

Official Transcript of Proceedings

NUCLEAR REGULATORY COMMISSION

Title: Advisory Committee on Reactor Safeguards
Meeting of the Metallurgy and Reactor Fuel
Subcommittee

Docket Number: (n/a)

Location: Rockville, Maryland

Date: Thursday, August 21, 2014

Work Order No.: NRC-1015

Pages 1-168

NEAL R. GROSS AND CO., INC.
Court Reporters and Transcribers
1323 Rhode Island Avenue, N.W.
Washington, D.C. 20005
(202) 234-4433

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

+ + + + +

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

(ACRS)

+ + + + +

MATERIALS SUBCOMMITTEE

+ + + + +

THURSDAY

AUGUST 21, 2014

+ + + + +

ROCKVILLE, MARYLAND

+ + + + +

The Subcommittee met at the Nuclear
Regulatory Commission, Two White Flint North, Room
T2B1, 11545 Rockville Pike, at 1:30 p.m., Ronald G.
Ballinger, Chairman, presiding.

COMMITTEE MEMBERS:

RONALD G. BALLINGER, Subcommittee Chairman

DENNIS C. BLEY, Member

JOY REMPE, Member

PETER C. RICCARDELLA, Member

STEPHEN P. SCHULTZ, Member

GORDON R. SKILLMAN, Member

JOHN W. STETKAR, Member

ACRS CONSULTANT:

WILLIAM SHACK

DESIGNATED FEDERAL OFFICIAL:

CHRISTOPHER L. BROWN

ALSO PRESENT:

KENSAKU ARAI, Nuclear Regulation Authority

Team

B. RICHARD BASS, ORNL

MICHAEL BENSON, RES

MICHAEL CASE, RES

TERRY DICKSON, ORNL

AMY FREED, Westinghouse

ERIC FOCHT, RES

RON GAMBLE, Sartrex Corporation

ROBERT HARDIES, NRR

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS

1323 RHODE ISLAND AVE., N.W.

WASHINGTON, D.C. 20005-3701

(202) 234-4433

(202) 234-4433

1 ALSO PRESENT (CONTINUED)
2 TIM HARDIN, EPRI
3 MARK KIRK, RES
4 MARVIN LEWIS*
5 JAMES MEDOFF, NRR
6 SEUNG MIN, NRR
7 MARTHA MITCHELL, NRO
8 NATHAN PALM, EPRI
9 JEFF POEHLER, NRR
10 STACEY ROSENBERG, NRR
11 DAVE RUDLAND, RES
12 SIMON SHENG, NRR
13 PETER SNYDER, NRR
14 GARY STEVENS, NRR
15 BRIAN THOMAS, RES
16 ROB TREGONING, RES
17 ANEES UDYAWAR, Westinghouse
18

19 *Present via telephone
20
21
22
23
24

1	C-O-N-T-E-N-T-S	4
2	Call to Order, Opening Remarks, and	5
3	Objectives	
4	Ronald G. Ballinger	
5	Staff Opening Remarks	6
6	Mike Case	
7	Director	
8	Division of Engineering	
9	Office of Nuclear Regulatory Research	
10	COMSECY on Appendix G and H Bifurcation	10
11	Robert "Bob" Hardies	
12	Office of Nuclear Reactor Regulation	
13	Objective and Description of Technical Issues	20
14	Mark Kirk	
15	Office of Nuclear Regulatory Research	
16	Technical Issues No. 1 and No. 2: Small	69
17	Surface-Breaking Flaws (SBFs), FAVOR Cladding	
18	Model	
19	Mark Kirk	
20	Office of Nuclear Regulatory Research	
21	Technical Issue No. 3: BWR Leak Tests	85
22	Mark Kirk	
23	Office of Nuclear Regulatory Research	
24	Public Comment	105
25	Martin Lewis	105

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

P R O C E E D I N G S

1:29 p.m.

CHAIRMAN BALLINGER: (presiding) Okay,
can the meeting come to order, please?

This is a meeting of the Metallurgy and
Reactor Fuel Subcommittee. I am Ron Ballinger,
Chairman of the Subcommittee.

ACRS members in attendance are Pete
Riccardella, Stephen Schultz, Dick Skillman, Dennis
Bley, John Stetkar, Joy Rempe, and the August Mr. Bill
Shack, Consultant.

Christopher Brown is the ACRS staff,
Designated Federal Official for this meeting.

The purpose of this meeting is to receive
a briefing from the staff on bifurcation -- I thought
that was a medical term -- but, anyway, bifurcation of
10 CFR 50, Appendices G and H, rulemaking, and 10 CFR
50, Appendix G, research efforts, probabilistic
evaluation of normal operations.

The Subcommittee will gather information,
analyze relevant issues and facts, and formulate the
position and action as appropriate for deliberation by
the full Committee in September, on September 4th.

You didn't put that on there? We are not
doing that? We are not doing anything.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

(202) 234-4433

(202) 234-4433

1 (Laughter.)

2 Deliberate, okay.

3 The rules for participation in today's
4 meeting have been announced as part of the notice of
5 this meeting and previously published in The Federal
6 Register on July 23rd, 2014. Is that true? Uh-hum.
7 Okay.

8 A transcript of the meeting is being kept
9 and will be made available as stated in The Federal
10 Register notice. It is requested that speakers first
11 identify themselves and speak with sufficient clarity
12 and volume so they can be readily heard. Also, silence
13 all iPhones and other electronic devices.

14 We have not received any request from
15 members of the public to make oral statements or written
16 comments.

17 There is a bridge line set up which will
18 be in listen mode only, opened toward the end of the
19 meeting.

20 We will now proceed with the meeting, and
21 we call on Mike Case to give a brief introduction and
22 introduce the presenters.

23 MR. CASE: Good afternoon, everyone.
24 Thanks for the opportunity.

25 I am Mike Case. I am the Director of the

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 Division of Engineering in the Office of Research, at
2 least for a few more days. I will be moving down into
3 another office in Research, down to DSA.

4 Sometimes it is good to start with the
5 obvious, as I call it. And so, I wanted to talk about
6 the reactor pressure vessel, and it is big. It is
7 expensive. It is difficult to replace. It grows old.
8 And next to the cooling tower and maybe Homer Simpson,
9 it is one of the most recognized iconic symbols of a
10 nuclear power plant. And finally, it is very important
11 to safety.

12 And so, given all those factors, what you
13 find is that reactor pressure vessel issues have a lot
14 of what I call emotional components. And what that
15 means is, if there is an issue with the reactor pressure
16 vessel, it is probably going to appear to be ten times
17 to a hundred times worse to the general public.

18 So, when we reflect upon that -- and the
19 Strategic Plan actually says this a lot more
20 eloquently -- probably what my strategy is for the RPV
21 is I don't want any problems to find me. And so, what
22 that means is that I need to be out ahead of potential
23 problems with the reactor pressure vessel. And so,
24 that puts a lot more emphasis, I think, on research
25 activities.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 And so, the agency has actually been pretty
2 good in the research area with reactor pressure vessels
3 way back into the Tom Merlinton days, and probably prior
4 to that. So, we have always had a robust program. So,
5 for the five or six years that I have been in
6 Engineering, we have had a relatively-robust program
7 in that area. You know, it probably averages about a
8 million dollars a year, which is, if you look at that
9 on the spreadsheet, that is probably a big program in
10 the research area.

11 And Mark is probably wondering where his
12 million dollars is. With sequestration and other
13 budget restrictions recently, it is probably less than
14 that now. But it is still a pretty robust program.

15 In many respects, it is like the steam
16 generators, which is another component that has the
17 same type of imprint to it, in that I don't have a
18 problem spending money in order to make sure that
19 problems don't occur.

20 And I really respect the NRR for having the
21 wisdom to allow us to do that. But it is not sufficient
22 just to build models about the reactor pressure vessel.
23 It is how do you take that knowledge and how do you
24 translate it into regulations or regulatory guidance,
25 so that we can accumulate the safety value of the

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 knowledge that we have gained and really, once we get
2 it into one of those processes, it starts to engage the
3 public and we start to build some of that confidence
4 in the regulations that we have out there for this
5 important component. So, it is good that we are
6 hearing about reactor pressure vessel research today
7 in the context of two rulemakings, you know, Appendix
8 H and Appendix G.

9 And then, finally, of course, we need your
10 help. So, when you are working out ahead of problems,
11 what you find is that what we want to produce in these
12 rulemakings is largely based on the technical expertise
13 that is presented in the rule. So, there is not
14 operating experience with the budget problems that
15 helps us move these regulatory products forward. It
16 is really the strength of the technical credibility of
17 what is being presented.

18 So, it is very important that our
19 rulemakings and our guidance is based on good technical
20 information. And that is really your role. You can
21 help us make sure that we don't have gaps in our
22 thoughts.

23 So, once again, I appreciate the help that
24 you are going to give us today. And I think I am turning
25 it over to Bob, right?

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 MR. HARDIES: Sure. Thanks, Mike.

2 For the record, I'm wondering where my
3 million dollars is, too.

4 (Laughter.)

5 I am Bob Hardies. I am going to talk about
6 bifurcation. That joke wasn't lost on me, whoever did
7 that. And also, I am going to introduce Mark. After
8 I introduce him, I am going to move out of the line of
9 fire and allow him to go.

10 But I am going to cover bifurcation. To
11 get to the end before I even begin, we did ask the
12 Commission to direct us to proceed with rulemaking on
13 Appendix H, and they did vote and decide to direct us
14 to proceed with rulemaking on Appendix H.

15 And I was going to brief you on the memo
16 that we sent them. You have got the memo and have seen
17 it. And now you know the result of it.

18 I am going to start here with Title 10 of
19 the Code of Federal Regulations in Appendix A and
20 General Design Criteria 31, which says that the reactor
21 coolant pressure boundary needs to be designed in a
22 manner, so that when it is stressed under operating
23 testing or maintenance or accident loads, that it
24 doesn't behave in a non-brittle manner.

25 It also states that the probability of

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 rapidly propagating fractures shall be minimized. And
2 it tells you to consider material properties, flaws,
3 and stress, which means fracture mechanics. And then,
4 it also tells you to consider irradiation.

5 And steel exhibits this ductile to brittle
6 transition behavior. So, that needs to be managed.
7 The way we accommodate General Design Criteria in 31
8 is through Appendix G of 10 CFR 50. And it basically
9 provides the fracture toughness requirements for
10 operating and hydrotesting, and by operating, it
11 includes anticipated events. And it makes you limit
12 the stored elastic strain energy in the reactor vessel,
13 depending on how the reactor vessel fracture behavior
14 is.

15 So, when it has got behavior that doesn't
16 absorb much energy during fracture, you can't store
17 much elastic energy in the vessel wall. And when the
18 vessel is hot and tough and fracture behavior is such
19 that it would absorb a lot of energy, you can store a
20 lot more elastic energy in the reactor pressure wall.
21 The only source of that elastic stress strain energy
22 is pressure.

23 So, you end up getting a cookbook in
24 Appendix G that correlates maximum allowable pressure
25 with temperature where the transition toughness is what

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 indexes that.

2 Criterion 31 also says you have to address
3 irradiation. And the way we address irradiation is we
4 index these pressure temperature limit curves in
5 accordance with how much fluence went through the
6 vessel, and those correlations come from shifts in
7 Sharpe behavior from lots and lots of specimens, from
8 lots of different materials irradiated to lots of
9 fluences. And they are correlated with material
10 chemistry and fluence and toughness shift. Those
11 specimens come from the Appendix H programs and reactor
12 vessel surveillance programs. They are all
13 agglomerated and evaluated to create Regulatory Guide
14 199.

15 The Appendix H establishes surveillance
16 programs for reactor pressure vessels. And it kind of
17 does two things. It tells you what you have to have
18 in a program, what kind of materials need to be there,
19 what kind of specimens, how many specimens, how many
20 capsules. So, it is the beginning of a surveillance
21 program before a vessel starts up, and, then, an
22 implementation phase. Once you have a vessel running,
23 you occasionally pull a capsule, tear it open, and it
24 tells you what temperatures to test, you know, to do
25 the testing at. It tells you to keep broken specimens

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

(202) 234-4433

(202) 234-4433

1 for later use.

2 And you learn things when you pull a
3 surveillance capsule about irradiation of the vessel
4 and about its embrittlement state that make you decide
5 to change the order or the interval between the next
6 withdrawal. So, part of Appendix H is evaluating
7 changes to the withdraw schedule.

8 The way Appendix H tells you to do a
9 surveillance program, it implements ASTM E185, the
10 American Society for Testing of Materials Standard
11 E185, which is surveillance programs.

12 The design portion of the surveillance
13 program E185, it is done once for a vessel. It is done
14 when the vessel is -- I am going to find this, unless
15 it is gone. It is done, before the vessel shows up
16 onsite, the design is done.

17 So, the current version of Appendix H
18 directs plants to use the 1973, 1979, or 1982 version
19 of ASTM E185. All operating vessels, their
20 surveillance programs meet those additions of E185,
21 including the ones that are being built now that are
22 being ordered. They are ordered to have a surveillance
23 program design that matches ASTM E185, the 1982
24 version.

25 And what we want to do when we update

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 Appendix H is update the allowable versions. So, for
2 design of programs, it wouldn't apply to any vessels
3 that exist right now or that are being built right now,
4 because it only applies when you order a new vessel.
5 So, this change won't impact any operating vessel for
6 the design of the program.

7 For the conduct of the program, testing
8 standards change; testing technology changes. I know
9 since ASTM E185 '82 was developed, a lot of test
10 standards have changed. I know that because, since
11 then, Mark Kirk graduated from high school, went to
12 college, graduated from college, and had a big, long
13 career where he changed some test standards.

