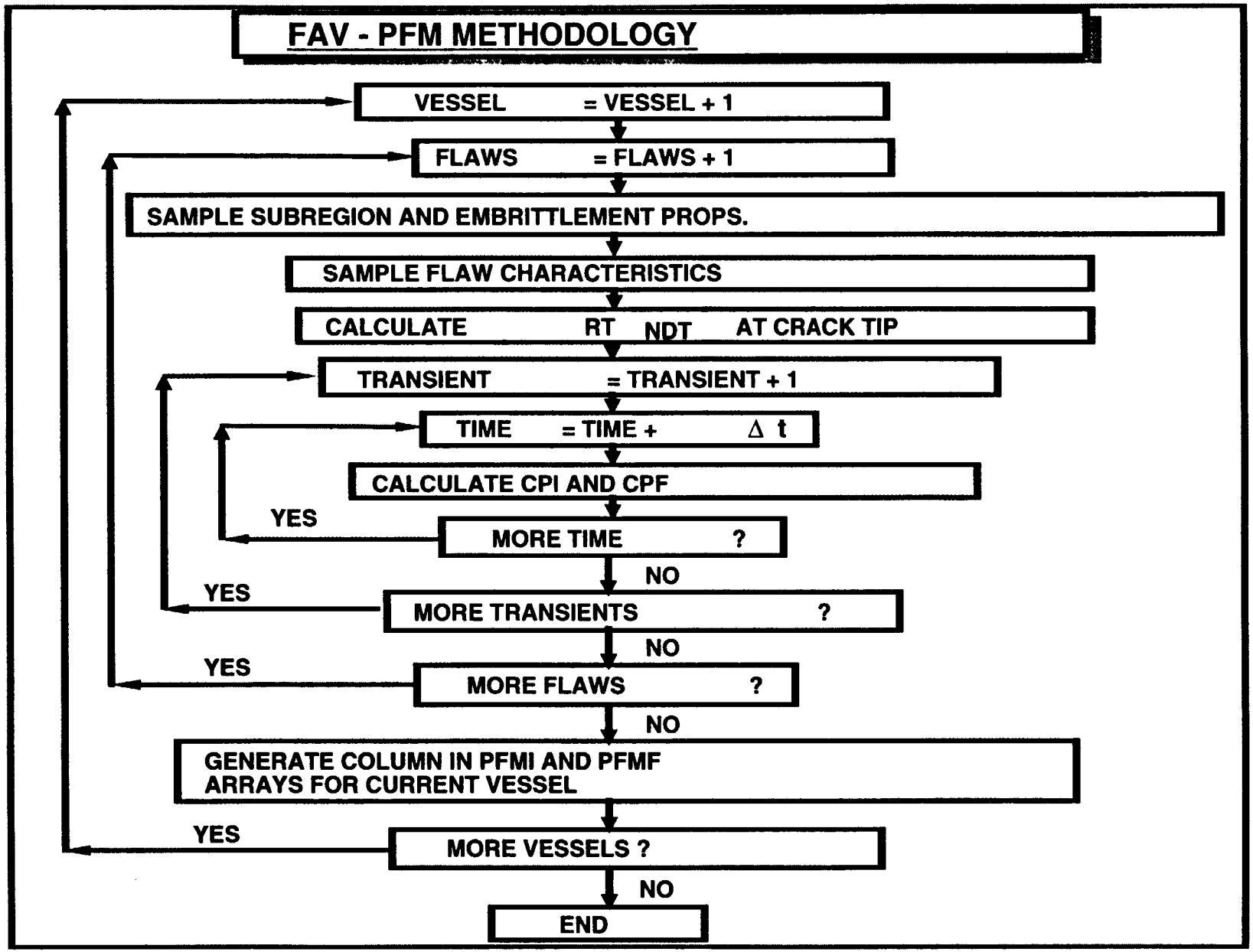
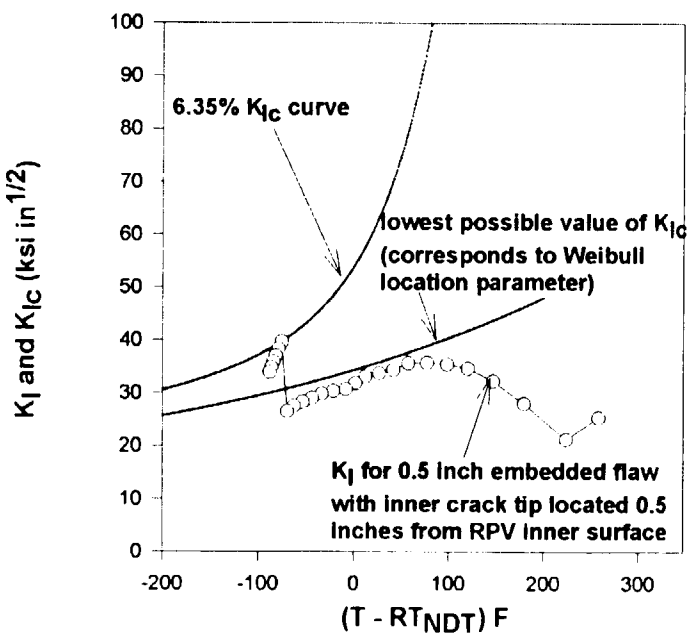
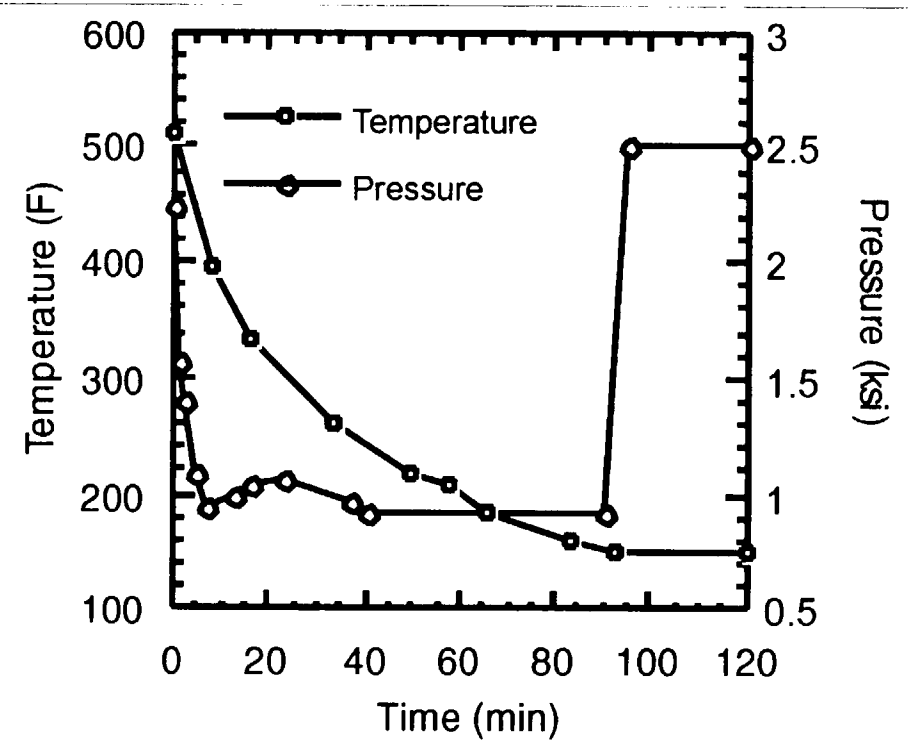

FAV - PFM METHODOLOGY
VESSEL = VESSEL + 1
FLAWS = FLAWS + 1
SAMPLE SUBREGION AND EMBRITTLEMENT PROPS.
SAMPLE FLAW CHARACTERISTICS
CALCULATE RT NDT AT CRACK TIP
TRANSIENT = TRANSIENT + 1
TIME = TIME + Δ t
CALCULATE CPI AND CPF
MORE TIME ?
YES
NO
MORE TRANSIENTS ?
YES
NO
MORE FLAWS ?
YES
NO
GENERATE COLUMN IN PFMI AND PFMF ARRAYS FOR CURRENT VESSEL
MORE VESSELS ?
YES
NO
END

The Conditional Probability of Initiation is Calculated by Solving the Weibull K_{Ic} CDF for the Fractional Part (Percentile) of the Distribution that Corresponds to the Applied KI(t)

$$\text{CPI (transient, time, flaw)} = P = 1 - \exp\{-[((K_I(t) - a)/b)^c]\}$$

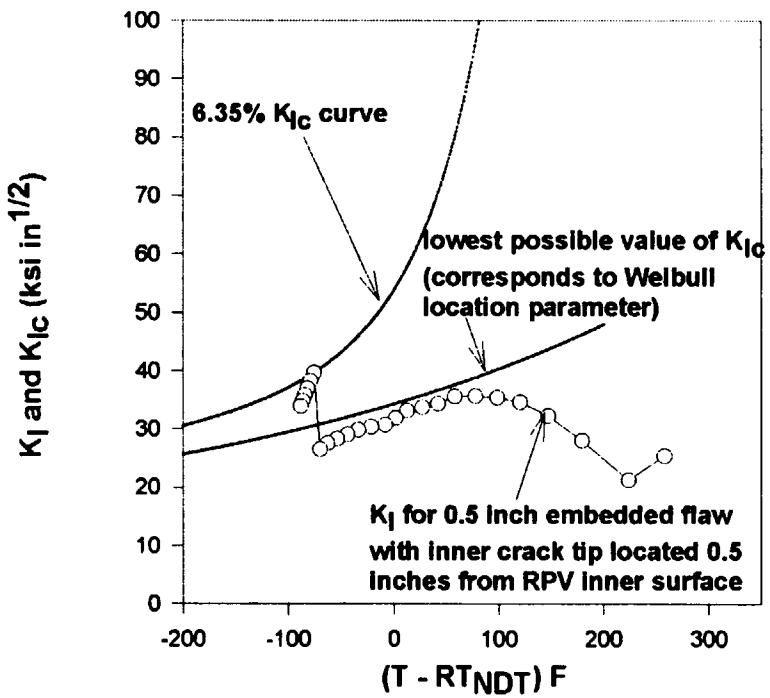


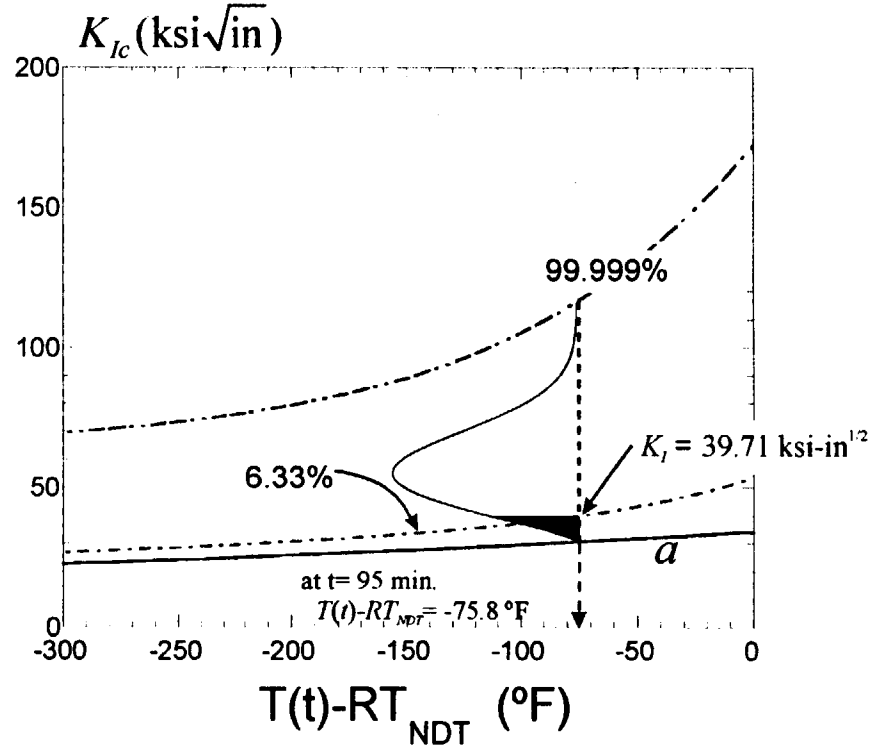


In the Illustrative Example Problem, at the time of Re-pressurization:

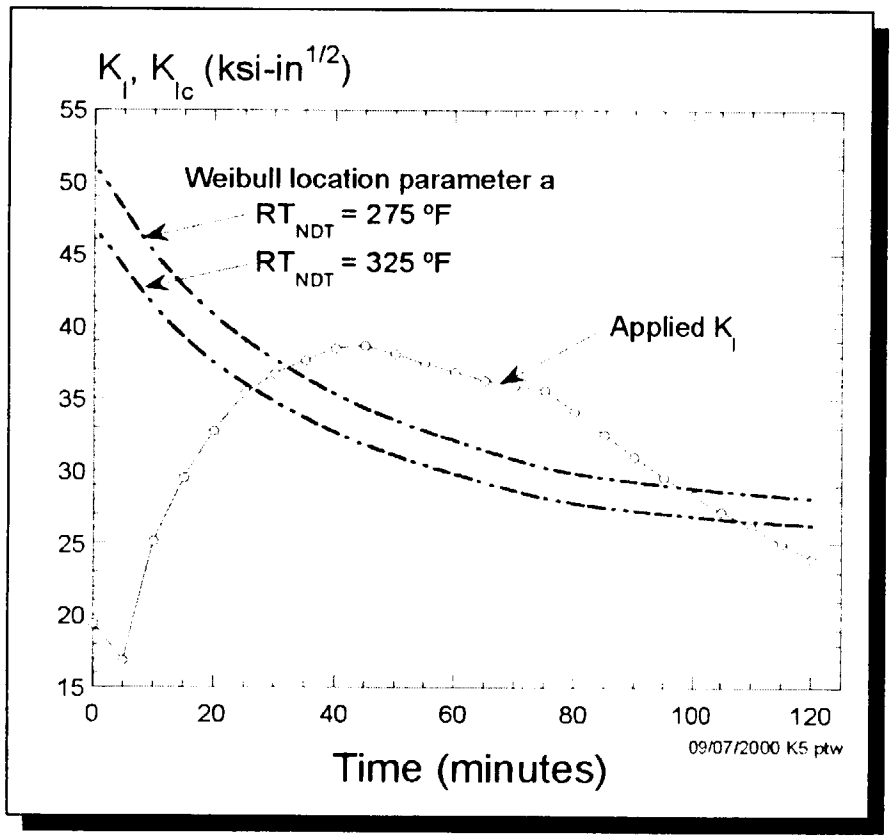
K_I > 0.0635 of the Weibull K_{Ic} distribution at [T(t)-RTNDT] = -75.8;

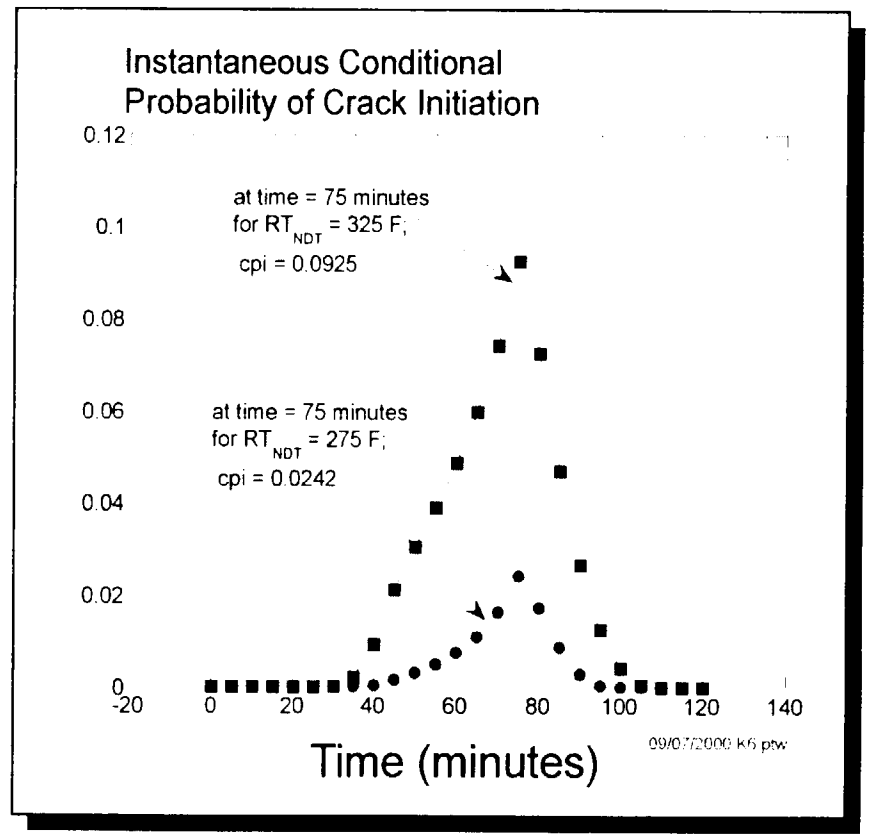
therefore, the CPI = 0.0635 for this flaw at this time





As embrittlement increases over the operating life of an RPV, Conditional Probability of Initiation (CPI) Increases for Given Flaw and Transient





The following computation processes array CPI *for each vessel to account for multiple flaws*

$$PFMI(transient\ i, vessel\ j) = \left(1 - \prod_{flaw=1}^{nflaw} [1 - CPI(transient\ i, \max, flaw))\right)$$

where:

$$\prod_{k=1}^{nflaw} \left[1 - CPI(i, \max, k)\right] = \left[1 - CPI(i, \max, 1)\right]\left[1 - CPI(i, \max, 2)\right] \ldots \left[1 - CPI(i, \max, nflaw)\right]$$

= Probability that none of the *nflaw* flaws initiates in cleavage fracture

$\therefore PFMI(transient i, vessel\ j)$ = Probability that at least one of the *nflaw* flaws (in vessel j) initiates in cleavage fracture when subjected to transient i

Near-Term Schedule for Development of the FAVOR Code has been Defined

- Current schedule specifies FAVOR to be ready for PTS re-evaluation analyses on March 1, 2001

- In the interim period:
  - models are being finalized
  - finalized models are being implemented
  - scoping studies are being performed

Fracture Toughness Distributions and Uncertainty Analysis

→ Status Report to ACRS ←

Mark Kirk
RES/DET/MEB

Rockville, Maryland
September 21, 2000

VG 1

Overview

- Goal and participants in cooperative effort
- Approach
- New data
- Uncertainty framework
- Current results
- Summary and future work

VG 2

Goal and Participants in Cooperative Effort

Goal: Characterize toughness using all available data in a way that is PRA consistent.

	Kirk Malik Siu	EPRI Electric Power Research Institute	***Rosinski***
CTRS	***Modarres*** Li Mosleh	PEAI	***Natishan***
UT-BATTELLE	***Williams*** Dickson Bass Bowman Merkle Nanstad		

VG 3

Approach

Goal: Characterize toughness using all available data in a way that is PRA consistent.