14 In 2002, ASTM split E185 into a design
15 standard and a program conduct standard. The design
16 standard, as I said, would only apply to future vessels.
17 The conduct standard provides current testing
18 techniques for people who are running operating plants,
19 and to update it by 32 years of progress and standards
20 technology is an appropriate thing to do.

21 There's a couple of other things this
22 change would accomplish. The new version of E185
23 requires fracture toughness, specimens to be put into
24 programs. All the new vessels, the new reactors are
25 installing them anyway. They are doing it at their

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 option, but they wouldn't be required to under the --

2 MEMBER RICCARDELLA: In addition to
3 Sharpe or --

4 MR. HARDIES: Yes, in addition to Sharpe,
5 both Sharpe and toughness specimens.

6 Also, E185 has you do a capsule very early
7 in life, and we wouldn't do that now. We know a lot
8 more about material radiation behavior. And frankly,
9 it is a waste of money, a waste of time, a waste of
10 resources, and a waste of radiation dose to workers to
11 have them pull a capsule after one cycle with the modern
12 steels.

13 MEMBER SKILLMAN: Was there any benefit to
14 a low-fluence capsule?

15 MR. HARDIES: Early on, if you go back to
16 the sixties and seventies when irradiation behavior
17 wasn't so well-known or understood, any irradiation
18 information was fickle.

19 MEMBER SKILLMAN: Today you are saying it
20 has been overtaken by events? It really is not a
21 value-added feature?

22 MR. HARDIES: Right.

23 MEMBER SKILLMAN: I understand. Okay.
24 Thanks. Thank you.

25 MR. HARDIES: E2215, which is the one for

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 conduct of programs, provides some guidance on how to
2 take a program that is for a vessel that was originally
3 designed to have a 40-year surveillance program, and
4 it provides guidance on how to change it to a 60-year
5 or an 80-year program. And that is useful guidance.

6 And finally, E185 has eliminated the need
7 to include heat-affected zone specimens, and they don't
8 provide very much useful information. I think we are
9 going to consider eliminating the requirement for
10 existing programs to test those specimens when we
11 change Appendix H.

12 Also, that first line up there, we would
13 like to be clever in how we do Appendix H, so that we
14 can actually get future changes to the ASTM standard
15 edition accomplished by changing 50.55(a), which is the
16 codes and standards rule, rather than having to wait
17 30 years, in 30-year chunks, to try changing Appendix
18 H.

19 The last thing I want to bring up is there
20 is a requirement, once you pull a capsule, to test it
21 within 12 months. In the seventies, some plants would
22 leave them in the pool for a while. There was some
23 urgency to get data because it wasn't well understood.
24 The radiation happened a little quicker than had been
25 anticipated. And so, it was put in the rule, this

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 12-month requirement.

2 There is now enough information that we
3 don't really need people to provide the information
4 within 12 months. And there are very good reasons why
5 12 months is too short of a time. There's contracting
6 difficulties. There's more players involved in the
7 handling of a capsule now. And some of these capsules
8 have much higher fluence, and they have to sit in the
9 pool and decay a little bit, so that the shipping
10 containers have adequately-low dose rates to meet
11 Department of Transportation external surface dose
12 measurements.

13 So, the industry has asked us to extend
14 this. They send us extension requests. We review
15 them. We grant them. And all of that involves
16 resources that are better spent on higher-priority
17 things.

18 Appendix G and Appendix H were bundled
19 several years ago. When they are bundled, the staff
20 can do a prioritization of rulemaking. The staff did
21 and prioritized it high and began working on them.

22 Appendix G you are going to hear about.
23 This technical basis isn't ready, but it has been 32
24 years since last time the ASTM standard -- or it is 32
25 years out of date. So, we wanted to proceed with

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 rulemaking on Appendix H. Mike Case talked us into it.

2 And so, the way you do that is you ask the
3 Commission to direct you to do that. We did; they did.
4 And so, we are going to proceed on rulemaking. That
5 is the end of the bifurcation problems. I can retire.

6 And I have covered most of the next one
7 because -- if I go the right direction -- we know what
8 Appendix G is now. We have covered all of this.

9 And I am going to go to General Design
10 Criteria 31 again and note that the second criteria it
11 said was that you minimize the probability of
12 rapidly-propagating fracture. In the middle of the
13 nineties to the middle to late 2000s, NRR asked Research
14 to do some probabilistic fracture mechanics analysis
15 of pressured thermal shock events. They did. They
16 developed the FAVOR code. Mark will go into that a lot
17 today. And it was used to develop the technical basis
18 for issuing the alternate PTS rule.

19 Near the end of that it became apparent to
20 us that we could apply that same methodology for other
21 reactor vessel integrity issues or subjects, like
22 heatup and cooldown. So, NRR wrote a user need and
23 asked Research to evaluate Appendix G, evaluate
24 risk-informing Appendix G.

25 And Research developed a modification to

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 the FAVOR code. Industry has been a partner on reactor
2 vessel integrity research or a collaborator for many
3 years, and they took the FAVOR code and did enough
4 analyses to come up with a risk-informed alternative
5 to Appendix G that was published in MRP-250, which is
6 the Materials Reliability Program, Report 250.

7 And that was incorporated into the ASME
8 code in 2011 as an alternative to the Appendix G that
9 is in the ASME code. At that point we needed to do
10 confirmatory research. So, Research looked at it and
11 evaluated it, and the failure frequencies of the
12 risk-informed approach were higher than we expected,
13 higher than Research expected, higher than anyone
14 expected.

15 The failure frequencies for the current
16 Appendix G were higher than anyone expected, and the
17 risk was coming from small flaws rather than the large
18 flaws, which is very counterintuitive. A big flaw in
19 a stress structure should, of course, be more risky than
20 a little, tiny flaw in a stress structure. And because
21 it was counterintuitive, we have been pouring some work
22 to understanding the results, and that is where we are
23 now.

24 We did do enough of a scoping study to
25 determine there is no immediate safety issue, no

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

(202) 234-4433

(202) 234-4433

1 immediate need to have plants change the way they are
2 operating, and we are working to understand the
3 results. In the meantime, Appendix G is kind of on
4 hold.

5 At that point, I am going to turn it over
6 to Mark Kirk, who will describe the results in much more
7 detail.

8 MR. KIRK: Are there any questions at this
9 point before Bob gets away?

10 Thank you.

11 Okay. So, the next part of the briefing
12 concerns the research efforts that Bob alluded to. We
13 started in 2007 looking at Appendix G requirements for
14 normal operation. I am the sole guy who is sitting up
15 here, which means that I was not clever enough to walk
16 away.

17 But there are many other contributory or
18 guilty parties, depending on how you like to talk about
19 it. I think all of them are in the room today, all
20 except for Paul Williams. Gary Stevens, Eric Focht,
21 Mike Benson, who many of you on ACRS. He used to work
22 here. He is now a pleasure working with us. And John
23 Kusnick. And then, at Oak Ridge, of course, Terry
24 Dickson, Richard Bass, and Paul Williams as developers
25 of the FAVOR code.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 So, as an outline of what I would like to
2 cover in the next several hours is give you a little
3 bit of background and objective. Bob has started that
4 on the Appendix G project in general.

5 And for those of you who didn't suffer
6 through the alternative PTS rule, Bill can take a break
7 at that point. We will talk a little bit about the
8 probabilistic fracture mechanics code FAVOR, which is
9 going to be our primary tool in doing this assessment.

10 I will, then, talk about what were
11 identified on your agenda as Technical Issues 1 and 2
12 together, this being the shallow interdiameter
13 surface-breaking falls in the context of the FAVOR
14 cladding model.

15 And then, I think there is probably a
16 much-needed break, at least I hope.

17 And then, we will talk about Technical
18 Issue No. 3, which is boiling water reactor leak test.
19 I should say, as Bob has already alluded to, the main
20 focus of this presentation is to describe to you, and
21 hopefully, get your good comments and feedback on this
22 question of shallow surface breaking falls in the
23 cladding, because that is really the thing that is
24 driving our results. Everything else is a sideshow
25 after that.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 So, the discussion of the boiling water
2 reactor leak test is but one example of the challenges
3 that are presented when we consider this particular
4 class of flaws.

5 In case I drift off into geek-speak, you
6 have a secret decoder ring sitting at your pillow-side.
7 We talk about conditional probabilities of crack
8 initiation and failure. Those are probabilities
9 calculated by FAVOR, conditioned on the loading event
10 actually having occurred.

11 If you were to, then, weight them in terms
12 of the probability of that loading event having
13 occurred, they would become the through-wall cracking
14 frequency.

15 P-T, of course, means pressure temperature
16 limits, as calculated by the ASME code. And then,
17 there are two subsets of those. ASME current means P-T
18 limits calculated, I will say, the way we have always
19 done; whereas, the risk-informed alternative is the new
20 proposed way. It was developed in MRP-250 and codified
21 in the 2011 version of the code. And I will have a
22 graphic that explains better, I hope, what the
23 differences between those two limits are.

24 So, a little bit of background on the
25 Appendix G project. Bob covered most of this. We were

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 requested to look at this in 2007 by our colleagues in
2 NRR.

3 What we are looking at in total are all the
4 provisions of 10 CFR 50, Appendix G, which incorporates
5 ASME Section 100, Appendix G, by reference. So, that
6 effectively makes ASME Section 11, Appendix G, part of
7 federal law unless conditioned or excluded by 10 CFR
8 5055(a). And hopefully, that is the end of the
9 legalistic-type comments I have to make.

10 The joint provisions of what I will
11 abbreviate is Code of Federal Regulations G and ASME,
12 Appendix G. I don't know how they both became G.

13 MEMBER RICCARDELLA: That was
14 intentional.

15 (Laughter.)

16 MR. KIRK: Okay.

17 MEMBER RICCARDELLA: To avoid confusion.

18 (Laughter.)

19 MR. KIRK: I have learned something. Our
20 pressure temperature limits for normal operation,
21 which include normal heatup, cooldown, and leak test,
22 and that is where we are going to be focused on today.
23 That is the discussion.

24 However, the totality of this project,
25 which hopefully we will get another chance to talk this

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 Committee on, includes other requirements like minimum
2 temperature requirements of the flange, limits on
3 Sharpe upper shelf, and so on.

4 In the fullness of time, once we get this
5 detail wrung out, our project addresses all of these.
6 And hopefully, we will be talking to you about them at
7 some future date.

8 So, again, the risk-informed alternative
9 was developed by the industry and documented in a
10 Technical Report published in 2009. The industry was
11 using the FAVOR model as its representation of the
12 reactor pressure vessel. So, very similar to our
13 assessment approach.

14 In 2011, those recommendations were
15 adopted by the ASME code. And now, what we are talking
16 today at least in part is the staff's evaluation of some
17 of those recommendations.

18 Again, I said this. We are focusing on the
19 part of the model that is the most important, where
20 "most important" means giving us the
21 highest-calculated failure probabilities. And we are
22 using operating pressure leak tests as just one example
23 of the impact of the shallow through-cladding falls
24 and, also, to give you a comparison of the current
25 provisions of ASME to risk-informed ASME.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 So, finally, a graph, thank goodness. So,
2 our evaluation approach to P-T limits, our model of the
3 RPV is the probabilistic fracture mechanics code FAVOR,
4 which stands for Fracture Analysis of Vessels, Oak
5 Ridge.

6 This is the same code, well, I should say
7 this is the same code that was used, reviewed and
8 approved for use in the PTS re-evaluation effort that
9 eventually gave rise to 10 CFR 50.61(a). It has since
10 been augmented. At the time of the PTS re-evaluation,
11 which was mid-2000s, it only dealt with cooldowns. Now
12 it has been augmented to address heatups, and it has
13 also been augmented to address boiling water reactors,
14 which, of course, have a different radius-to-thickness
15 ratio than Ps. So, we needed to include other
16 influence calculations. But, basically, the failure
17 model, the same ideas hold.

18 So, our weighting conditions are twofold,
19 and I think that is shown by illustration. Let's just
20 focus on the cooldown. So, following the ASME Appendix
21 G limits, you are allowed to have a cooldown up to 100
22 degrees Fahrenheit per hour. And then, you plug that
23 temperature and time into the ASME equations, which
24 have a structural factor on the membrane load and assume
25 a quarter t flaw. And that allows you to calculate the

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 maximum allowable pressure as a function of time.

2 And this diagram illustrates the effect of
3 the risk-informed alternative that is now itself part
4 of the ASME code, which is -- I will leave out the
5 mathematics. That is in the reports, if you are
6 interested. But the net effect of the risk-informed
7 revision or alternative relative to current practice
8 is it requires a drop from full operating pressure at
9 an earlier in transient, but allows higher pressures
10 at the end of the transient. Obviously, at the end of
11 the cooldown, you need to be down to atmospheric
12 pressure. You are going to have a hard time unbolting
13 the head. These changes were of interest to the
14 industry in terms of increasing operability.

15 What we are doing in this analysis is our
16 loading follows these P-T limits, as established by the
17 Code of Federal Regulations and ASME Appendix G. So,
18 when I talk about an assessment of the current approach
19 or the risk-informed approach, that is something that
20 is dropping at a linear cooling rate and is following
21 this pressure curve.

22 This is something we recognized at the
23 beginning, and you will see it a little bit later. If
24 we overlay on these graphs an actual operational
25 cooldown or heatup, you will find out they don't hug

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 the curve. They don't really come anywhere close to
2 it, except down here in the low temperature regime, but
3 they are also protected by LTOP in that regime.

4 So, we recognized that following these
5 limit curves was a conservative approach. But we did
6 it for two reasons. One was we believed, based on the
7 rather large changes that we were able to adopt in the
8 PTS embrittlement limits, and since these are much
9 less-aggressive transients than anything in PTS, we
10 thought, well, we can have this small amount of
11 conservatism in there. Well, I shouldn't say "small".
12 We can have this conservatism in there without unduly
13 affecting the practicality of our results.

14 And also, it is kind of logical in that,
15 if we are evaluating, what we wanted to do is to evaluate
16 a change from the current approach to the risk-informed
17 approach, it is kind of natural I think to evaluate
18 cooldowns along the limits that are permitted by those
19 two approaches.

20 Also, I will note this is exactly the same
21 approach that was used by the industry in its
22 evaluation. They again assumed cooldowns or heatups
23 along these limits curves.

24 What we found out is things are a little
25 bit more complicated than that. Following this

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 approach, we got, as Bob alluded to, higher CPIs and
2 CPFs than expected. And so, one of the things we will
3 share with you today is also a modeling of cooldowns
4 along actual and plant procedural loadings. So, you
5 can see the effect of following something closer to what
6 really happens versus that which is allowed.

7 MEMBER RICCARDELLA: Mark, a couple of
8 questions.

9 MR. KIRK: Yes.

10 MEMBER RICCARDELLA: Refresh my memory on
11 LTOP.

12 MR. KIRK: The LTOP requirement is that
13 there be systems in place to ensure that the P-T limits
14 are respected. So, the words say you need to stay below
15 the curve.

16 Now you are more familiar with the actual
17 implementation of that than I am. You need to account
18 for valve errors and all sorts of things. So, the
19 actual setpoints may be considerably lower than the P-T
20 limits curve, especially in a single setpoint valve.

21 But the only written requirement that gets
22 weaved into the regulation is you just need to have a
23 physical system there to make sure that these curves
24 are respected.

25 MEMBER RICCARDELLA: LTOP is Low

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 Temperature over Pressure Protection?

2 MR. KIRK: Right.

3 MEMBER RICCARDELLA: Right?

4 MR. KIRK: So, there is generally an
5 LTOP-enabled temperature that says you have to turn on
6 that system once your RCS temperature goes below a
7 certain value.

8 MEMBER RICCARDELLA: And did you say that
9 when the industry did their analysis for the
10 risk-informed approach, they used FAVOR as well?

11 MR. KIRK: They used FAVOR, yes. So, we
12 are both using the same computational model. The only
13 significant difference is in our assumptions about the
14 flaw population.

15 In the industry approach, they used the
16 population of embedded flaws. They only used the
17 population of embedded flaws that was developed as part
18 of the PTS reevaluation project. So, that is lots and
19 lots, in any given simulated thousands of rather
20 smallish flows, but none of them breaking the surface
21 of the vessel, all of them fully embedded in the
22 ferritic steel.

23 In our assessment, we wanted to stay
24 completely consistent with the PTS evaluation. So, we
25 did that population of embedded flaws and, also, this

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 population of shallow-surface breaking flaws, which we
2 will be discussing in detail.

3 CONSULTANT SHACK: And both of those
4 populations come from 6817?

5 MR. KIRK: Correct. Those are both --

6 CONSULTANT SHACK: That hasn't changed?

7 MR. KIRK: No. No. And 6817, for those
8 of you that don't know, is the basis document developed
9 for us by PNNL with advice from an international panel
10 of experts as to what should be in those flaw
11 distributions. And I will talk a little bit about
12 that.

13 MEMBER BLEY: Mark, before you go ahead,
14 you don't have to answer me now, but when you talk about
15 favor, a couple of things I would like you to try to
16 point out as you go through it.

17 My familiarity with that dates back to when
18 the PTS work was going on, and I was involved in some
19 of the work on human modeling --

20 MR. KIRK: Uh-hum.

21 MEMBER BLEY: -- and on the
22 thermohydraulics.

23 MR. KIRK: Right.

24 MEMBER BLEY: FAVOR was being developed to
25 support that work --

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 MR. KIRK: Right.

2 MEMBER BLEY: -- or modified.

3 MR. KIRK: Right.

4 MEMBER BLEY: And I remember one thing
5 that troubled me a little bit at the time, and it was
6 what seemed to be a real strong sensitivity to what
7 appeared to be minor changes in timing or temperature
8 that led to very wildly-different predictions of the
9 likelihood of failure.

10 And the other thing I don't remember seeing
11 addressed was uncertainties in -- I think with respect
12 to flaws you think you are taking a conservative
13 position, as I am looking at the uncertainties in that.
14 Correct me if I am wrong on that.

15 And then, kind of associated with what
16 seems to be a sensitivity to small changes would be,
17 is there any approach to try to deal with the
18 uncertainties that are within the model as the
19 development continues and to the point it is now?

20 So, if you can address those as you go
21 forward or --

22 MR. KIRK: Okay. I think I would like to
23 take them on now because --

24 MEMBER BLEY: Okay.

25 MR. KIRK: -- otherwise I am likely to

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 forget them.

2 And I am not sure exactly what you are
3 referring to, if it came out of the HRA, or whatever.
4 In terms of sensitivities to small changes, in some
5 cases they exist. I will say I have personally wrung
6 it out enough in my mind to say they are in an errant
7 part of the model and, moreover, they are accurate.

8 MEMBER BLEY: Okay, that is what I was
9 getting at.

10 CONSULTANT SHACK: There are more of them
11 today.

12 MR. KIRK: And you will see even more of
13 them. I will highlight one example of that today,
14 based on that.

15 In terms of the uncertainties, what we have
16 done is -- well, we will talk about the flaw model as
17 an example. The flaw model was developed -- I am going
18 to try to go ahead to a slide, so I have something
19 meaningful to talk to.

20 I don't know where it is. There it is. I
21 am on slide 33, and we will go back to it.

22 The flaw model was developed based on a
23 number of different inputs, destructive and
24 non-destructive evaluation of the sections taken from
25 the PV rub vessel, welding simulations using the

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 PRODIGAL code, some exams done at Bettis Laboratories,
2 and expert elicitation done by Debbie Jackson and Lee
3 Abramson in the early 2000s.

4 All of that got mushed together into what
5 Bill was referring to, which is NUREG/CR-6817, which
6 gives the model to be used in FAVOR. Now we are
7 focusing on the shallow cladding flaws here, but this
8 accounts probabilistically for distributions
9 in-depth, aspect ratio, flaw size, and so on.

10 As we went through this, there was an
11 attempt to be -- if this doesn't make your head
12 hurt -- both realistic and conservative at the same
13 time, which is to say, if we felt like we had good
14 information, we tried to be realistic and sample
15 against it. However, when we ran up against
16 situations, as you inevitably do, where there wasn't
17 adequate information, we tried to be conservative.

18 The net effect of this, again, using flaws
19 as an example, is in any given vessel that is simulated
20 in FAVOR, it is simulated to have thousands of embedded
21 flaws. However, when you go out and do a vessel
22 exam -- and I will use my most current reference, which
23 is the exam of the Palisades vessel, which was just
24 submitted to the staff for review under 5061(a), I don't
25 have the exact count in my head, but they didn't find

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 thousands of flaws in or near their beltline welds.
2 They found more like dozens.

3 So, that is one example of where the
4 process we went through trying to be both realistic and
5 conservative, if you bounce it up against a datapoint
6 from an actual operating plant, you get a sense of where
7 we are.

8 There are lots of other areas in the model
9 where uncertainties, what I would say is uncertainties
10 are dealt with everywhere in FAVOR. Each and every
11 input, each and every submodel has been independent
12 assessed for its uncertainties.

13 In some cases, like say the distribution
14 of fracture toughness data, where the uncertainties
15 were large and we just knew or we knew through
16 sensitivity studies that they would be significant,
17 they are explicitly modeled through statistical
18 distributions --

19 MEMBER BLEY: For parameter
20 uncertainties?

21 MR. KIRK: Those are parameter
22 uncertainties.

23 MEMBER BLEY: Are there places where you
24 have addressed any areas where you have uncertainty in
25 the models, where you are not sure you have got the right

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 model?

2 MR. KIRK: Not quantitatively.

3 MEMBER BLEY: Okay.

4 MR. KIRK: A good example of that would be
5 the attenuation function through the vessel wall. We
6 know there is a model uncertainty there. There are
7 other models predicting many different things. We are
8 using a conservative model.

9 MEMBER BLEY: Conservative in the sense
10 of?

11 MR. KIRK: Conservative in that it doesn't
12 attenuate as much as other models do.

13 MEMBER BLEY: Okay.

14 MR. KIRK: As I would think we --

15 MEMBER BLEY: This is like the other areas
16 where you haven't directly addressed the uncertainty;
17 you have tried to put some bound on it and be
18 conservative?

19 MR. KIRK: Yes. Right.

20 MEMBER BLEY: Okay.

21 MR. KIRK: What I would say, we have looked
22 under every rock and tried to do the best job possible.
23 Where we can, we have incorporated it quantitatively
24 in the model.

25 MEMBER BLEY: I think you are dealing with

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 what I wanted. The first part at the time, I saw these
2 sensitivities to small changes, nobody had a good
3 answer to why things were jumping around.

4 MR. KIRK: Uh-hum.

5 MEMBER BLEY: But you have really dug into
6 it, and you are pretty confident in the models now, that
7 they are doing what you want them to do? There is not
8 glitch in the code.

9 MR. KIRK: Right. As an example, I mean,
10 just as one example -- we will get to Bill's
11 example -- is the lower bound of the fracture toughness
12 distribution, it has a zero percentile. And if you go
13 to the physics of cleavage fracture, there is a zero
14 percentile. You can get at that.

15 So, say you do an analysis at 10 EFPY. If
16 all the KFY values are below that zero percentile, you
17 have got zero failure probability. You ratchet it up
18 a little. You go from zero to 10 to the minus 9. That
19 is still a small number, but it is a huge percentage
20 change.

21 So, yes, there are -- I'll use Bob's words
22 again -- there are bifurcations in the model, and we
23 believe them to be real.

24 MEMBER RICCARDELLA: What about residual
25 stresses? Are they in there deterministically or --

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 MR. KIRK: Residuals?

2 MEMBER RICCARDELLA: -- or are they --

3 MR. KIRK: Residual stresses are in
4 there -- I don't like the word "deterministically".
5 So, I am going to say there is one residual stress
6 profile. It is not sampled.

7 MEMBER RICCARDELLA: That seems like a big
8 uncertainty.

9 MR. KIRK: Yes.

10 MEMBER RICCARDELLA: In similarly, the
11 clad to base metal residual stress?

12 MR. KIRK: Well, we will get to that.
13 With regards to weld residual stresses, I mean, they
14 have got to go through yield. It turns out in any of
15 our analysis they haven't made a big difference in the
16 calculated failure probabilities.

17 MEMBER RICCARDELLA: Well, you mean they
18 have to go through YIELD? I mean, they are cross-weld
19 heat-treated. They are less than YIELD, aren't they?

20 MR. KIRK: Yes, and that is what we are
21 using in the model.

22 MEMBER RICCARDELLA: Okay.

23 MR. KIRK: In terms of the clad residual
24 stresses, they are also tied up in the coefficient of
25 thermal expansion mismatch.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 MEMBER RICCARDELLA: Right.

2 MR. KIRK: That is a physical property.
3 That doesn't vary much at all.

4 MEMBER RICCARDELLA: Oh, no, I will bet
5 there is a big uncertainty in that. I know you took
6 it from a test. You took data from a test of
7 stress-free temperature.

8 MR. KIRK: Uh-hum.

9 MEMBER RICCARDELLA: But I will bet there
10 is variability in that parameter.

11 MR. KIRK: I think we are maybe getting a
12 little ahead of ourselves. In the PTS work we didn't
13 focus a lot on the cladding model and the shallow flaws,
14 simply because they didn't contribute a lot. You don't
15 look too hard at things that don't contribute.

16 What we will get to here is we now
17 understand much better why they didn't contribute in
18 PTS, why they are contributing here. And so, the
19 various aspects of that model are now being subjected
20 to a lot more scrutiny along some of the lines you are
21 getting at.

22 So, just a little history of FAVOR. It
23 goes back quite a ways. The FAVOR code first was named
24 FAVOR in 1995, but it finds its origins in PFM codes
25 dating back to the integrated PTS studies of the

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 eighties and Yankee Rowe of the 1990s. In the
2 timeframe of 1999 to 2005, there were significant
3 developments toward the PTS project; as I have tried
4 to reflect, a very thorough evaluation of all models;
5 coding for both aleatory and epistemic uncertainties,
6 incorporation of warm pre-stress.

7 Since 2009, we have expanded it to address,
8 as I said, BWRs and heatups. And 2012 is the most
9 recent release, and I think you can expect to see
10 another release in 2015.

11 In terms of review and V&V, again,
12 throughout the PTS reevaluation project, it felt like
13 every time I turned around there was a review. There
14 were thorough internal reviews of the code and all its
15 models, including those done by our colleagues in our
16 industry. There were thorough reviews by this group.
17 There was explicit V&V, as published in NUREG-1795, and
18 there was also review by six external experts that we
19 explicitly contracted with and paid to review our work.
20 And that is all documented in Appendix B of NUREG-1806.
21 And they found some things that they found lacking in
22 the code, and we updated the code to address those
23 things.