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

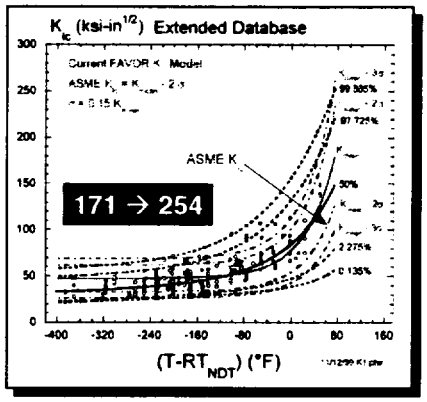
ORNL

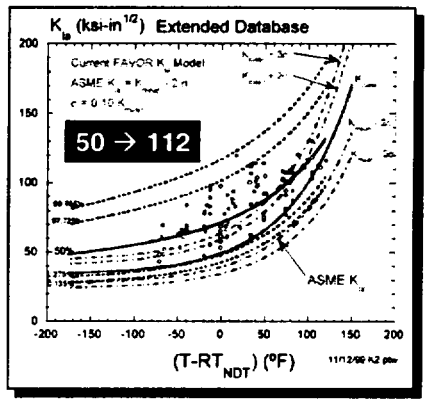
- Purely statistical fit

University of Maryland / PEAI

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

Fracture Toughness Characterization
→ *New Data Collected by ORNL* ←





Old *FAVOR* scatter-bands too narrow

Effect on Probability of Vessel Failure
Depends on Transient Considered

VG 5 **[Bowman and Williams, 2000]**

Uncertainty Analysis

Root Cause Analysis

- ✓ **Identify sources of uncertainties**
- ✓ **Physically based material model for toughness curves in ductile-to-brittle transition temperature range**
- ✓ **Distinguish epistemic (state of knowledge) and aleatory (randomness) parts of uncertainties**
  - **Natishan (EPRI funding)**

PRA Framework

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

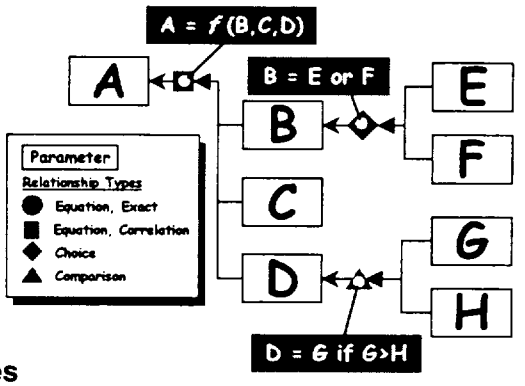
Product: ✓ **Recommended program structure for FAVOR**

- **Modarres, Fei, and Mosleh (NRC funding)**

VG 6

Root Cause Analysis

- Describe uncertainties
  - Data
  - Model / equation
  - Expert judgements
- Classify uncertainties
  - Aleatory
    - ✓ Non-reducible
  - Epistemic (state-of-knowledge)
    - ✓ Reducible
- Propagate uncertainties through model



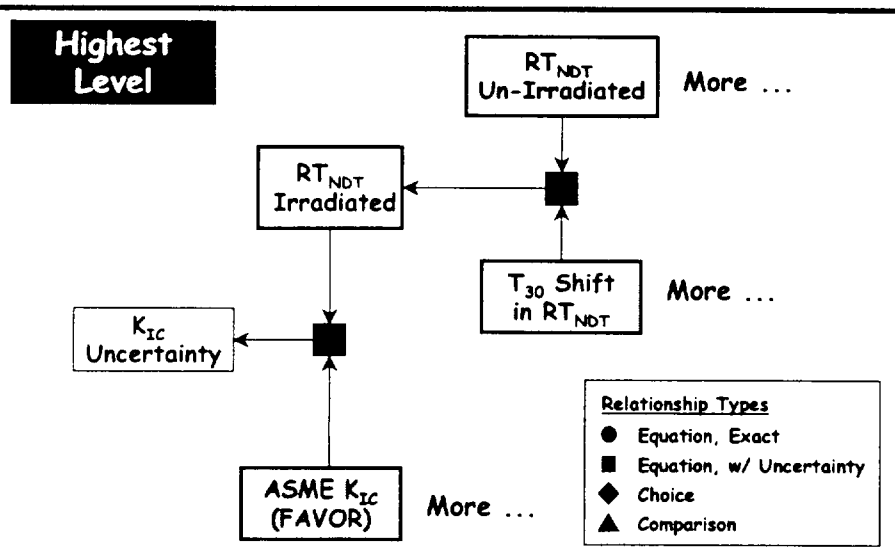
[Natishan & Modarres, 2000]

The BIG Change from the Old Ways

Input uncertainties propagate to output uncertainties via a systematic and critiquable process, rather than margins being prescribed to the analysis *a priori*.

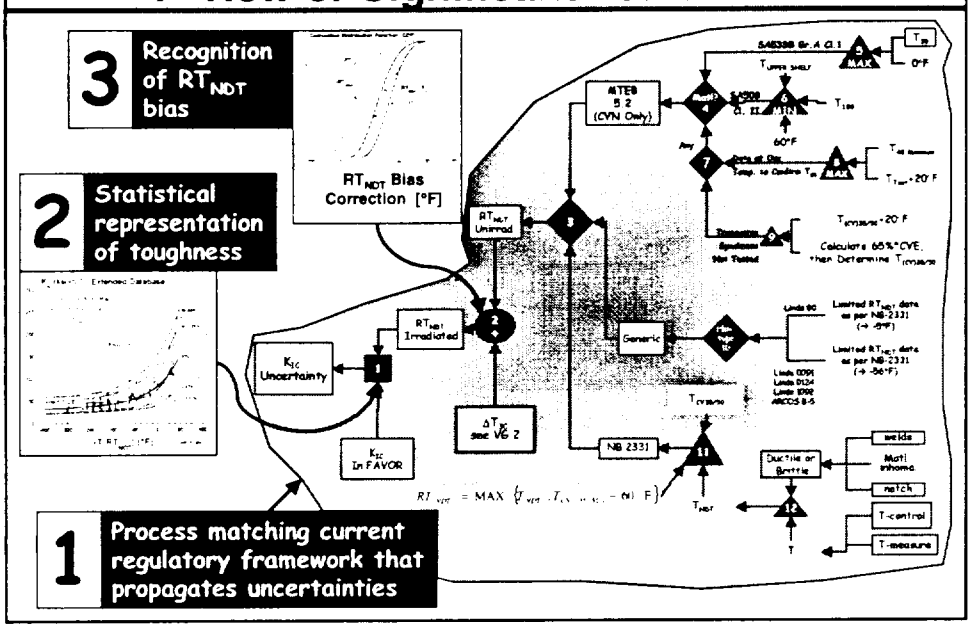
VG 7

Root Cause Analysis of K_{IC} / RT_{NDT} Process

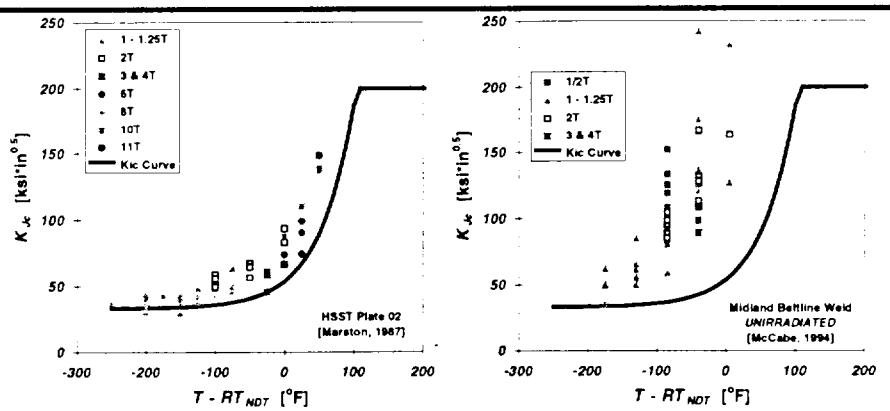


VG 8

Root Cause Analysis of K_{IC} / RT_{NDT} Process
→ New or Significant Features ←



Bias in RT_{NDT}

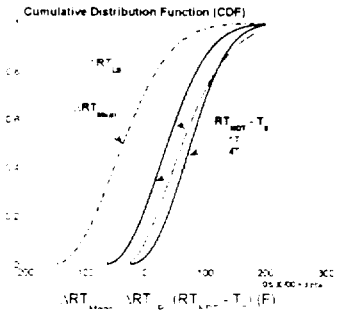


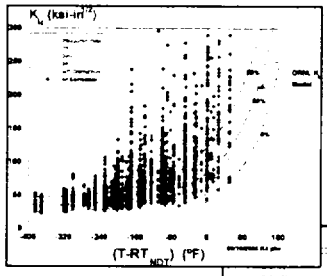
Expected since RT_{NDT} designed to be a bounding estimate of transition temperature, but …

Inconsistent with a PRA approach that relies on "best estimates."

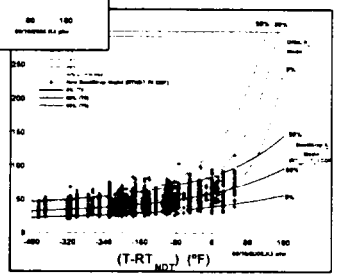
Bias in RT_{NDT}

Candidate Correction Functions





Different Correction Procedures



Appropriate correction and procedure to correct still being developed.

VG 11

Summary and Future Work

- Completed
  - Statistical transition fracture toughness model
    - ✓ Data collected
    - ✓ Fit completed
  - PRA-uncertainty framework
    - ✓ Current processes understood using root-cause diagram approach
    - ✓ Mathematical models developed
      - ➢ Details of FAVOR implementation discussed / clarified
- On-going
  - Full implementation of uncertainty model into FAVOR
  - Resolution of RT_{NDT} bias correction function and modeling procedure
  - Assembly of input data to run the models

VG 12

Revision of ΔT_{30} Embrittlement Trend Curves

→ Status Report to ACRS ←

Mark Kirk
RES/DET/MEB

Rockville, Maryland
September 21, 2000

VG 1

Application of this Information

- PTS rule (10CFR50.61) revision
  - PTS screening criteria
- Reg. Guide 1.99 Revision 3
  - PTS assessment methodology
  - Heat up / cool down calculations

VG 2

Parts of Reg. Guide 1.99 Rev. 3

Part of the Reg. Guide	RG 1.99 R3 Status / Proposed Resolution	PTS Re-Eval. Need?
Transition Shift, Mean Trend Curve	Work Done. Tech Basis Doc Being Written.	Yes
Transition Shift, Uncertainty	Work underway to develop a PRA-consistent uncertainty framework	
Thru Wall Attenuation	Consider new information	
Plant Specific Data: Surveillance Credibility	No technical basis for credit. Use heat average chemistry.	
Plant Specific Data: Ratio Procedure	Not needed if all shifts are based on heat average chemistry.	
Upper Shelf Energy: Mean Trend	Work Done	No
Upper Shelf Energy: Uncertainty	Work Done	

VG 3

Reg. Guide 1.99 Revision 2

$$\Delta T_{30} = (CF)(\phi t)^{(0.28-0.1\log(\phi t))}$$

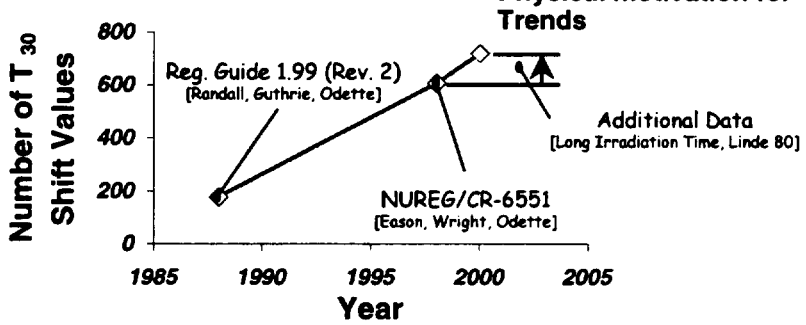
- Chemistry factor depends on
  - Cu
  - Ni
  - Product form