24 Since that time, since the expansion of
25 FAVOR to address BWRs and heatup, it has again been

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 V&Ved by Southwest Research Institute. And also, I
2 will just note in passing that, along the way, papers
3 providing benchmarking of the K solutions to ABAQUS,
4 which we consider the gold standard, have been
5 published throughout the years to make sure those are
6 correct.

7 Just a very high-level view of FAVOR, what
8 we are going to be talking about mostly is what happens
9 in the middle part, the FAVPFM or Probabilistic
10 Fracture Mechanics module. There is also a load
11 generator that puts the transients into FAVOR in a
12 post-processor that multiplies them by event
13 frequencies on the way out. But those two parts, by
14 and large, were not used. Those were developed and are
15 an inherent part of the PTS evaluation. They weren't
16 really used here because on the front end, as I
17 indicated, the loading follows the allowed P-T limit.
18 So, it is a much simpler loading case than this library
19 of cooldowns that we had for PTS.

20 And at the other end, there is no event
21 frequency weighting. There could be. There might
22 need to be. But that is not a part of the briefing
23 today.

24 So, mostly, we are in the middle in the PFM
25 module that, given a load input and embrittlement

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 conditions with distributions, of course, and flaw
2 conditions calculates conditional probabilities of
3 crack initiation and conditional probabilities of
4 vessel failure.

5 Just internally to the code -- and if
6 people are interested in details, there are folks on
7 the side who can do much better than me -- it is a pretty
8 brute-force PFM code. There is no important sampling.
9 It is just a Monte Carlo simulation inside a nested loop
10 structure. So, on the outside we simulate RPVs.
11 Then, we go through flaws, transients. We don't use
12 that here because we have essentially got one transient
13 to run. We go through the time of the transient. And
14 then, at each time in the transient you are calculating,
15 does the crack initiate, does the crack initiate, does
16 the crack initiate?

17 If the crack initiates, then you run a
18 simulation of does the crack arrest, does the crack
19 arrest, does the crack arrest? At that time, if it
20 arrests, you go back into the initiation loop and
21 continue.

22 This diagram -- and again, we can get into
23 whatever level of detail you want, but I have stripped
24 out all the details -- shows you the major modules in
25 FAVOR. There is a flaw distribution module, a

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 neutronics model that does both the distribution of
2 fluences around the vessel. I have taken account of
3 the different distances from the core and, also, the
4 extenuation through the vessel wall.

5 Then, you have got the crack initiation and
6 through-wall cracking model, which addresses both
7 crack arrest and the possibility of ligament failure
8 by ductile overload.

9 We have already talked about
10 uncertainties. In all cases we have looked at them.
11 We have decided explicitly how to treat them. A lot
12 of them are modeled explicitly, numerically. Some are
13 represented as constants. In some cases, because we
14 believe them to be less significant, like the vessel
15 is imperfectly round. It is not the same radius all
16 the way around. That is not modeled. It probably
17 won't be modeled.

18 Conversely, the welding residual stresses
19 are also modeled as a one-size-fits-all distribution.
20 That might be modeled in the future. We will see.

21 And also, like I said, there are areas
22 where, if we didn't feel like we had enough data to
23 construct a credibility stochastic model, we adopted
24 a conservatives model.

25 MEMBER BLEY: Thinking back to what you

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 showed us about the PTS runs and what you are doing here,
2 in the PTS the plant is doing something. It puts you
3 through a thermal cycle over time.

4 MR. KIRK: Right, right.

5 MEMBER BLEY: And you can see what is
6 happening over time. Here you are using the pressure
7 temperature limit curves.

8 MR. KIRK: Uh-hum.

9 MEMBER BLEY: Do you apply that instantly?
10 Or it seems to me that what happens depends on rates
11 in approaching and exceeding those curves. So, how do
12 you handle that?

13 MR. KIRK: Well, we follow, in most of our
14 analysis, we follow a linear ramp cooldown.

15 MEMBER BLEY: Okay.

16 MR. KIRK: A hundred degrees Fahrenheit
17 per hour is the maximum allowed cooldown. We have also
18 done 75 and 50.

19 MEMBER BLEY: Okay. So, that curve is on
20 the linear --

21 MR. KIRK: Is accounted for, yes.

22 MEMBER BLEY: Okay. Fair enough.

23 MR. KIRK: Yes, yes.

24 MEMBER SKILLMAN: So, Mark, how do you
25 handle the steamline break where you cool down much

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 faster than 100 degree Fahrenheit an hour?

2 MR. KIRK: We cool down much faster than
3 100 degrees Fahrenheit per hour. But that is not a part
4 of this analysis.

5 In PTS, we did steamline breaks. We did
6 large-break LOCA, small-break LOCA, and in all cases
7 I think we followed the advice of Dennis Bley.

8 MEMBER SKILLMAN: On some things.

9 MR. KIRK: On some things.

10 (Laughter.)

11 MEMBER SKILLMAN: But they also looked at
12 you are injecting cold water. You get mixing. So, the
13 thermohydraulics guys did a lot of analysis to see --

14 MR. KIRK: Right, right.

15 MEMBER SKILLMAN: -- if you get mixing.
16 What if you don't get mixing? And each of those
17 possible timelines got set over to the --

18 MR. KIRK: The transients for PTS, which
19 included steamline break and many, many other things,
20 were much more complex than what we are modeling here.

21 MEMBER SKILLMAN: I see. Thank you.

22 MR. KIRK: Yes.

23 MEMBER SKILLMAN: Thanks.

24 MEMBER BLEY: The last question along the
25 line I started. It would seem to be in real-world

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 transients that are driven not by a ramp, if you get
2 arrest, it might be possible, if the transient changes
3 nature, that you could reinitiate the crack.

4 MR. KIRK: Yes.

5 MEMBER BLEY: But here I don't think that
6 arises, or does it?

7 MR. KIRK: It depends on, well, I have got
8 one picture of a transient from a plant record, and it
9 has got a repressurization. So, given adequate K, it
10 could. I mean, that is not -- I am not sure I want to
11 say it is typical or not. I am not plan ops guy.

12 But, yes, sometimes --

13 MEMBER BLEY: But it is primarily just run
14 against assumed cooldown rates and --

15 MR. KIRK: Yes.

16 MEMBER BLEY: -- and heatup rates?

17 MR. KIRK: Yes.

18 MEMBER BLEY: Rather than looking at those
19 kinds of situations that --

20 MR. KIRK: As I alluded to, our initial cut
21 at this is we are going to do something simple and,
22 admittedly, conservative or bounding. I realize those
23 words have different interpretations to different
24 people. So, I don't like to throw them around, but I
25 do.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 What we thought was we would do that and
2 we would calculate probabilities that were very low,
3 and it would be easy. It turns out for the shallow
4 surface breaking flow we are not calculating that. So,
5 we will kind of get onto that.

6 CONSULTANT SHACK: Are you going to tell
7 us what you got when you did the whole distribution?

8 MR. KIRK: Uh-hum. Of embedded flaws?

9 CONSULTANT SHACK: Embedded.

10 MR. KIRK: Yes.

11 CONSULTANT SHACK: And surface-breaking
12 flaws?

13 MR. KIRK: Right.

14 CONSULTANT SHACK: I mean, I know what the
15 results were when you don't have the surfaces-breaking
16 flaws from MRP-250.

17 MR. KIRK: Right.

18 CONSULTANT SHACK: But I haven't seen
19 anywhere where somebody computed a number.

20 MR. KIRK: It's here. It is coming up.
21 Yes.

22 CONSULTANT SHACK: Where do you go?

23 MEMBER SKILLMAN: Mark, would you go back
24 to 29 just for a second?

25 MR. KIRK: No, there you don't go.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 (Laughter.)

2 MEMBER SKILLMAN: A crazy question, but I
3 have got to ask it. Most of the time we read left to
4 the right, upper left to lower right. This is right
5 to left. Is there any significance to that.

6 MR. KIRK: I was in an alternative
7 universe when I --

8 MEMBER SKILLMAN: Okay. That's fine. I
9 was just curious.

10 MR. KIRK: No, no.

11 MEMBER SKILLMAN: Thank you. That's all
12 I had. Thanks. Thank you.

13 CONSULTANT SHACK: Now it bothers me.

14 (Laughter.)

15 MR. KIRK: Okay. So, Bill, here is a
16 result just for a spectrum of surface-breaking flaws
17 with different crack depth-to-thickness ratios.

18 CONSULTANT SHACK: Yes, you showed me that
19 one. What I am more worried about is the absolute
20 probability. This is conditional in having one of
21 those flaws.

22 MR. KIRK: No, no, no. No, no. This is
23 conditional --

24 MEMBER SKILLMAN: On having the
25 transient.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 MR. KIRK: This is conditional on -- okay,
2 maybe this is subject to interpretation. So, I will
3 tell you what this is.

4 Based on NUREG/CR -- you remembered the
5 number, and I didn't.

6 CONSULTANT SHACK: 6817.

7 MR. KIRK: 6817. 6817 tells us that,
8 based on all of that destructive and non-destructive
9 evaluation, the PRODIGAL runs and the expert opinion,
10 that the best advice we could get at that time -- and
11 I also point out there has not been a lot of development
12 since then, so it might still be the best advice, is
13 we should be simulating .0037 surface-breaking flaws
14 per square foot of ID real estate. That doesn't sound
15 like a lot, but when you consider the amount of ID real
16 estate in a PWR, or a BWR, you get between two and four
17 flaws.

18 CONSULTANT SHACK: Per vessel?

19 MR. KIRK: Per vessel.

20 CONSULTANT SHACK: Uh-hum.

21 MR. KIRK: So, this is reflecting, I
22 think, in this particular vessel it was two flaws. So,
23 that is two flaws per vessel. But the other thing you
24 need to realize is those flaws aren't ceded
25 preferentially at the worst location. Every time

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 FAVOR runs it says, oh, here's my two faults for this
2 vessel; throw them at the wall.

3 Well, you know the fluence distribution
4 inside a reactor. Most of those areas are essentially
5 unembrittled. So, a lot of times those two flaws go
6 to a spot where there is adequate toughness, no failure
7 probability whatsoever.

8 MEMBER RICCARDELLA: And not always in a
9 weld, right?

10 MR. KIRK: Not always in a weld, no. No.

11 MEMBER RICCARDELLA: Rarely in a well,
12 right?

13 MR. KIRK: I mean, this is now -- PWR Plant
14 A is codeword for a weld-limited plant. So, in this
15 plant, only about 2 percent of the ID area has any
16 significant embrittlement at all. Most of it is banal.

17 So, two flaws per vessel based on .037 per
18 square foot of ID area, randomly ceded into each vessel.
19 Do the FAVOR runs until you converge, and that is the
20 CPF you've got.

21 So, I am going to say all models can be
22 improved, and we all recognize that. But I am going
23 to say it is conditional only on having that transient
24 occur.

25 CONSULTANT SHACK: Okay. I didn't

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 understand how you did that calculation.

2 MR. KIRK: Yes. Yes. And so, what we
3 see -- and this is sort of a launch point -- is I think
4 Bob said, well, it is counterintuitive to think that
5 this big flaw that is two inches deep could have a lower
6 failure probability than this itty-bitty flaw.

7 MEMBER RICCARDELLA: But if you did the
8 analysis right, on the big flaw you would look at K at
9 all the points along this cracked surface. And when
10 you got close to the cladding, you would have a higher
11 K. You know, the analysis of the big flaw only
12 considers the deepest point, right?

13 MR. KIRK: That's correct. That is
14 correct.

15 MEMBER RICCARDELLA: So, it is really an
16 artifact of the big flaw analysis --

17 MR. KIRK: Well, I mean, yes, we talk about
18 this, that the small, shallow flaws, or as one of my
19 colleagues in the industry has called it, an
20 inconveniently-sized flaw, which is a name I like, yes,
21 given this model calculated that way, calculating only
22 the K at the deepest point, you get a higher failure
23 probability.

24 Maybe the more significant thing is just
25 simply the number. We are in the 10-to-the-minus-4 or

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 10-to-the-minus-3 region. Whereas, we weren't
2 anywhere close there in PTS. So, we said, again, this
3 part of the model now needs some more investigation to
4 see if we believe it.

5 MEMBER RICCARDELLA: The guidance that
6 you were using for the shallow flaw distribution --

7 MR. KIRK: Uh-hum.

8 MEMBER RICCARDELLA: -- they say
9 surface-breaking, but were they all touching on the low
10 alloy steel like this is?

11 MR. KIRK: Yes. Yes. What the guidance
12 was was that, in fact, in the destructive
13 examinations -- it is probably too far to go to
14 that -- in the destructive examinations of the PV rough
15 vessel, which was primarily the basis for the .0037
16 value, they looked at 47 square feet of cladding. In
17 that 47 square feet of cladding, they did not find a
18 flaw that fully penetrated the cladding. They found
19 one that was about a third of the way through, one that
20 was about two-thirds of the way through.

21 But now, here is where the expert judgment
22 part comes in. The judgment was, okay, 47 square feet,
23 that is my table and your table, but relative to the
24 ID area of a PWR or a BWR, that is about 2 percent.
25 Relative to all the cladding in the fleet, that is like

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 .05 percent.

2 The judgment was, based on that group at
3 that time and that evidence, that wasn't sufficient
4 information for them to say no through-clad flaws ever.
5 So, they took that information, combined with others,
6 and I am simplifying -- we really need to go to the
7 report -- to say, to give us the guidance that we should
8 have .0037 or, basically, two flaws per vessel.

9 MEMBER RICCARDELLA: Okay. That is a
10 pretty big extrapolation, what he is saying.

11 (Laughter.)