VG 4

Reg. Guide 1.99 Rev. 3 Activity

Objective: Develop a model to predict the shift in T_{30} due to irradiation embrittlement

- More data
  - Better coverage of primary variables
  - Longer time exposures
  - Higher fluences
- Statistical methods
- Physical motivation for Trends



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Modeling Considerations

- Nonlinear fitting
  - Some coefficients based on all of the data set, some based on subsets
  - Some functional forms physically motivated
- A "good" fit has
  - Minimum standard error
  - Residuals
    - ✓ Average = 0
    - ✓ Balanced +/-
    - ✓ No trend with
      - Modelled variables
      - Un-modelled variables
- Statistical significance
  - Physical understanding suggests appropriateness of a one or two tailed test
- Model stability checked
  - Relative to initial estimates
  - Relative to data used to calibrate

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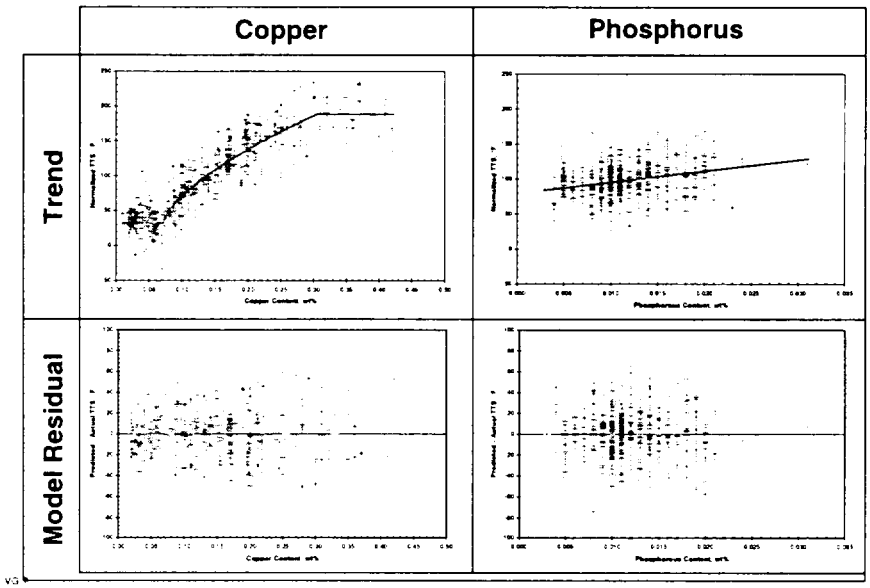
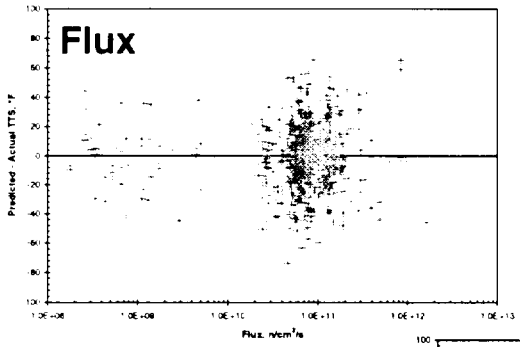
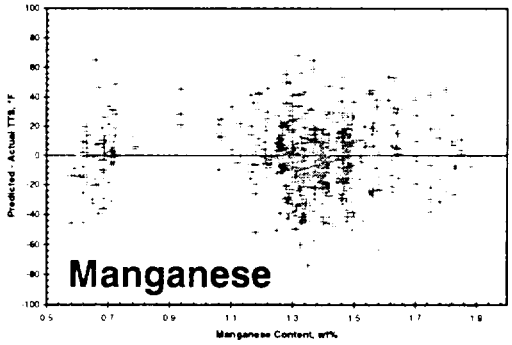
Variables Modeled, Examples



VG 7



Variables Not Modeled, Examples



VG 8

Gating Criteria for Effect Inclusion

- Effects considered (recently)
  - Copper saturation
  - Phosphorus
  - Flux – time
  - Long time
  - Vessel Fabricator

Gating Criteria

Physical Rationale	Statistical Basis		
	Strong (>95%)	<95% & >90%	Weak (<90%)
Well Accepted	Include	Maybe	Maybe
Plausible	Include	Maybe	Exclude
Not Established	Probably	Exclude	Exclude

VG 9

Gating Criteria for Effect Inclusion

- Effects considered (recently)
  - Copper saturation 99%
  - Phosphorus 99.9%
  - Flux – time 99%
  - Long time 99.8%
  - Vessel Fabricator 99.9%

Gating Criteria

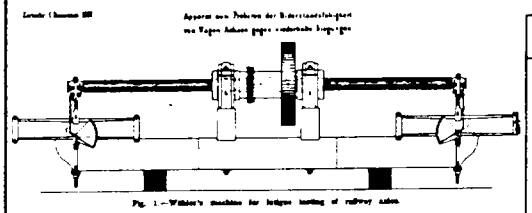
Physical Rationale	Statistical Basis		
	Strong (>95%)	<95% & >90%	Weak (<90%)
Well Accepted	Include	Maybe	Maybe
Plausible	Include	Maybe	Exclude
Not Established	Probably	Exclude	Exclude

Deference to Empirical Evidence

VG 10

Deference to Empirical Evidence, Part 1

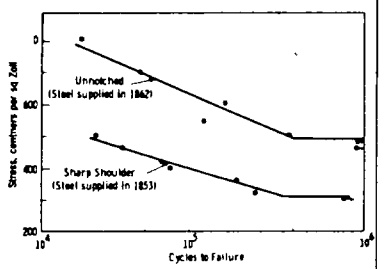
1860: Wöhler's fatigue experiments on German railway axles.



Physical Understanding

The metal crystallized, and so it broke.

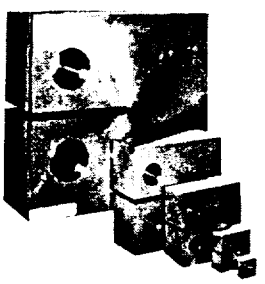
Emprirical Evidence



VG 11

Deference to Empirical Evidence, Part 2

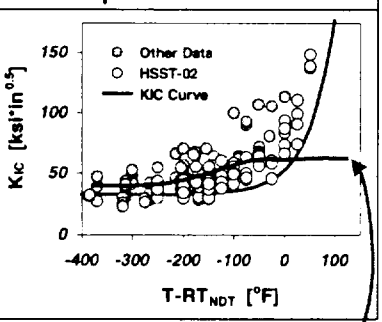
1972: A LEFM K_{IC} curve used then (and now) for analysis of nuclear RPVs.



Physical Understanding

Not *quite* so refined as we enjoy today.

Empirical Evidence



Circa-1972 physically motivated prediction

VG 12

New Embrittlement Correlation

ΔT_{30} = SMD (Phos., fluence, product form, coolant temp.) +

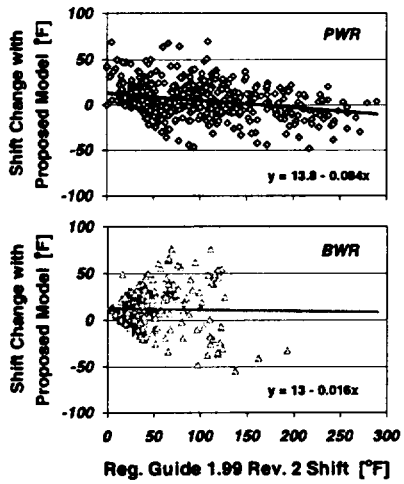
CRP (Cu, Ni, fluence, time, product form, mfgr.) +

BIAS (time)

[Eason & Wright, 2000]

VG 13

Changes Relative to RG 1.99 Rev. 2



- ✓ **Mean shift somewhat higher**
- ✓ **Fit uncertainty reduced for welds**

Data subset	Standard Deviation °F	
	New Trend Curve	RG 1.99 R2
Forgings	19.3	17
Plates, CE vessels	21.0	
Plates, non-CE vessels	19.5	
Welds, Linde 80 or Linde 0091 flux	24.0	28
Welds, Linde 1092 or other flux	23.6	
All Materials	21.5	

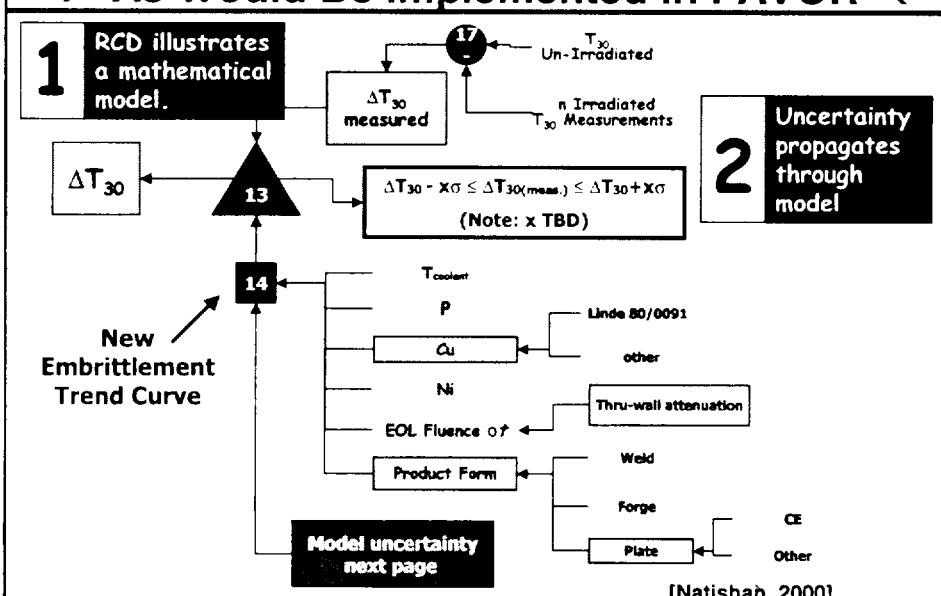
VG 14

Uncertainty Framework

- Developed using same methodology as employed to characterize RT_{NDT} / K_{IC} uncertainty
  - Data assembled and curve fit developed (MCS / UCSB)
  - Nature of uncertainties understood, framework for mathematical model developed (PEAI, EPRI Contractor)
  - Mathematical model developed consistent with PRA (UM)

VG 15

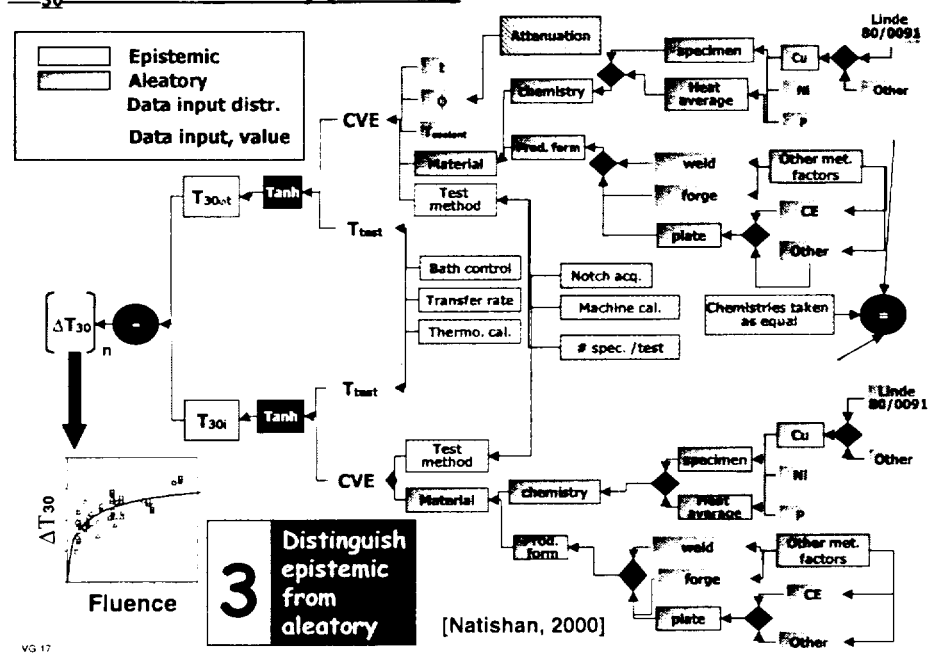
Uncertainty in ΔT_{30} Prediction
→ As Would Be Implemented in FAVOR ←



[Natishah, 2000]

VG 16

ΔT_{30} Model Uncertainty (Node 14)



Treatment of Surveillance Data

- Currently, there is no technical basis relating uncertainty reduction to the availability of surveillance data
- Consequently,
  - Continued "credit" for surveillance data by reducing the σ_Δ margin term (a.k.a RG 1.99 Rev. 2) cannot be justified
  - Proposal: Use ΔT_{30} measured from surveillance merely as a check on the embrittlement trend curve
    - ✓Define value of x in "xσ"
- A basis for a technically defensible uncertainty reduction may / could emerge from the uncertainty analysis

13

$$\Delta T_{30} - x\sigma \le \Delta T_{30(meas.)} \le \Delta T_{30\,(pred.)} + x\sigma$$

(Note: x TBD)

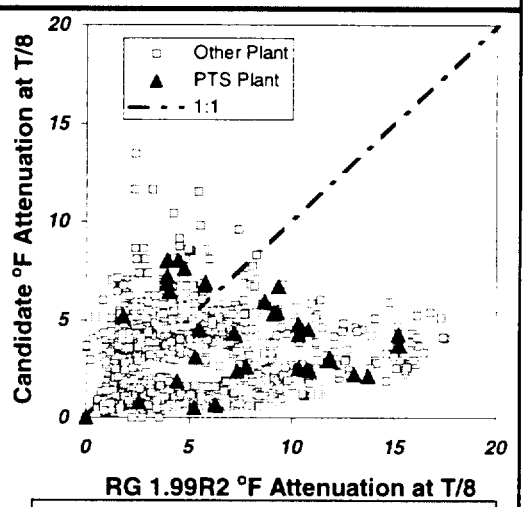
VG 18

Through Wall Attenuation

- For now use RG 1.99 R2 function to attenuate ϕt in embrittlement trend curve
  - Do not attenuate t_i
  - Do not attenuate bias

$$\phi t = \phi t_{ID} \exp(-0.24 \cdot x)$$

- For the RG consider
  - New data basis for revising this function – or not
  - Appropriate damage measure (dpa vs. ϕt w/ E>1MeV)
  - May have to await Rev. 4



Attenuation a More Significant Consideration for HU/CD & for BWRs

VG 19

Next Steps – On Going Work

- PRA-type uncertainty analysis for PTS project (Natishan and Modarres)
- Regulatory impact analysis
- Staff consideration of
  - Treatment of surveillance
  - Thru-wall attenuation
- Tech. basis document being written

VG 20

Status of Pressurized Thermal Shock Screening Criterion Re-evaluation Project

Shah Malik
Materials Engineering Branch
Office of Nuclear Regulatory Research,
U.S. Nuclear Regulatory Commission

Presentation to:
Advisory Committee Reactor Safeguards,
Materials and Metallurgy Subcommittee
September 21, 2000

PTS Re-evaluation Project
Probabilistic Fracture Mechanics
Presentation Outline

- Major PFM technical areas
- Progress in major PFM technical areas
- Concluding remarks

Probabilistic Fracture Mechanics Major Technical Areas

1. Fabrication Flaw Distributions in RPV beltline
2. Rigorous statistical representation of fracture toughness, K1c and K1a, data as functions of ($T-RT_{NDT}$), and uncertainties
3. Improved irradiation embrittlement correlations to predict shift in RT_{NDT}, and uncertainty
4. Improved statistical distributions for material chemistry (Copper, Nickel, Phosphorus)
5. Beltline neutron fluence maps, and uncertainty
6. PFM computer code, FAVOR, revision

Fabrication Flaw Distributions

- Objective: Determine generalized flaw size, 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 experts' judgement process
- RES Staff: Deborah Jackson, Lee Abramson
- NRC Contractor: PNNL

Fabrication Flaw Distributions (Contd.)

- NDE/DE of welds in several RPVs completed, some still continuing
- NDE/DE of limited plate material continuing
- Experts' elicitation completed in April '00
  - Public workshop held on June 27-28
- Generalized flaw distributions developed during July-Sept. '00
- Distributions for use in FAVOR code being developed during Sep.-Oct. '00

Fracture Toughness (K1c, K1a) Curves

- Objective: Revise fracture initiation and arrest toughness distributions based on expanded LEFM-valid data (ASTM E-399 standard) and rigorous statistical methods
  - Distributions used previously were based on:
    - limited 1970's/80's toughness data
    - Adhoc distributions developed from lower-bound ASME toughness curves
- RES Staff: Mark Kirk, Shah Malik, Nathan Siu
- NRC Contractor: ORNL, Univ. of Maryland
- EPRI-funded work: PEAI -- develop uncertainties

Fracture Toughness (K1c, K1a) --Contd.

- ORNL searched and collected additional test data (database increased considerably)
  - Weibull distributions developed based solely on test data
- Uncertainty in normalizing parameter, RT_{NDT} being investigated
- Univ. of Maryland and EPRI assisting in:
  - separating epistemic and aleatory uncertainty
  - Material variability and model uncertainty
- Completion in Nov. '00

Irradiation Embrittlement Correlations

- Objective: Develop revised model to predict shift in RT_{NDT} (ΔRT_{NDT}) due to irradiation embrittlement using up-to-date data and statistical methods
  - Consistency with RG 1.99 Rev. 3 draft development
- Current correlations in RG 1.99 Rev. 2 are based on early-1980's data
- RES Staff: Mark Kirk, Carolyn Fairbanks
- NRC Contractors: Modeling & Computing Services, Univ. of California-Santa Barbara, ORNL, Univ. of Maryland
- EPRI-funded work: PEAI -- develop uncertainties

Irradiation Embrittlement Correlations (Contd.)

- **Progress:**
  - **Mean correlation developed in July '00**
  - **Uncertainty characterization started**
    - **Completion in Nov. '00**

Material Chemistry Distributions

- <u>Objective</u>: Use NRC and industry data to determine --
  - Heat-specific distributions for Copper, Nickel and Phosphorous
  - Investigate local variability
  - 4 PTS plants have
    - 15 weld heats, 2 with Nickel addition
    - 16 plate heats
- <u>RES Staff</u>: Doug Kalinousky, Tanny Santos, Lee Abramson

Material Chemistry Distributions (Contd.)

- Weld heat-specific distributions
  - **Normal**
- Weld local variability
  - **Logistic for Copper and Nickel**
  - **Normal for Phosphorus**
- Plates
  - **Limited data for the heats in PTS plants**
    - **Chemistry values taken as Heat Estimate**
- Plate local variability – limited data from CE
  - **Normal distributions**

Beltline Neutron Fluence

- <u>Objectives</u>:
  - Determine up-to-date EOL fluence maps for the plants using currently available cycle-by-cycle fuel loading histories and plant data
  - estimate uncertainty in fluence calculations
- Dosimetry Draft Guide-1053 (1999), and draft NUREG/CR-6115 methodology used
- <u>RES Staff</u>: William R. Jones
- <u>NRC Contractor</u>: Brookhaven National Lab.

Beltline Neutron Fluence (Contd.)

- **Plants analyzed:**
  - **Oconee-1, Palisades, Calvert Cliffs-1**
  - **Beaver Valley-1 (plant-data being received)**
- **Very refined axial, circumferential, radial grids used:**
  - **218 axial, 60 x 8 circum. for Oconee-1**
  - **205 axial, 97x8 circum. for Palisades**
  - **142 axial, 79 x 8 circum. for Calvert Cliffs-1**
- **Uncertainty in calculated fluence estimated to be:**
  - **1σ fluence $\cong$ 15% of the mean**
- **Need for evaluating nonlinear interactions among fluence parameters is being considered**
  - Vessel diameter, core inlet temp., nuclear cross-section, core neutron source

FAVOR Computer Code Revision

- FAVOR (Fracture Analysis of Vessels - Oak Ridge)
- Implement refined PFM methodology and up-to-date materials data
- Make 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)

Concluding Remarks

- Several analysis models being finalized
  - Scoping studies continuing
  - Implementation of finalized models underway
- Application to first plant (Oconee-1) has started in PRA and TH areas
  - PFM analysis expected to start in March '01
- Additional time and resources being used to develop rigorous uncertainty models for key variables.