12 CONSULTANT SHACK: Well, now that flaw
13 distribution is dependent on depth. So, you get
14 different depths. You know, they predict flaws that
15 just come up to the surface and shallower flaws. I
16 mean, it is --

17 MR. KIRK: So, we are not simulating the
18 shallower ones --

19 CONSULTANT SHACK: Right.

20 MR. KIRK: -- because they are all in
21 stainless steel?

22 CONSULTANT SHACK: In stainless steel. I
23 mean, so he has set the depth so that he only looks at
24 that.

25 MEMBER RICCARDELLA: I understand, but in

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 the particular vessel you analyzed to get this data,
2 you had none of those --

3 CONSULTANT SHACK: Well, I mean, they --

4 MEMBER RICCARDELLA: -- in the 47 square
5 feet that you measured, yes.

6 CONSULTANT SHACK: They had expert
7 judgment because they did PRODIGAL simulations, which
8 gave them even lower numbers. So, I think they would
9 argue that that number is conservative, I believe.

10 MR. KIRK: Well, like I answered in answer
11 to Dr. Bley's question, the intent is, when you don't
12 have enough information, be conservative. The
13 slippery slope issue I think we have got. Quite
14 frankly, at the time I argued against, I personally
15 argued against including any surface-breaking flaws.
16 And I was told no by the experts, no by this Committee,
17 and no by the international committee.

18 CONSULTANT SHACK: But you convinced the
19 MRP.

20 MR. KIRK: Well, I'm going to send out a
21 job app.

22 (Laughter.)

23 Anyway --

24 CONSULTANT SHACK: I am just saying I
25 think, if we wish to reassess that -- and that is a

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 perfectly legitimate decision -- I think we need, we
2 are obligated to bring new information into this. Just
3 getting a different group of experts together and
4 saying, "I'm going to look at the same information,"
5 and conveniently come up with a different number
6 because it solves my problem, that is not a good
7 process. We need to find other information.

8 MEMBER RICCARDELLA: But, understand, for
9 PTS I think it was a "No, never mind," right? And for
10 this problem, it's controlling.

11 MR. KIRK: Well --

12 MEMBER RICCARDELLA: So, it is something
13 you ought to look at.

14 MR. KIRK: Well, for PTS, it turned out to
15 be a "No, never mind," but there was significant wailing
16 and gnashing of teeth --

17 MEMBER RICCARDELLA: Yes.

18 MR. KIRK: -- at the beginning from our
19 colleagues in the industry who said, "Oh, geez, you are
20 putting in surface-breaking flaws. You're going to
21 kill us."

22 It turned out -- I keep wanting to go to
23 some future slide -- but we now understand why they are
24 not controlling in PTS and they are here. But you're
25 right, they are important here and they deserve further

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 scrutiny. All I am saying is, to further scrutinize
2 it, we need to bring in new evidence to get a new
3 answering. Just looking at the old evidence and coming
4 up with a different answer is I think not a good process.

5 CHAIRMAN BALLINGER: Going forward, like
6 Peter was saying, you are going to treat the K
7 distribution around the flaws in a more rigorous way?
8 No?

9 MR. KIRK: No. No.

10 MEMBER RICCARDELLA: They don't honorize
11 that big flaw in this process. I am saying there really
12 isn't the non-intuitive thing that they were talking
13 about because, if you honorize that big flaw
14 completely, you wouldn't come up with it being less
15 harmful than a smaller flaw.

16 CHAIRMAN BALLINGER: Certainly, if the
17 NRR, if we did a point-by-point K evaluation all around
18 this, it would certainly increase the calculated
19 probabilities, especially near the surface. I mean,
20 if that conveniently made these numbers the same as
21 these, fine. So, there is not a quarter t flow in the
22 vessels. I think we all agree on that.

23 MEMBER RICCARDELLA: No, I am saying, if
24 you did the deterministic analysis and you did the
25 point-by-point --

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 CHAIRMAN BALLINGER: I understand.

2 MEMBER RICCARDELLA: -- you would come out
3 with a worse result than what is commonly used as the
4 deepest point analysis. But that is just a side point.

5 CHAIRMAN BALLINGER: Yes.

6 MEMBER RICCARDELLA: I mean, what is
7 really killing us here is those numbers up there on E
8 to the minus 3, E to the minus 4. I mean, you want to
9 be below E to the minus 6 for a vessel. So, we have
10 to look at the things that are driving those numbers.
11 And I think what it is is the small flaws, right?

12 MR. KIRK: Yes. Yes. So, we will get to
13 that.

14 So, given all that has been said, we
15 commissioned Oak Ridge to do a detailed, I'll say
16 reevaluation of the basis for the shallow-flow model
17 and the basis for the cladding stress model. Really,
18 those are the two things that are contributing.

19 They prepared this Oak Ridge Technical
20 Memo. I think that was sent to the Committee for your
21 review.

22 So, the next group of slides is going to
23 be an attempt to distill all that down to points that
24 might make you interested to read it in your spare time.

25 MEMBER RICCARDELLA: I don't think I got

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 this.

2 MR. KIRK: Yes.

3 MEMBER RICCARDELLA: I did?

4 MR. KIRK: Yes.

5 CONSULTANT SHACK: It doesn't say Oak
6 Ridge. We have sort of got a preliminary version of
7 it, I think.

8 MEMBER RICCARDELLA: Chris, will you
9 resend that to me, please? Thank you.

10 MR. KIRK: Okay, and we will make sure you
11 have the right version.

12 So, in the report is the discussion of the
13 basis for having these flaws, which we have, I think,
14 mostly covered. The stress is generated by the
15 cladding, and the probability results, and I am just
16 going to go through those here as well.

17 Okay. We have talked about this. So, I
18 think we have covered that. In the Oak Ridge TM they
19 reviewed the information in CR-6817 and operating
20 experience of IGSCC in two BWRs.

21 This is my summary, and I will stand by it.
22 There really hasn't been much evolution of the state
23 of knowledge of the existence or non-existence or
24 density of these types of flaws since the NUREG/CR was
25 completed, at least not that we are aware of.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 CONSULTANT SHACK: But, coming back to
2 Dennis and John, who believe in model uncertainty and
3 that, you would get different results if you weighted
4 perhaps the plottable results in 6817 heavier than some
5 of the other results.

6 MR. KIRK: Yes. Yes.

7 CONSULTANT SHACK: So, there is a question
8 of how you evaluate even the data that you had then.

9 MR. KIRK: Yes.

10 CONSULTANT SHACK: And you took a
11 conservative approach at that time because --

12 MR. KIRK: Right.

13 CONSULTANT SHACK: -- because, as you
14 said, nobody is ever going to shoot you for the
15 conservative approach if you can live with the answer.

16 MR. KIRK: Right. So, where we are now
17 is, based on the NUREG and the Oak Ridge TM, right now
18 the staff finds the model acceptable. Note the staff
19 doesn't find the model perfect. It doesn't find the
20 model even maybe realistic. That word hasn't been
21 used, either. It is just that we don't have anything
22 better right now.

23 And certainly, as Dr. Shack points out,
24 different weightings of information could lead to
25 different results. But I think the way I would put this

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 is, based on the evidence available right now, the staff
2 is uncomfortable saying, absolutely, no, we can exclude
3 these type of flaws from our probabilistic model. We
4 don't think that is a defensible position.

5 As I mentioned, the industry's model
6 supporting the risk-informed provisions do not
7 consider shallow surface-breaking flaws in MRP-250,
8 which, if you don't have a copy, we should get you one.
9 They explain their rationale for that, which has to do
10 with high-fabrication standards that were applied to
11 nuclear vessels, inspections and other factors.

12 So, here is another group of experts,
13 well-respected engineers in their field, who have
14 looked at similar information and said, "No, we feel
15 comfortable excluding it."

16 MEMBER RICCARDELLA: Does it require
17 actual destructive examination to come up with this
18 kind of data, I wonder. I mean, you looked at basically
19 50 square feet of cladding. And your assumption, the
20 .0037 is one flaw per 270 square feet, say 250 square
21 feet.

22 MR. KIRK: Right.

23 MEMBER RICCARDELLA: So, if we look at
24 five more vessels -- but what about all the vessels that
25 are out there? Haven't there been in-service

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 inspections? Don't they do some P-T exams on those?

2 MR. KIRK: Part of the problem is
3 that -- and I realize I am talking to somebody that knows
4 a lot more than me, so I might be about to say something
5 totally wrong -- but the ASME inspection volume isn't
6 anywhere close to the whole idea of the vessel, you
7 know. So, you are only getting the area in the well.

8 MEMBER RICCARDELLA: Yes, and that is the
9 volumetric. But I think there are some P-T inspection
10 requirements.

11 CONSULTANT SHACK: Well, that is part of
12 the argument for the MRP-250, is that you do the P-T
13 requirements when you are fabricating the vessel.
14 Therefore, at that point you do the P-T on the whole
15 vessel. You don't see any. And so, their argument is
16 that you are not likely to be generating these cracks
17 in-service and you have inspected it completely. So,
18 again, there is an argument for why it is a very low
19 number.

20 And I think everybody agrees that it is a
21 low number.

22 MEMBER RICCARDELLA: You are talking
23 about how low?

24 CONSULTANT SHACK: It is just how low is
25 low here, it comes down to it. So, yes, the P-T that

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 you have done as part of your quality control would
2 suggest that there is none, but --

3 MEMBER RICCARDELLA: Right. I think
4 there is also some in-service cladding exams that are
5 done, you know. Maybe someone --

6 CONSULTANT SHACK: I wouldn't want to be
7 the guy to do them.

8 (Laughter.)

9 MEMBER RICCARDELLA: Huh?

10 CONSULTANT SHACK: I will go back and look
11 that up. I will go back and look. I think originally
12 we wrote that into Section 11, you know, back in the
13 1970s. Now whether that survived or not, I don't
14 remember. Originally, we did have patches of cladding
15 that needed to be examined.

16 MEMBER RICCARDELLA: Okay. But, again,
17 examining patches of cladding, when we are talking at
18 the levels that we are at, are going to -- you have to
19 look at a lot of patches.

20 CONSULTANT SHACK: Add them all up. All
21 the vessels that have been inspected in 30 years, that
22 could be a lot of square inches or square feet.

23 MR. STEVENS: This is Gary Stevens, Office
24 of Research.

25 The Appendix 8 exams that are being done

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 on vessels for Section 11, PDI exams, aren't capable
2 of detecting a flaw of the size that is being postulated
3 here. So, the serious exams you are talking about
4 would provide limited information regarding flaws of
5 this size.

6 MEMBER RICCARDELLA: The ultrasonic
7 exams?

8 MR. STEVENS: Correct.

9 MEMBER RICCARDELLA: At one time we had
10 requirements in there to do ID surface exams.

11 MR. STEVENS: I will check it out.

12 MR. KIRK: Okay. So, now we are going on
13 to a description of the FAVOR cladding stress model.
14 So, from a stress analysis perspective, it is just
15 simple 1-D, axisymmetric finite element model, which
16 I am going to kind of skip over the details because it
17 is pretty vanilla.

18 The main aspect of this is that the
19 cladding effects get taken up in this Tref value, also
20 sometimes referred to as the stress-free temperature.
21 In FAVOR we have determined Tref from measurements,
22 which I will describe in the next slide.

23 So, what was done -- and this dates back
24 to the late 1990s -- is a block of vessel steel was taken
25 out of, Richard, PVRUF? PVRUF. And four fiducial

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 marks were placed on the cladding. And then, the base
2 metal was machined away, which, then, led to a
3 relaxation of the tensile stresses in the cladding.
4 So, the cladding contracts. And then, based on
5 putting -- those fiducial marks were measured as the
6 machining was taking place, which would then likely to
7 provide an input to a finite element analysis that
8 allowed us to determine 21.3 ksi tensile stress in the
9 cladding and 70 degrees Fahrenheit, due to the
10 differential and the thermal expansion between the
11 cladding and the ferritic steel. Put that into an RPV
12 model, and you come up with the value of the stress-free
13 temperature. So, that is the temperature at which the
14 cladding is in a zero-stress state.

15 As you point out, certainly, we are not the
16 only -- by "we," I mean actually Oak Ridge -- are not
17 the only ones to make these type of measurements of
18 cladding residual stresses. And the value in the 20s
19 of ksi is very consistent with other measurements and
20 simulations that have been done worldwide.

21 So, again, there could be differences in
22 detail. I don't think there are differences in large
23 numbers.

24 MEMBER RICCARDELLA: Could this go in as
25 a random variable?

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 MR. KIRK: It could go in as a random
2 variable if you had a basis on which to sample. Right
3 now, it goes in as a single variable.

4 MEMBER RICCARDELLA: I mean, have you done
5 a sensitivity study?

6 MR. KIRK: Yes, we have. We tried
7 dropping the stress-free temperature to the point that
8 the problem went away, if you will. And I can't
9 remember the exact number, but that gives us a
10 stress-free temperature in the low 200 range. It is
11 just too far away to be credible. So, yes, we have
12 tried that, and that doesn't help us out.

13 But the thing I want to draw the
14 Committee's attention to is what this says is that the
15 temperature during a heatup or a cooldown where you are
16 the most different from the stress-free temperature,
17 which if you go back to the equation is where you are
18 going to have the largest sigma theta theta, is at room
19 temperature. So, this is saying you get the maximum
20 stress in the cladding, and therefore, the maximum
21 applied driving force on any flaws that you postulate
22 in the cladding when the RPV is cold, when the RPV is
23 sitting at ambient temperature.

24 MEMBER RICCARDELLA: Or shut down.

25 (Laughter.)

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 MR. KIRK: I didn't want to go through my
2 simulation again. Sorry about that. So, we said.