Development of a Generalized Flaw Distribution for U.S. Reactor Pressure Vessels

Presented to: ACRS

September 21, 2000

By: Deborah A. Jackson, Lee Abramson

Office of Research

U.S. Nuclear Regulatory Commission

Background

- US NRC is re-evaluating the guidance and criteria in the Code of Federal Regulations as it relates to reactor vessel integrity, specifically PTS
- Fracture mechanics calculations are used to address the consequences of transients in reactor pressure vessels
- Reactor pressure vessel flaw distributions are an important input to fracture mechanics calculations

Background (con't)

- Fabrication processes of reactor pressure vessels is a significant factor for flaw introduction

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
- Expert panel may resolve specific technical issues for which there is significant scientific uncertainty
- Structured expert elicitation process used to obtain responses from experts

Domestic Reactor Pressure Vessel Fabricators

- Combustion Engineering
- Babcock and Wilcox
- Chicago Bridge and Iron
- Rotterdam
- Societe Creusot
- New York Shipbuilding

RPV Material Selected for Generalized Flaw Distribution

	Midland	PVRUF	Shoreham	River Bend Unit 2	Hope Creek Unit 2
Manufacturer	B&W	CE	CE	CB&I	CB&I
LWR Type	PWR	PWR	BWR	BWR	BWR
Weld Metal	4 meters	20 meters	24 meters	15 meters	3 meters
Base Metal	0	0.9 m^3	6.8 m^3	1.0 m^3	0.6 m^3
Years of Construction	1968-1974	1976-1981	1968-1974	1974-1978	1971-1975
Beltline Material	Ring Forgings	Bent Plate	Bent Plates	Bent Plates	Bent Plates
Welds Inspected	Circ	Circ	Circ and Axial	Circ and Axial	Circ and Axial

Reactor Vessel Material

- Categorization of Flaws
  - Region of the vessel
    - Inner region
    - Mid region
    - Outer region
  - Volumetric vs. planar
  - Weld, clad, and base metal
  - Repair weld vs. non repair weld

Expert Judgment Process

- Define 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 Judgment Process

- Identify elicitation team
- Elicitation of experts
- NRC staff processes results
- Expert panel meets to review responses and rationales
- NRC staff aggregates responses and summarizes rationales

Expert Judgment Process

- Successfully completed 17 individual elicitation sessions
- Evolving process
- Preliminary review of the results revealed the need to re-elicit the experts
- Quantitative and qualitative characteristics

Expert Judgment Process
Areas of Expertise

- ASME Construction Code
- Failure Analysis
- Metallurgy
- NDE
- Reactor Vessel Fabrication
  - Base metal fabricators
  - Weld material suppliers
- Statistics
- Welding

Expert Judgment Process Definitions

- Flaw
  - An unintentional discontinuity that has the potential to compromise the reactor vessel integrity and is in the vessel after preservice inspection

Expert Judgment Process Definitions

- Small Flaw
  - Weld metal and cladding
    - Less than or equal to 1 bead thickness for a stated weld process
  - Base metal
    - Less than or equal to ¼" (6mm)
- Large Flaw
  - Weld metal and cladding
    - Greater than 1 bead thickness for a stated weld process
  - Base metal
    - Greater than ¼" (6mm)

Issues/Characteristics

- Product Form
- Weld Processes
- Flaw Mechanisms
- Field vs. Shop
- Repairs
- Weld Procedure
- Weld Materials
- Welder Skill
- Inspection Procedure
- Inspector Skill
- Base Metal Properties
- Surface Prep and Parameters
- Flaw Location

Characteristics Presented to Expert Panel - Page 1

Characteristic	Rank	LMH Value	Flaw Size/Fabricator
1. Product Form			
Forgings			
Plate			
Cladding			
Weldment			
2. Weld Process			
SMAW			
SAW			
ESW			
SMAW			
Cladding			
3. Flaw Mechanisms			
Base Metal			
Weldmetal			
4. Field vs. Shop Fab			
5. Repairs			
Weld metal			
Base metal			
Cladding			
6. Weld Procedure			
Axial Welds			
Girth Welds			
Repairs			
Cladding			

Characteristics Presented Expert Panel - Page 2

Characteristic	Rank	LMH Value	Flaw Size/Fabricator
7. Weld Materials			
Axial Welds			
Girth Welds			
Repairs			
Cladding			
8. Welder Skill			
Axial Welds			
Girth Welds			
Repairs			
Cladding			
9. Inspection Procedure			
Forgings			
Plate			
Weld metal			
Repairs			
Cladding			
10. Inspector Skill			
Forgings			
Plate			
Weld metal			
Cladding			
Repairs			
11. Base Metal Properties			
12. Surface Prep and Parameters			
13. Flaw Location			

Relative Assessments

- Rank characteristics in order from highest to lowest in terms of contributing to or having a flaw after preservice inspection
- Comparison with highest ranked for relative likelihood of a flaw
- Quantitative and Qualitative responses

Expert Judgment Process

- Quantitative characteristics
  - The experts were able to provide numerical comparisons and
  - Necessary records for use in generalized flaw distribution are available
- Qualitative characteristics
  - The experts were unable to meaningfully quantify or
  - Necessary records are unavailable

Some Conclusions of the Expert Judgment Process

- A generalized flaw distribution for domestic RPVs can be developed but with a wide range of uncertainty
- The flaw density of base metal is substantially less than that for weld metal
- Discontinuities in the cladding that do not affect the clad base metal interface may not be of concern for RPV integrity

Some Conclusions of the Expert Judgment Process (con't)

- Large flaws are usually caused by loss of control of the welding process and would be detected by NDE
- Variations in weld quality are greatly affected by welder skill and inspector skill
- Weld processes are an important factor in the introduction of flaws

Concluding Remarks

- Expert judgment process is complex
- Significant amount of information was obtained from the experts during the process
- As a result of the process, NRC staff was able to identify important factors of the fabrication process which are important in considering the introduction of flaws into the RPV

Generalized Flaw Distribution Methodology

- Flaw densities
- Volumes or areas
- Distributions of crack depths

Generalized Flaw Distribution Methodology (contd.)

$N_S(x)$ = number of small flaws > x, for $x \leq b$

$N_L(x)$ = number of large flaws > x, for x > b

x = crack depth

b = bead thickness

PF = Product Form (Weld Metal, Cladding, Plate, Ring Forgings)

WP = Weld Process (SMAW, SAW, ESW; Strip, Single & Multi Wire)

R = Repair State (Unrepaired, Repaired)

Generalized Flaw Distribution Methodology (contd.)

$\rho_S(PF, WP, R)$ = density of small flaws per unit volume or area

$\rho_L(PF, WP, R)$ = density of large flaws per unit volume or area

$V(PF, WP, R)$ = volume or area of material.

$$N_s = \Sigma\ \rho_S(PF, WP, R) \bullet V(PF, WP, R)$$

$$N_L = \Sigma\ \rho_L(PF, WP, R) \bullet V(PF, WP, R),$$

Generalized Flaw Distribution Methodology (contd.)

$G_S(x)$ = ccdf for small flaws = Prob {crack depth > x}, where $x \leq b$

$G_L(x)$ = ccdf for large flaws = Prob {crack depth > x}, where $x > b$.

Each GFD is the product of the number of flaws and the corresponding crack depth distribution.

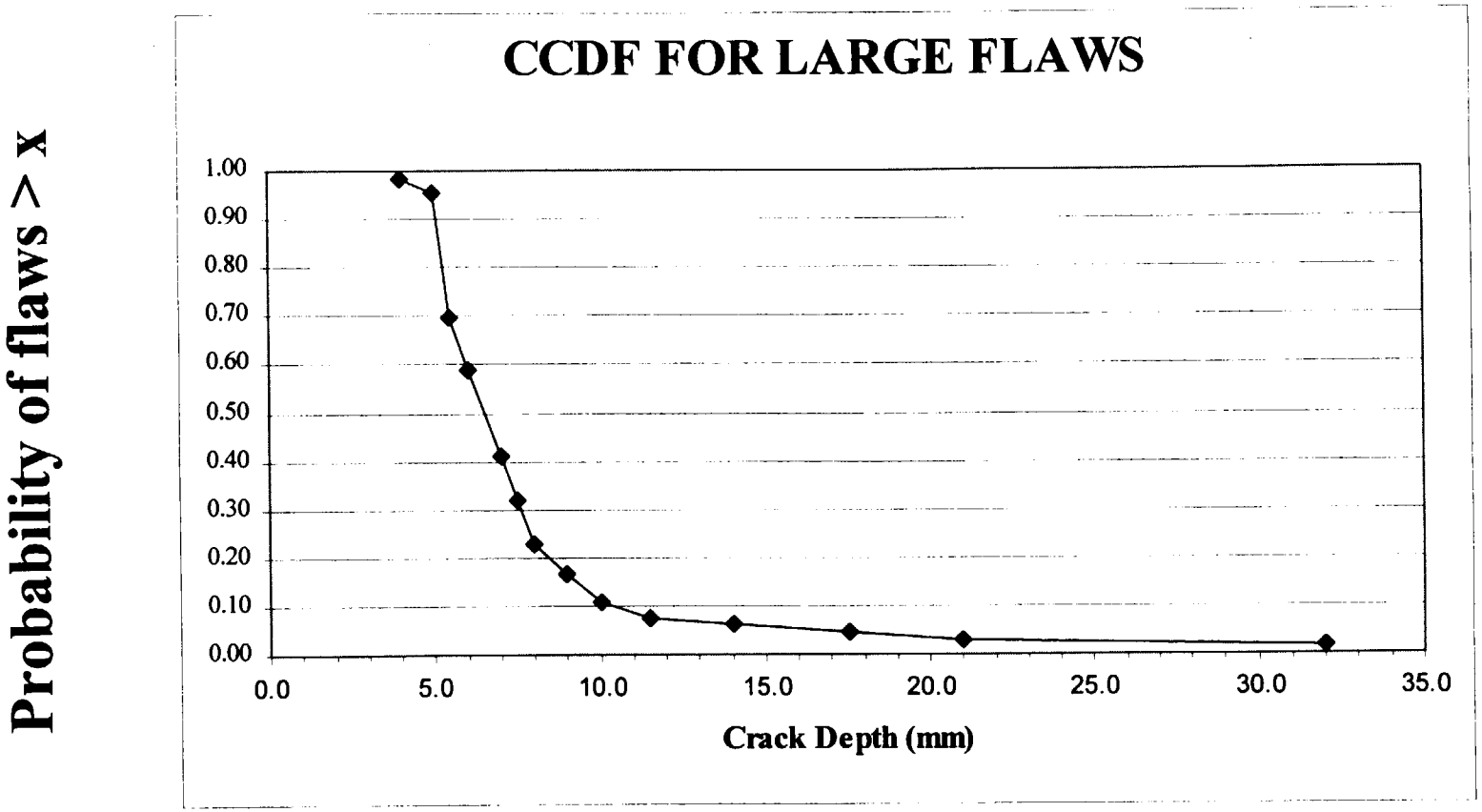
$$N_s(x) = N_S \bullet G_S(x) = [\, \Sigma\, \rho_S(PF, WP, R) \bullet V(PF, WP, R)\,] \bullet G_S(x)$$

$$N_L(x) = N_L \bullet G_L(x) = [\, \Sigma\, \rho_L(PF, WP, R) \bullet V(PF, WP, R)\,] \bullet G_L(x).$$