3 So now, depending on the specific flaw or
4 cooling rate in geometry, that means that the peak K
5 for the transient can occur at the very end of the
6 transient. Here we are focused on cooldown.

7 So, you put in a linear ramp along the
8 cooldown from operating temperature to ambient end
9 temperature, say prescribed at the limiting cooling
10 rate of the curve, which is 100; churn that through the
11 K_{1c} equation in the code. You are allowed the maximum
12 pressure versus time.

13 And then, use that to calculate the K's for
14 the small flaws, and it falls into one of two
15 categories. Either you get a peak K here at the end
16 of your pressure hold phase, because the pressure
17 contribution is, of course, constant here. The
18 thermal stress is steadily rising. As soon as the
19 pressure drops, then the total K drops. But the
20 thermal contribution continues to rise, especially the
21 contribution of the cladding. And in some cases, in
22 fact, in a significant number of cases, you get
23 situations where the peak K, and therefore, the time
24 during the transient that is controlling the failure
25 probabilities occurs at the very end.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 That is what all of these are going to look
2 at. The numbers will be different, but the curves will
3 be the same. And, of course, if that peak K is above
4 the minimum fracture toughness, which it frequently is
5 because the K, just due to the cladding alone, is often
6 right below the minimum fracture toughness on the lower
7 shelf. You get significant failure probabilities that
8 we have seen.

9 MEMBER RICCARDELLA: Excuse me. What
10 caused the pressure to go up at the very end?

11 MR. KIRK: Oh, that is just because you
12 stopped cooling -- really, I chop this illustration off
13 here -- because you stopped cooling, you would be
14 allowed to have more pressure.

15 MEMBER RICCARDELLA: Okay.

16 MR. KIRK: But it turns out that the K
17 drops. So, I should have raised that. That is
18 meaningless; the transient is over.

19 MEMBER RICCARDELLA: And the ambient you
20 are assuming is?

21 MR. KIRK: Seventy.

22 MEMBER RICCARDELLA: Seventy?

23 MR. KIRK: We have done sensitivity
24 studies on that, and that didn't help us, either.

25 MEMBER RICCARDELLA: It didn't help?

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 MR. KIRK: No. It changes things. Yes,
2 it changes things, but you are changing your failure
3 probabilities around. It is not dropping them to zero.

4 MEMBER RICCARDELLA: When we refuel, do
5 you really come down to ambient temperature?

6 MEMBER SKILLMAN: Well, yes, if you
7 offload, you come down to the temperature inside
8 containment. And depending on when you are doing your
9 shutdown and refuel, you can come on down to 85 degrees
10 Fahrenheit, 80, 75, 70. It depends on what the
11 containment temperature is.

12 MEMBER RICCARDELLA: During the
13 refueling.

14 MEMBER SKILLMAN: During the refueling.
15 You know, if you do an offload, once you cool down --

16 MEMBER RICCARDELLA: But this analysis, I
17 mean, doing refueling is the problem. Right? I mean,
18 am I right?

19 MEMBER BLEY: You're not wrong.

20 CHAIRMAN BALLINGER: You're not
21 pressurized.

22 MEMBER RICCARDELLA: I know, and the
23 pressure is zero.

24 MR. KIRK: The big point is this is not a
25 pressure-driven problem. As you will see when we get

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 to the leak test, I can set the pressure to zero and
2 I still have an issue.

3 MEMBER BLEY: Of course, now you've got
4 the head off. So, it is a different vessel.

5 (Laughter.)

6 But I'm surprised.

7 (Laughter.)

8 MEMBER RICCARDELLA: I mean, a whole lot
9 of vessels sit around for a lot of time, and none of
10 them are broken yet.

11 (Laughter.)

12 MR. KIRK: I should say we did do a
13 sensitivity study on T ambient. We had data for 50
14 cooldowns. And so, we took a distribution off that
15 that ranged from -- and this was a year ago, so my memory
16 is probably bad -- I think at the low end it was 50;
17 at the upper end it was 100.

18 And, yes, it had an effect. At the upper
19 end it didn't make it go away, but certainly there were
20 also data for end temperatures lower than the ones we
21 were using.

22 MEMBER RICCARDELLA: Lower than 70?

23 MR. KIRK: Lower than 70.

24 MEMBER RICCARDELLA: Could be.

25 MR. KIRK: Yes.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 MEMBER RICCARDELLA: Could be.

2 CONSULTANT SHACK: Chicago.

3 MEMBER RICCARDELLA: Kewaunee.

4 MR. KIRK: So now, I am going to take you
5 through some of the things we have done to try to
6 critique, and you are reminding me of things that we
7 have done that maybe I should have shown you some slides
8 on, critiqued different parts of this model.

9 So, first off, well, we have an LEFM model.
10 We wanted to go back and, just as a check -- we have
11 done it before, but to be thorough -- compare the LEFM
12 K solution in FAVOR, which uses 10 nodes through the
13 thickness, to an LEFM solution using ABAQUS, which I
14 think just in my little picture there is more than 10
15 nodes.

16 And the ABAQUS LEFM and the FAVOR track
17 reasonably well. I am showing you results here for an
18 a/t of .05. It turns out .05 is an interpolated result
19 in FAVOR. When we did the comparison for an a/t where
20 it is not an interpolative result, you couldn't see one
21 curve on top of each other. So, as we kind of knew going
22 in, we benchmarked FAVOR to ABAQUS LEFM before, and we
23 are getting the same result.

24 The next step was to look at EPFM to kind
25 of touch on the effects of stress relaxation, because

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 this is a secondary stress. And you can see here, up
2 to the first peak, actually, the EPFM is a little bit
3 higher than FAVOR is predicting. But, when you get to
4 the second peak that is controlling everything, the
5 EPFM calculated K, due to the yielding and the
6 relaxation in the cladding, is about 13 percent below
7 FAVOR. So, there is a little bit of benefit there.

8 But the thing I want to point out is in this
9 analysis the second peak is still higher than the first
10 peak, which means it is out here at the end of the
11 transient that is controlling the CPI and CPF. So,
12 yes, this would drop the failure probabilities if we
13 implemented an EPFM solution. It wouldn't make them
14 totally go away. So, maybe part of an answer, not the
15 whole answer.

16 MEMBER RICCARDELLA: But the first peak
17 versus the second peak, that is just whether you get
18 warm pre-stress.

19 MR. KIRK: Right, and we adopt the warm
20 pre-stress model.

21 MEMBER RICCARDELLA: But how high the
22 second peak is is important.

23 MR. KIRK: Is important, yes, absolutely.
24 Yes. Right. Absolutely.

25 But they are all above. I mean -- my

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 pointer is gone -- this horizontal line, I believe,
2 yes, the horizontal line represents the absolute
3 minimum of the K_{1c} distribution in FAVOR. So, in this
4 case the second peak, you are still getting failure.

5 MEMBER RICCARDELLA: You are getting some
6 failures, but --

7 MR. KIRK: Yes.

8 MEMBER RICCARDELLA: But it is likely
9 better than 10 to the minus 3rd or 10 to the minus 4.

10 MR. KIRK: The other thing we looked at was
11 to see if we could get any benefit from accounting for
12 constraint loss because, of course, these are very
13 shallow flow. If you were to test a shallow flow in
14 a fracture mechanics test in the laboratory, you would
15 have lots of constraint loss and lots higher toughness.
16 But this, of course, isn't a shallow flow in a bend bar.
17 It is a shallow flow in a big, thick pressure vessel.

18 So, to assess that, we calculated the
19 evolution of the T stress, which is the constant stress
20 acting parallel to the clad tip throughout the loading.
21 And generally speaking, if you have a positive T stress,
22 you are in a situation of high constraint like you would
23 be in a fractured mechanics specimen. And in that
24 case, using typical fracture mechanics data is the
25 right thing to do. So, in this case the T stress

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 analysis told us that there is really no benefit to be
2 gained by accounting for constraint loss in the
3 calculations group. Our fracture toughness
4 distributions are based on standard fracture mechanics
5 specimens, are the right things to use.

6 Finally, we look at an analysis of one
7 transient. We had a set of about 50 that were
8 available. We have analyzed a few. This is just one
9 to show you as an example.

10 What we wanted to do is, as I said, on the
11 bottom here is the pressure temperature curve. Here
12 is the curve we are normally following then. And the
13 blue line represents the actual cooldown that was
14 measured in the plant. And you can see here there is
15 a little bit of a repressurization at the end, of
16 course, staying below the limit curve. And you can see
17 that repressurization right there.

18 So, we applied that actual pressure,
19 temperature, time -- we put that into FAVOR and
20 calculated the CPFs for the various wall depths.
21 Really, it is only the shallow ones that are of interest
22 here.

23 What we see is we have taken the CPFs for
24 the limiting or allowable P-T values from 10 to the
25 minus 5ish regime and dropped it down to 10 to the minus

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 9.

2 So, as we expected, as I would say we all
3 hoped, following the actual cooldowns results in a
4 considerable diminution of CPF, which is good. So, in
5 large part, this is the basis for saying it is not a
6 current safety issue. But, nevertheless, cooling down
7 along the reliable curve does still give you these high
8 values.

9 MEMBER BLEY: I am a little confused here,
10 and I have been hanging up on the things you guys were
11 talking about a minute ago. That time scale is fair.
12 I thought we were doing cooldowns that were
13 primarily -- the first cooldown like 100 degrees.

14 MR. KIRK: Right, right.

15 MEMBER BLEY: But we are out here at four
16 hours --

17 MR. KIRK: Right.

18 MEMBER BLEY: -- 400 hours --

19 MR. KIRK: This is real deal.

20 MEMBER BLEY: Oh, this is a real deal?

21 MR. KIRK: Yes.

22 MEMBER BLEY: Okay. Okay.

23 MEMBER RICCARDELLA: Is that 400 or 4?

24 MR. KIRK: No, that is 400.

25 CHAIRMAN BALLINGER: That is 20 days.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 MEMBER RICCARDELLA: That is real slow.

2 MR. KIRK: We have looked at others that
3 are faster and we get similar results. Actually, this
4 was the highest one.

5 MEMBER BLEY: So, when Pete was asking if
6 you go all the way down to something under 100 degrees,
7 and Dick was saying, well, if we get all the fuel
8 out -- well, at that pace that is not going down. I
9 mean, you are going down in temperature inside, but that
10 is very quickly, 100 degrees an hour, for not this, but
11 for the others.

12 MR. KIRK: Right.

13 MEMBER BLEY: And how long does it take for
14 the temperature to equilibrate across the vessel if you
15 are assuming you come down to the outside ambient
16 temperature inside the vessel?

17 MR. KIRK: We are applying the ID
18 temperature of the vessel to the first node of the
19 model.

20 MEMBER BLEY: Uh-hum, but, then, the rest
21 of it is heat conduction.

22 MR. KIRK: I don't have the time in my
23 head, but --

24 MEMBER RICCARDELLA: But you are talking
25 about a vessel that is not cooling down --

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 MR. KIRK: That happens after a couple of
2 days. It has got to be equilibrated.

3 MEMBER RICCARDELLA: But you would still
4 have a problem --

5 MR. KIRK: Yes.

6 MEMBER RICCARDELLA: -- even then.

7 MR. KIRK: Yes. Yes. The thing to
8 appreciate is, I mean, the cooling rate, whether you
9 are coming down at 500 degrees Fahrenheit every hour
10 or what -- I think this one worked out to, we figured
11 out an average cooling rate of like 1.3 degrees
12 Fahrenheit per hour. It was just painfully slow.

13 The through-thickness thermal gradient is
14 nil. You are getting nothing from that. All of this
15 was in effect for the specialty temperature.

16 MEMBER RICCARDELLA: It is residual
17 stress, you know, low temperature, and the flaw
18 assumption --

19 MR. KIRK: Yes.

20 MEMBER RICCARDELLA: -- means that when
21 you are sitting there during refueling, you have got --

22 MR. KIRK: It has nothing to do with
23 thermal stress.

24 MEMBER RICCARDELLA: -- 10 to the minus 4
25 probability of failure.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 MEMBER BLEY: You can take away the
2 thermal stress and it remains.

3 MEMBER RICCARDELLA: The thermal stress
4 is gone, and it is just --

5 CONSULTANT SHACK: It is waiting for the
6 rest of the riddle.

7 (Laughter.)

8 MR. KIRK: It has been a while since I
9 looked at the details of this analysis, but I am very
10 uncomfortable in saying that most of the residual
11 failure probability that you are seeing here is simple
12 the result of the vessel being at room temperature and
13 the assumed single stress pre-temperature being at 488.
14 That's it. It is a consequence of the model.

15 MEMBER RICCARDELLA: And the distribution
16 of the fracture toughness.

17 MR. KIRK: Right. Right.

18 MEMBER RICCARDELLA: It follow the
19 fracture toughness curve.

20 MR. KIRK: Right. If we were more
21 conservative in our assumptions on fracture -- and the
22 fracture toughness model was pretty good in my
23 opinion -- if we were more conservative, it would look
24 worse. We are not. We have accounted for R.t and D.t.

25 So, we have beat that to death.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 The risk-informed has a little bit higher
2 CPF, but, you know, who would argue over an order of
3 magnitude?

4 So, summary -- summary? -- so,
5 considerable differences between P-T limit, between
6 cooling down along the allowed limits, and cooling down
7 along the actual transients, as we hoped and expected.

8 But what we find out is, when you look at
9 these, here is the limit. There is generally lots of
10 space between the actual curves and the limit curves.
11 So, there are lots of things, plant-specific factors,
12 that are, in fact, more limiting than embrittlement,
13 with the exception being at the low-temperature,
14 low-pressure end, where the curves approach the limit
15 curve.

16 Let's see. Yes, from these analyses,
17 okay, actual cooldowns have lower CPF. Even for the
18 actual cooldowns, the second peak in applied K still
19 generates CPF, and you saw the numbers.

20 What more do I have? Oh, okay, so here is
21 the story on why did these not affect PTS. And so, we
22 went back into our PTS rapid-cooldown databank and we
23 picked a number of transients and categorized them in
24 terms of their average cooling rate per hour, all the
25 way from 75 Fahrenheit per hour to something like these

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 normal cooldowns, all the way up to -- here's your main
2 steamline break clocking in at 2,000 degrees Fahrenheit
3 per hour.

4 The graph you see is the ratio of the CPI
5 for the embedded flaws versus the CPI for the shallow
6 surface-breaking flaws. And what we see is the faster
7 the cooldown, the more the embedded flaws dominate.
8 That is what was driving PTS.

9 But, for the slower cooldowns, it is the
10 shallow surface-breaking flaws that are dominating.
11 And the reason is illustrated in the cartoon. In both
12 cases at the end you are cooling down to ambient
13 temperature, whether it is 50, 75, 100; let's not argue.
14 So, they are all going to come to the same K applied
15 at the end for the shallow surface-breaking flaw due
16 to the difference in the stress pre-temperature.

17 The difference is, with the very rapid
18 cooling in PTS cooldowns, you get a huge K spike in the
19 beginning which you are using a warm pre-stress model,
20 as we do. This means this is where all the action is.
21 So, the shallow surface-breaking flaws were
22 effectively numbered benign by the early K peak due to
23 the rapid cooldowns.

24 MEMBER BLEY: Rather than benign, the
25 chance of failure was high enough for this that it

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 washed out the other one. No?

2 MR. KIRK: No, because here you are taking
3 a high K when you have got -- well, maybe I shouldn't
4 have used the word "benign". I'll just go with "much
5 less".

6 MEMBER BLEY: Yes, I like that.

7 MR. KIRK: Because, yes, you have got a
8 high K applied, but you have got very high fracture
9 toughness.

10 MEMBER RICCARDELLA: You stress it while
11 it is warm, let's call that autofrettage.

12 MEMBER BLEY: No. In that period of time
13 if it didn't break, eventually we would get to the same
14 thing. Assuming you were shut down, eventually you
15 have got residuals there.

16 MR. KIRK: But having gone through this,
17 even though at the end of the transient you may still
18 be above the minimum K_{Ic} , the criteria for failure that
19 is adopted by FAVOR -- and FAVOR is certainly not unique
20 in this regard; it is used in many areas -- it is that
21 K_{FI} needs to be above the minimum K_{Ic} and K_{FI} need to
22 be increasing with time, and it needs to be above the
23 previous peak.

24 So, down there, even though --

25 MEMBER BLEY: It is not above.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 MR. KIRK: Yes.

2 So, to summarize, the flaw model was
3 established in NUREG/CR-6817. I think, as we have
4 discussed, it is the best we could do at the time based
5 on the available information. It was well-reviewed.
6 The shallow surface-breaking flows were, I think,
7 generally thought to be a good idea, but also they
8 weren't significant. So, it hasn't gotten a lot of
9 scrutiny in terms of the implications until now. And
10 certainly more could be done with it. I would be first
11 in line to say that.

12 The stresses in the cladding, a simplified
13 model, but based on experiments, and, moreover, I would
14 point out pretty much an industry standard. Lots of
15 people use a stress pre-temperature model.

16 We have benchmarked successfully to
17 ABAQUS, but the natural outcome of the model is applied
18 stresses are maximum at room temperature. And that is
19 vexing us, vexing us in the context that we calculate
20 probabilities that are rather high for these flaws.

21 So, that, absent questions, is the end of
22 this part.

23 MEMBER BLEY: But were they high enough
24 that in the breadth of industry, not just power plants,
25 we would have seen them somewhere under these really

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 same conditions?

2 MR. KIRK: Without wanting to do algebra
3 in my head, I am going to say probably -- were they high
4 enough? I mean, I am getting my question I am
5 answering.

6 MEMBER BLEY: We don't necessarily have
7 nuclear reactors, but we have lots of high-temperature
8 chemical reactors that cool down and have residual
9 stress.

10 MR. KIRK: The actual CPIs and CPFs are
11 going to be more like these values I have calculated
12 here, 10 to the minus 9, because I think we all agree
13 we are not -- even though it is the limit that is set
14 in the code, people aren't following that limit. That
15 is agreed to. So, the actual failure probabilities are
16 more like 10 to the minus 9, 10 to the minus 12. You
17 would have to do the math. I don't think it is --

18 MEMBER BLEY: Be unlikely.

19 MR. KIRK: It would be unlikely to have
20 seen it.

21 MEMBER SCHULTZ: But you also had
22 conditional statements in your previous slide where you
23 talked about reasons why that should not be a
24 significant concern.

25 MR. KIRK: I'm sorry, what? Refresh my

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 memory.

2 MEMBER SCHULTZ: You talked about the
3 pathway which you followed to get to those points versus
4 what an actual path --

5 MR. KIRK: Oh, yes. Yes.

6 MEMBER SCHULTZ: And so, I am not sure how
7 we capture those conditions, that conditional piece of
8 the description. So that, when one looks at the plot,
9 one doesn't get excited.

10 MR. KIRK: That has been our problem.

11 MEMBER SCHULTZ: Yes. That is a problem,
12 but we need to talk about it or write it down.

13 MEMBER RICCARDELLA: Mark, on that
14 previous slide --

15 MR. KIRK: This one?

16 MEMBER RICCARDELLA: I'm sorry. Yes.
17 You know, I misinterpreted that at first. I thought
18 that was conditional probability versus time. Would
19 it be possible to make a plot of the conditional
20 probability of failure versus time during the change?

21 MR. KIRK: Yes.

22 MEMBER RICCARDELLA: When it occurs
23 during the change?

24 MR. KIRK: And that is coming up in the
25 leak test.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 MEMBER RICCARDELLA: Okay.

2 MR. KIRK: We haven't done. We don't have
3 those plots for the cooldown.

4 MEMBER RICCARDELLA: I would just like to
5 confirm that it is really happening at the end of the
6 transient.

7 MR. KIRK: I will confirm that.

8 MEMBER RICCARDELLA: Okay.

9 MR. KIRK: yes.

10 MEMBER SKILLMAN: Mark, let me ask this:
11 is there any international OE that would suggest that
12 there have been flaws that grew to failures --

13 MR. KIRK: No.

14 MEMBER SKILLMAN: -- and at the time
15 couldn't be explained? But now maybe they can be?

16 MR. KIRK: I think we would all know about
17 that.

18 MEMBER SKILLMAN: Okay.

19 CHAIRMAN BALLINGER: Okay, this is a
20 convenient break point. We are way ahead of schedule,
21 by the way by this.

22 MR. KIRK: Well, we are right on schedule
23 with the previously-published one.

24 CHAIRMAN BALLINGER: That's right. Well
25 done. Well done.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 (Laughter.)

2 In any case, can we take a break until 25
3 after?

4 (Whereupon, the foregoing matter went off
5 the record at 3:09 p.m. and went back on the record at
6 3:25 p.m.)

7 MR. KIRK: Okay, so this part of the
8 concerns the operating pressure leak test in boiling
9 water reactors. Just as an example of some of the
10 challenges that are proposed by surface-breaking flaws
11 in our calculations, this is a briefing on the research
12 report that we sent you in draft form several weeks ago.

13 So, it may be self-evident, but leak tests
14 include, of course, both a heatup and a cooldown phase
15 and a constant pressure and temperature hold in the
16 middle. In BWRs leak tests occur at the start of every
17 operating cycle, so between one a year and half a year.
18 So, for all practical purposes -- and I should also say
19 they also follow these curves -- so, for all practical
20 purposes, for leak tests, CPF is approximately
21 through-wall cracking frequency. And this I think the
22 Committee is aware the agency adopted a
23 10-to-the-minus-6-per-year limit on through-wall
24 cracking frequency in a PTS reevaluation.

25 In this example problem, we are focused on

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 three different loading possibilities. One is loading
2 following the ASME Appendix G risk-informed approach.
3 So, the graph gives you the temperature ramp up and
4 down. We followed a ramp of 40 degrees Fahrenheit per
5 hour, the calculated maximum pressure. The same thing
6 for ASME, Appendix G, current approach.

7 And then, we also give one loading
8 following plant procedures. So, you see the same
9 40-F-per-hour thermal ramp, but the pressure, instead
10 of being these rather higher values that are allowed
11 by the equations at the beginning and the end, we
12 started at zero gauge pressure and, then, step up
13 following the plant procedures. So, per-plant
14 procedure would be a much more realistic loading than
15 following the permitted limits.

16 Just to show you where these come from
17 equation-wise, leave it to help your sleep to work on
18 the equations. So, all these are, these are the ASME
19 Section 11, Appendix G, equations. K_{lc} is less than
20 2 times K_{lm} plus K_{lt} . Solve for both the leak test
21 temperature and the maximum pressure with all of the
22 variables retained, so that you can see the effects of
23 things like geometry and R 's and square roots of t 's
24 and the various risk-informed factors like α and
25 β .

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 So, these equations give us the loading
2 conditions for following the P-T limits. Also, the
3 little table gives you the various factors.

4 For current practice, the structural
5 factor on pressure is 1.5. There is no beta factor,
6 which is essentially a transition temperature shift.
7 And the trend curve and the margin term come out of Reg
8 Guide 1.99, per a foot note in ASME Section 11, Appendix
9 G.

10 The risk-informed approach, the
11 structural factor on pressure is set to one. There is
12 a beta factor, again, essentially a transition
13 temperature shift of 60 degrees. It uses a different
14 ETC, but for these purposes that is not a difference
15 that matters, and zero margin. The plant procedure is
16 as shown here, and the embrittlement is calculated by
17 Reg Guide 1.99. So, those are our loading curves.

18 In terms of flaws or flaw populations, we
19 did three different runs, one using the embedded flaw
20 population we have been talking about a lot, another
21 using the embedded flaw population that we barely
22 talked about at all, the population of shallow
23 surface-breaking flaws that we have talked about a lot.

24 And then, just for comparison purposes -- I
25 am not saying that this flaw exists in a vessel -- is

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 the single quarter t 6-to-1 surface-breaking flaw that
2 established the P-T limits, just for purposes of
3 comparison.

4 The results in the table I am not going to
5 focus on. They are what they are. What is, I think,
6 of more interest is to look at an answer to Pete
7 Riccardella's question of earlier, is: where do these
8 CPIs and CPFs occur for these different flaw
9 populations?

10 Now we will look at the shallow
11 surface-breaking flaws, and the graphs I will show are
12 the cumulative percentage of CPI accumulated as a
13 function of time in the transient. And on all the
14 graphs, the light shaded area, that is the time during,
15 I will call it during the operating pressure leak test.
16 You are at the leak test temperature. You are at the
17 full system pressure. And then, the dashed line is
18 simply the time at which the plant returns to ambient
19 temperature. And, of course, it is the ambient
20 temperature time equals zero.

21 MEMBER RICCARDELLA: And pressure? The
22 dashed line is also returning to essentially zero --

23 MR. KIRK: Well, what we are returning to
24 in the ASME case is the allowed pressure, which was
25 shown here. In the case of current practice, the

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 allows pressure for this transient was about 500, 600,
2 in the Appendix G, and this is just simply the
3 difference between the 1.5 and the 1 factor. It is up
4 to about 800.

5 MEMBER RICCARDELLA: Yes, but the plant
6 procedure is zero.

7 MR. KIRK: The plant procedure is zero,
8 yes. The plant procedure, zero applied pressure,
9 beginning and end.

10 So, again, ignoring a few details, all very
11 common in that at time zero there is some percentage
12 of CPI accumulated, anywhere from 20 to 40 percent.
13 And then, the rest of it occurs at the end.

14 The most striking factor is that
15 absolutely nothing is happening CPI-wise or
16 CPF-wise -- it doesn't matter -- associated with the
17 time and duration of the leak test. It is totally
18 irrelevant. And you can see why that is when you look
19 at the variation of K with time. So, in these graphs,
20 the green curve is a variation of the applied K for the
21 shallow surface-breaking flaw. There are the orange
22 curves, the minimum fracture toughness.

23 So, since you are heating up, the ID of the
24 vessel is being driven more and more into compression.
25 So, as you heat up, the applied K actually drops for

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 an ID flaw. However, since it is above the minimum K
2 actually in all three cases -- it doesn't show
3 graphically very well at the bottom -- but it is just
4 a tiny bit above. So, in all three cases, like was
5 shown before, you get a significant percentage of the
6 CPI occurring at time equals zero. Since K then drops,
7 no more CPI accumulation. In fact, in all three cases,
8 during the time of the leak test, the applied K is always
9 below the minimum fracture toughness.

10 So, no possibility of additional CPI or CPF
11 accumulation until you have the cooldown coming out of
12 the leak test. Now, since you are cooling down, the
13 ID of the vessel is going progressively more and more
14 into tension. And again, brushing aside the
15 particulars, you start to tick up more CPI as you return
16 to ambient temperature.

17 And actually, all of this can be easily
18 compressed onto a single diagram. So, really, the only
19 significant difference between these three loadings is
20 the initial or final pressure. Try to blind yourself
21 to the CPI or CPF numbers for right now.