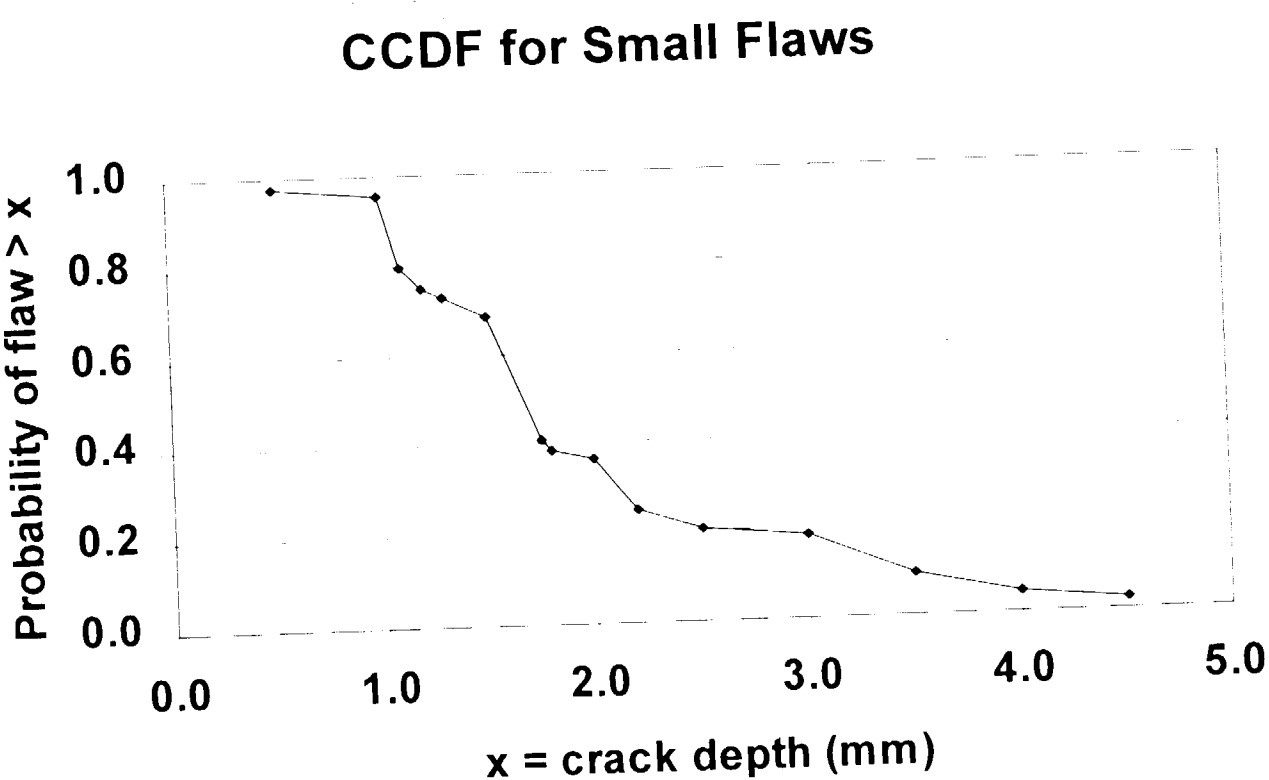
PVRUF Flaw Distribution

Product Form/ Weld Process/ Repair State	PVRUF Volume (m^3)	Density of Flaws		No. of Flaws	
		Small/m^3	Large/m^3	Small	Large
Weld Metal/SMAW/NR	0.025	14,000	280	350	7
Weld Metal/SAW/NR	0.45	7,900	22	3,600	10
Plate/NR	16.7	790	0.55	13,200	9
Weld Metal/SMAW/R	0.007	13,000	1,000	120	70
Plate/SMAW/R	--	7,900	5.5	--	--
Total Weld Metal & Plate				17,270	96
	PVRUF Area(m^2)	Small/m^2	Large/m^2	Small	Large
Cladding/SMAW/NR	2.9	57	1.7	160	5
Cladding/Strip/NR	72	69	2.1	5,000	150
Cladding/MultiWire/NR	0	N/A	N/A	N/A	N/A-
Cladding/SMAW/R	unk	106	5.3	--	--
Total Cladding				5,160	155
TOTAL				22,430	251

CCDF for Large Flaws



CCDF for Small Flaws



Input to FAVOR

	Large Flaws	Small Flaws
Weld Material	$\{x_i\}_{WL}$	$\{x_i\}_{WS}$
Plate Material	$\{x_i\}_{PL}$	$\{x_i\}_{PS}$

x_i = crack depth

Concluding Remarks

- Generalized flaw distribution combines:
  - Densities (generic)
  - Crack depth distributions (generic)
  - Volumes/Areas (plant specific)
- Generic inputs based on all available data and expert judgment

Backup Slides

List of Experts

- Frank Ammirato — EPRI NDE Center
- Francis Berry — F.C. Berry & Associates, Retired Chicago Bridge & Iron
- Spencer Bush — Review & Synthesis Associates, Retired PNNL
- Domenic Canonico — Consultant, President ASME BPV
- Vic Chapman — O.J.V.C. Consultancies, Retired Rolls Royce
- Robert Denale — Naval Surface Warfare Center

List of Experts

• Jack Lareau	Westinghouse (formerly ABB-CE)
• Carl Lundin	Materials Applications Inc., Professor University of Tennessee
• Harry Lunt	Consulting Metallurgist, Retired Burns & Roe
• Edward Nisbett	Consulting Metallurgist, Retired National Forge
• Robert Pond	Consulting Metallurgist, Professor Johns Hopkins University

List of Experts

- Stan Rosinski — EPRI NDE Center
- James Sims — Consulting Welding Engineer, Retired Chicago Bridge & Iron
- Kenneth Stuckey — Framatome Technologies
- Helmut Thielsch — Thielsch Engineering, Inc
- R. David Thomas — R. D. Thomas & Co., Retired Arcos Corporation
- Robert Warke — Southwest Research Institute

Quantitative Characteristics

- Product form
  - base metal
    - ring forgings
    - Plate
  - cladding
  - weldmetal
- Weld processes
  - SAW
  - ESW
  - GMAW
  - SMAW
- Flaw mechanisms
  - base metal
  - weld metal
- Repairs
  - basemetal
  - weld metal
  - cladding
- Flaw location
- Flaw size

Qualitative Characteristics

- Field vs. Shop fabrication
- Weld procedure
  - plate to shell
  - shell to shell
  - repairs
  - cladding
- Weld materials
  - plate to shell
  - shell to shell
  - repairs
  - cladding
- Welder skill
  - plate to shell
  - shell to shell
  - repairs
  - cladding

Qualitative Characteristics (con't)

- Inspection procedure
  - plate to shell
  - shell to shell
  - repairs
  - cladding
- Inspector skill
  - plate to shell
  - shell to shell
  - repairs
  - cladding
- Base metal properties
- Surface preparation and parameters

Re-elicitation of Experts

- Flaw size
- Cladding vs. weldmetal
- Basemetal vs. weldmetal
- Repairs vs. non-repairs (small and large flaws)
- Underclad cracking
- Weld processes (weldmetal and cladding)

Large Flaws in PVRUF and Shoreham

Flaw Size (mm)										BT (mm)	PVRUF
4	5	5-6	6	7	7-8	8	9	10	>10		
2	2									3.5	
					4					6.5	
		2**			2					6	
		5							11.5, 17.5	3.5	
2	2	7			6				11.5, 17.5	#=19	Total PVRUF

Flaw Size (mm)										BT (mm)	Shoreham (NV)
4	5	5-6	6	7	7-8	8	9	10	>10		
			4							5	
	10*									5	
				1					21, 32	5	
								1		6	
				1					14	5	
	1*		1	1		2	3			5	
	4*		7	3		2	1	1		5	
	15		12	6		4	4	2	14, 21, 32	#=46	Total Shoreham
2	17	7	12	6	6	4	4	2	11.5, 14, 17.5, 21,32	#=65	Total

Quantitative Assessment

X = Quantity to be assessed

X_L = Low value

X_H = High value

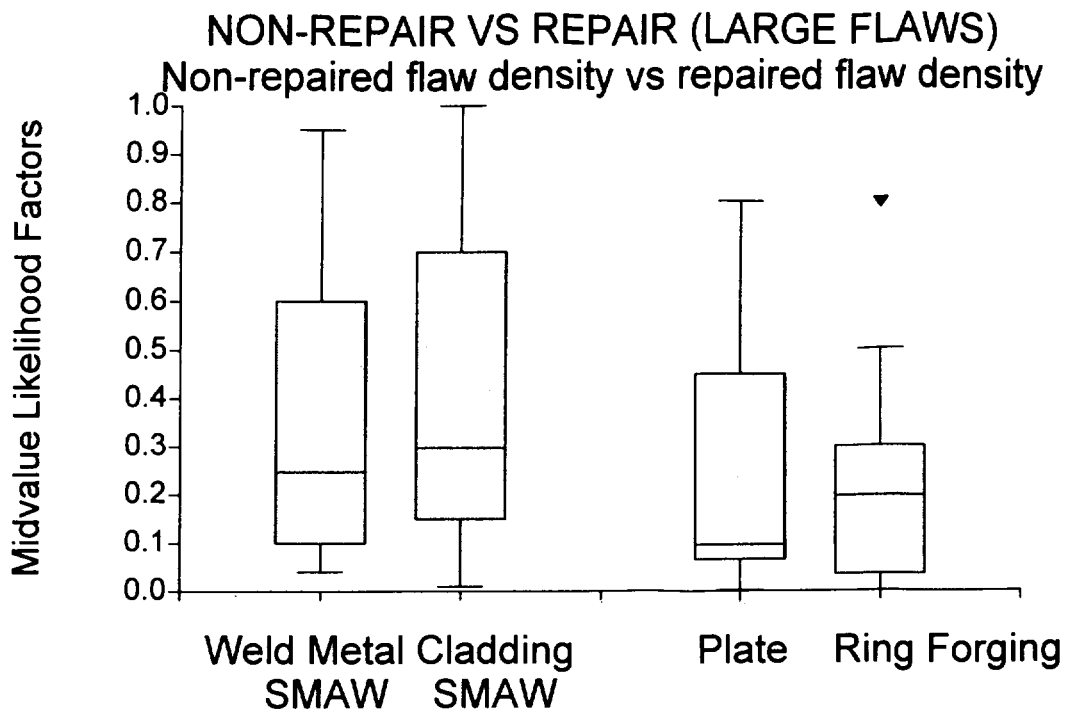
X_M = Midvalue

Chance { $X < X_L$ } ÿ 5%

Chance { $X > X_H$ } ÿ 5%

Chance { $X < X_M$ } ÿ Chance { $X > X_M$ } ÿ 50%

(X_L , X_H) is an approximate 90% coverage interval for X



	Weldmetal SMAW	Cladding SMAW	Base Metal Plate	Base Metal Forging
MIN	.04	.01	.002	.0004
LQ	.1	.15	.06	.03
MED	.25	.3	.1	.2
UQ	.6	.7	.5	.3
MAX	.95	1.0	.8	.8

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Status of Thermal Hydraulic Input to PTS

ACRS
Subcommittee on Materials and Metallurgy

Rockville, MD
September 21, 2000

Objective

- To ensure that, for the risk-significant classes of events, the thermal hydraulic inputs developed at the time of the Integrated Pressurized Thermal Shock Study (IPTS) conducted during 1982-1985 are still operative, or, are otherwise updated as needed

- Additionally, to provide an estimate of the uncertainty of these values

- In the IPTS study, three PWRs were selected for analysis, one from each vendor:

  1. Oconee Unit 1 (Babcock and Wilcox)

  2. Calvert Cliffs Unit 1 (Combustion Engineering); and

  3. H.B. Robinson (Westinghouse). In the current study we have switched to a similar 3-loop plant, Beaver Valley Unit 1

Thermal Hydraulic Issues

- Single and two phase loop natural circulation
- Criteria for interruption of loop flow, which causes flow stagnation
- Number of cold legs which must be flowing to assure mixing in the downcomer
- Local fluid mixing and onset of thermal stratification in the cold leg
- Plume mixing in the downcomer
- These are being studied in a experimental program in the APEX facility

RELAP Analyses of Oconee Transients

- Total of 25 transients were calculated for Oconee-1 thus far with RELAP5/MOD3 (version 322γ)
- Transients were run to 10,000s. Significant improvement from IPTS study
- Downcomer modeled with 6 channels instead of single channel

RELAP Analysis of Oconee Conclusions

- Useful interchange between PRA and thermal hydraulics. Good progress made on Oconee-1

- The break spectrum that was calculated for Oconee-1 covers the range of interest from where the primary system pressure stays near the steam generator secondary pressure to where the primary system pressure drops below accumulator pressure and further to low pressure injection

- The results are sensitive to the trip criteria for the reactor coolant pumps on loss of subcooling. Once subcooling is lost in a small break LOCA it will generally not be reestablished unless the break can be isolated.

- Stuck open valves on the secondary combined with a small break on the primary help to maintain subcooling and, therefore, the reactor coolant pumps are not tripped

- When the reactor coolant pumps are tripped, stagnation beginsand the downcomer cools in response to high pressure injection

- Cold leg breaks slightly less severe than hot leg breaks (similar to IPTS results)

TRAC Analysis of Oconee

- Coupling REMIX with TRAC
- 2 inch (to be run also with REMIX-RELAP)
- Main steam line break, Normal trip of main feedwater and turbine driven emergency feedwater pump upon low steam generator pressure, full uninterrupted flow of emergency feedwater to the broken generator, normal level control of emergency feedwater to the intact generator normal actuation of HPI, failure to trip HPI, normal trip of RCPs if subcooling is lost
- 1.414 inch with two stuck open safety valves
- Stuck Open PORV, Turbine trip with PORV fails to close, normal response of main and emergency feedwater to steam generator level control, normal actuation of HPI, normal trip of RCPs if subcooling is lost
- Results will be obtained by 10/00

Thermal Hydraulic Uncertainty Evaluation

- Performed by University of Maryland for Oconee-1
- Based on simplified treatment based on energy and mass conservation supplemented by RELAP analyses

APEX PTS Testing

- Objective is to provide experimental data on thermal hydraulic PTS issues and for code assessment
- Scaling evaluation performed to compare APEX to Palisades
- Facility was modified to add loop seals, HPI connections to cold legs, additional thermocouples in cold legs and downcomer
- Pre-test calculations performed using RELAP, REMIX
- First test conducted in August, 2000
- Remaining test to follow during the Fall, 2000

APEX PTS Test Matrix

1. Inject HPI into cold legs and measure plume effects in the vessel downcomer. The loop flow conditions will be stagnant

2. Depressurization/repressurization test simulating one of the most risk dominant sequence from the IPTS studies (stuck open PORV followed by closing of the block valve)

3. Flow interruption in one steam generator prior to the other

4. Small (2 inch) hot leg break where the operator is assumed to follow the emergency operating procedures

5. Small hot leg break similar to preceding test, but simulating Westinghouse HPI, accumulators, and LPI, instead of Combustion Engineering

6. Small cold leg break. Similar to hot leg break, but to assess the difference between the same break in the hot leg versus the cold leg. RELAP analysis of Yankee Rowe (4-loop plant) cold leg break in bottom of loop seal indicated possibility that broken loop could remain liquid solid. This needs to be checked by experiment and further analysis.

7. Main steam line break

Status of Calculations of Beaver Valley, Calvert Cliffs and Palisades

- No calculations performed thus far beyond exercising input models for H.B. Robinson and Calvert Cliffs using TRAC and RELAP
- We have begun conversion of the H.B. Robinson decks to model Beaver Valley
- Calculations with Beaver Valley deck are scheduled by 1/2001
- Calvert Cliffs and Palisades calculations scheduled for 5/2001

Conclusions

- Oconee RELAP results ready for transmittal to ORNL
- Using modified H.B. Robinson models, we expect to be able to provide thermal hydraulics analysis for Westinghouse 3-loop plant in a schedule consistent with requirements of PRA and fracture mechanics (early 2001)
- Calvert Cliffs and Palisades calculations to follow Beaver Valley (mid-2001)

RELAP Analyses of Oconee-1

- Break Spectrum (hot leg breaks located in the pressurizer surge line)

  1. 1 inch (diameter)
  2. 1.414 inch
  3. 1.5 inch
  4. 2 inch (to be run also with REMIX using boundary conditions from the RELAP calculation)
  5. 2.828 inch
  6. 4 inch

- Break Plus Additional Failure

  7. 1 inch with one stuck open safety valve
  8. 1 inch with two stuck open safety valves
  9. 1.414 inch with two stuck open safety valves

- Break Location

  10. 1.414 inch cold leg break (compared to hot leg break)
  11. 2 inch cold leg break (compared to hot leg break

- Subcooling Criteria for Tripping Reactor Coolant Pumps

  12. 1.414 inch with tripping the pumps at 5F subcooling instead of 0.5F

- Subcooling Criteria for Throttling HPI

  13. Trip HPI when 100F subcooling is reached for 1 inch LOCA with one stuck open safety valve
  14. Trip HPI when 100F subcooling is reached for 1 inch LOCA with two stuck open safety valves

- Low Decay Heat

  15. 1-inch LOCA with Low Decay Heat (0.3 x normal) [variation on earlier calculation]
  16. 1-inch LOCA with one stuck open safety valve with low decay heat (0.3 x normal) [variation on earlier calculation]

- Stuck Open PORV

  17. Turbine trip with PORV fails to close, normal response of main and emergency feedwater to steam generator level control, normal actuation of HPI, normal trip of RCPs if subcooling is lost

RELAP Analyses of Oconee-1 (cont'd)

- **Secondary Side Breaks**

  18. One stuck open steam dump valve with continued feed to the open steam generator

- **Steam Generator Overfeed**

  19. Emergency feedwater continued to 96% operating range
  20. Emergency feedwater continued until the separator is flooded.
  21. Turbine trip, normal reduction in feedwater, and with failure of level control, uninterrupted flow of feedwater
  22. Turbine trip, no reduction in main feedwater from full power flow rate, and with failure of level control, uninterrupted flow of feedwater HPI starts normally upon demand and is never terminated]

- **Main Steam Line Break**

  23. Normal trip of main feedwater and turbine driven emergency feedwater pump upon low steam generator pressure, full uninterrupted flow of emergency feedwater to the broken generator, normal level control of emergency feedwater to the intact generator normal actuation of HPI, failure to trip HPI, normal trip of RCPs if subcooling is lost

- **Other**

  24. 1-inch LOCA with no HPI, normal feedwater control, after 15 minutes steam dumps to go full open to cool down to LPI pressure

  25. Turbine trip, main feedwater trip, and reactor coolant pump trip. Emergency feedwater on to bring steam generator level to natural circulation setpoint. Terminate emergency feedwater and allow steam generators to dry out. When primary side reaches PORV setpoint and steam generators are dry, open steam dumps to allow secondary side to depressurize to allow condensate pumps to inject. Keep steam dumps open and keep feeding the steam generators. Allow HPI to actuate as normal. Turn off HPI if subcooling becomes > 100F.