22 The ASME risk-informed alternative has
23 higher CPIs and CPFs, and they are essentially
24 identical to then current practice. And that is
25 understandable because there is a higher initial

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 allowed pressure.

2 Following plant procedure, which is a much
3 more realistic view of how a plant would go through leak
4 tests, the CPIs and CPFs are lower and, in fact, there
5 is a greater difference, but they are still all above
6 10 to the minus 6.

7 I should point out these analyses are done
8 for a plate-limited BWR at 72 EFY. So, fairly high
9 embrittlement BWR. We have done low embrittlement
10 BWRs. We have done different BWRs. The numbers
11 change a bit, but this isn't a rare case is what I would
12 like to say. This is a good example of what happens.

13 So, the initial final pressure drives the
14 CPI/CPF differences between these different loadings,
15 current plant procedure being the lowest, but still
16 above 10 to the minus 6. It probably drops a little
17 with embrittlement.

18 But the significant thing is actually
19 something that I didn't say in the middle. It is that
20 there is nothing that an operator can do to change this
21 result. It is all a part of the model. There is
22 nothing going on here during the leak test portion.
23 You can't increase the temperature of the leak test.
24 Nothing is going to happen. It is all at the beginning
25 and the end. So, it is all a consequence of the model.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 That is not to say the model is right. It is just to
2 say you can't change it by changing your operating
3 practice.

4 I am just going to go quickly through
5 embedded flaws because, frankly, they are not
6 controlling. I will just point out that now the time
7 of the CPI accumulation depends on the loading method.
8 For the risk-informed, for ASME current and plant
9 procedure, the time to CPI accumulation now corresponds
10 to the duration of the retest itself. Whereas, with
11 the risk-informed alternative, it ticks up
12 predominantly you ever get to the leak test, and there
13 is only a slight adder as you get to the leak test.

14 Again, I am not going to dwell on it because
15 this isn't the significant part of the briefing. But
16 you can understand better where the CPI is accumulating
17 and not accumulating when you look at the KFYs. It is
18 one, of course, follows from the other.

19 When we look at the end, if we look at
20 loading along the risk-informed P-T limits, certainly
21 it increases CPI and CPF to the current P-T limits and
22 it changes the time that is important in the transient
23 from during the leak test to before the leak test.

24 All those things said, the CPI and CPF
25 values, even for the risk-informed alternative, remain

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 well below 10 to the minus 6, presuming they are only
2 embedded flaws in the vessel. And this is the same
3 conclusion even for highly-embrittled BWR. And this
4 is the same conclusion that the industry reached in
5 MRP-250.

6 So, to summarize, for surface-breaking
7 flaws, CPI and CPF are increased by the risk-informed
8 alternative. It is always greater than 10 to the minus
9 6, even for a more realistic loading case. And the
10 whole game is in the assumptions of the model.

11 We initially went into this thinking,
12 well, maybe if we required a higher retest temperature,
13 that would fix things. The action is enduring a leak
14 test for surface-breaking flaws. So, the remedy, we
15 need to look someplace else. For embedded flaws, all
16 the values are low, even for a more embrittled BWR.

17 MEMBER SCHULTZ: Are low and very low in
18 comparison?

19 MR. KIRK: Yes. Yes. Looking at what we
20 are doing moving forward, obviously, we are here to
21 summarize our findings to you and solicit your
22 comments. We are working on completing our
23 documentation of this work, sort of plugging through
24 this a bit at a time. Within the next year, I think
25 a year, we hope to complete 10 Technical Letter Reports

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 and summarize them all in a single NUREG.

2 We are also motivated by the things that
3 we talked to you about today, performing a
4 comprehensive review of the conservatisms in the FAVOR
5 model. That goes off a similar examination done during
6 the PTS project and documented in NUREG-1808, but we
7 are taking this opportunity to do it again, of course,
8 motivated by some of the things we told you today.

9 As we work through that, we are performing
10 more detailed investigations of factors we have
11 identified as significant, which means offering a
12 possibility, at least in our view, of significantly
13 changing the results.

14 Currently, we are in the process of trying
15 to develop more detailed model of cladding stresses and
16 stress re-temperatures in FAVOR. We recognize that
17 what we have got is a fairly rudimentary model. And
18 so, we want to see if we can gain some improvement there.

19 Other topics that we have talked about but
20 haven't initiated investigations on, some of which were
21 alluded to today, some of which have been brought up
22 today -- so I need to go through the
23 transcript -- include elastic plastic effects, load
24 history effects, the effects of actual loading, the
25 effects of corrosion on crack driving force, including

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 both blunting effects and corrective wedging effects,
2 looking at making more measurements of cladding
3 residual stresses. And, of course, we will be seeking
4 peer review in this and other forums on the various
5 insights.

6 Also something I should notice or I should
7 say is we have brought these results to the attention
8 of the ASME Boiling Pressure Vessel and the people that
9 attend, and particularly our colleagues in the
10 industry. And they are doing some work in this regard.
11 In particular, we are following the industry's
12 developing full-tolerance approach where they are
13 working on a way to manage CPI and CPF accumulation by
14 controlling heatup and cooldown breaks. And that was
15 something that was just literally yesterday discussed.
16 So, there are some ideas there.

17 And I just note that these and other
18 research plans are consistent with NRR needs and are
19 reflected in their current user need request to us,
20 NRR-2014-007.

21 So, I think, with that, we are up to
22 questions and comments.

23 CHAIRMAN BALLINGER: Can we get the bridge
24 line open?

25 CONSULTANT SHACK: You gave the example of

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 the elastic plastic fracture mechanics lowering the K,
2 and it didn't seem to do very much. But did you
3 actually run through a probabilistic calculation?

4 MR. KIRK: No. No, we have not done that.
5 Like I said, that is one of the things on our list.

6 CONSULTANT SHACK: Small things seem to
7 make such a difference here.

8 MR. KIRK: Well, they do, because in all
9 these simulations the applied K is just getting into
10 the K_{Ic} or K_{Ia} distribution. So, yes, small things can
11 make a difference.

12 MEMBER RICCARDELLA: Yes, you know, on the
13 surface-breaking flaw, could you go back to slide 31,
14 please?

15 MR. KIRK: Yes, I can. Sorry. There we
16 go.

17 MEMBER RICCARDELLA: You know, the EPF
18 calculation for that shallow surface-breaking flaw is
19 not just the standard EPF calculation because most of
20 that cracked surface is in that blue ductile material.

21 MR. KIRK: Uh-hum.

22 MEMBER RICCARDELLA: And all you have got
23 is that little tip of the crack --

24 MR. KIRK: Yes.

25 MEMBER RICCARDELLA: -- going out into the

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 brittle material. And you are saying, if that little
2 tip exceeds K_{Ic} , you get initiation and in some cases
3 all the way through wall fracture. And you have tear
4 that blue part, which is really hard to do. You know,
5 it is a very ductile material. I think a detail of the
6 elastic plastic analysis, pressure mechanics analysis
7 of that might make a lot of these surface-breaking flaw
8 go away.

9 MR. KIRK: Richard Bass from Oak Ridge
10 National Lab, he did the EP analysis. So, maybe he can
11 comment.

12 MR. BASS: What I wanted to say to address
13 Pete's comments here, back in the eighties we at ORNL
14 we ran some thermal shock experiments in large
15 cylinders that were both clad and unclad with surface
16 flaws through the clad. And we had no problem
17 initiating those flaws, and they would run the full
18 length of the cylinder beneath the cladding and well
19 into the vessel.

20 And we have data that attests to the
21 behavior of these flaws under thermal -- this is
22 strictly thermal shock loading. It is not pressure
23 loading. But we demonstrate a full capability of these
24 shallow flaws to initially brittlely and run beneath
25 the clad and into the vessel wall, in some cases

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 two-thirds of the way through the wall.

2 MEMBER RICCARDELLA: But not through the
3 wall?

4 MR. BASS: Well, driving a crack then
5 strictly by thermal loading through the wall, that is
6 problematic.

7 MEMBER RICCARDELLA: But is that what we
8 are talking about though?

9 MR. BASS: Yes, but in our particular case
10 here you could also have a foundation of partial
11 loading, too.

12 MEMBER RICCARDELLA: I am just looking at
13 those high probabilities of fractures, you know, 10 to
14 the minus 4, 10 to the minus 5th, at zero pressure.

15 MR. KIRK: Yes, and I think maybe Richard
16 can also help me with this one. In FAVOR a crack is
17 said to have gone through a wall when it is predicted
18 to propagate to 90 percent or more through a wall by
19 either cleavage initiation arrest,
20 reinitiation/rearrest, and/or leaving an instability.

21 I know we went through this in PTS. I
22 don't remember the details, but I believe the reason
23 for the 90 percent is just the computational
24 difficulties of getting influence coefficients out to
25 the --

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 MR. BASS: Well, that is also user input,
2 too. You can specify what you want to be a failure.

3 MR. KIRK: Yes.

4 MR. BASS: And typically, we run 90
5 percent.

6 MEMBER RICCARDELLA: Well, it just seems
7 to me that at zero pressure, by the time that crack gets
8 to be 70 or 80 percent through a wall, and you driving
9 force is predominantly that cladding stress, which has
10 pretty much gone away, and your irradiation
11 embrittlement attenuates as you go through a wall.

12 MR. KIRK: And all the things you have said
13 are accounted for in --

14 MEMBER RICCARDELLA: I just can't
15 understand how you could break that vessel at zero
16 pressure. I'm sorry.

17 MR. BASS: Well, I can tell you from our
18 experiments that we were able to drive the flaw strictly
19 with thermal loading through the majority of the wall
20 thickness in these large-scale experiments.

21 MEMBER SCHULTZ: What was the thermal
22 loading?

23 MR. BASS: We basically took the vessel,
24 heated vessel, and submerged this into liquid oxygen.
25 And when you open the top of this thing, it is floating

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 with liquid nitrogen and you have thermal shock. It
2 initiates the flaw. It runs under cladding and through
3 the wall.

4 MR. KIRK: And I know you said "break the
5 vessel," but I think we need to be careful. We are
6 predicting a vessel failure probability. That means
7 in all the simulations that we run we are getting
8 failure at zero pressure conditions in the end a little
9 bit more than 1 in a million. That, to me, isn't the
10 same as "break". "Break the vessel" sounds, I will use
11 your word, "deterministic" to me for that trial. In
12 the huge majority of the trials, it didn't break the
13 vessel. So, I think your intuition is correct almost
14 a million out of a million times.

15 MEMBER BLEY: When you say "a trial," does
16 that mean a crack is initiated or a trial includes
17 initiation?

18 MR. KIRK: A trial is an RPV, a RPV
19 simulation.

20 MEMBER BLEY: Okay. So, to turn that
21 around a little bit, every crack initiation, every
22 trial that had crack initiation, what fraction actually
23 go 90 percent?

24 MR. KIRK: If we look at the cases where
25 there was significant pressure, for the risk-informed

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 Appendix G, the end pressure was -- I lost it
2 here -- like 800, 800 pounds per square inch. Let's
3 just say that. There CPI and CPF are identical. So,
4 essentially, everything that initiated went through
5 the wall at 800 pounds.

6 Down here, where there is no applied
7 pressure, we have got about 9 times 10 to the minus 6
8 CPI, but only 3 times 10 to the minus 6 CPF. So,
9 roughly, a third.

10 MEMBER BLEY: So, that's the number that
11 he was talking about. One out of three seems pretty
12 high.

13 MR. KIRK: It seems high.

14 Certainly, we can follow that through. In
15 any probabilistic code, what you will find that is
16 self-evident, especially to this group, these failure
17 probabilities are going to be driven by the tail. So,
18 you sort of already know the answer. It is going to
19 be location of the simulated at high TOP or high
20 fluence, whatever. But that is the result.

21 All I can say is all of the things that you
22 indicated as mitigating factors, the temperature
23 gradient, the fluence gradient, all those things are
24 modeled in FAVOR the best we could at the time. And
25 all the things you outlined are pretty good models.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 MEMBER BLEY: Now I want to ask you about
2 one other thing. And I haven't studied this, and I need
3 to go back and do more reading.

4 In the experiments on which so much of this
5 is based, where we see you have tried to initiate cracks
6 and we have purposely created cracks, my question is
7 really, where are we calibrated on the probability
8 scale for, say, crack initiation? In the experiments,
9 I would expect several conditions where it is pretty
10 likely or one out of one or one out of ten experiments
11 leads to an initiation. And yet, through our models,
12 we are predicting cases of 10 to the minus 4.

13 It is that translation from places where
14 it is quite likely and we have studied it carefully to
15 these cases where it is quite unlikely and we are
16 depending on our models.

17 MR. KIRK: Yes.

18 MEMBER BLEY: And I don't have a good feel
19 for how well we are calibrated as we make that
20 transition from what we do in experiments to these cases
21 where we are seeing quite unlikely cases.

22 MR. KIRK: I think Richard can reflect on
23 it -- I am not sure if this is the nature of your comment
24 or not -- on the model test, both thermal shock and
25 pressurized thermal shock that were done years and

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 years ago at Oak Ridge.

2 I think, to me, the big-picture outcome of
3 that when your elastic plastic mechanics to predict the
4 failure of vessels.

5 MR. BASS: As a matter of fact, we made
6 that presentation here about 10 years ago --

7 MR. KIRK: Yes.

8 MR. BASS: -- to the ACRS.

9 MR. KIRK: To a previous version of the
10 ACRS.

11 MR. BASS: To a previous version of the
12 ACRS.

13 MR. KIRK: Maybe it is time for a revision.

14 MR. BASS: On the basis of the very
15 question that you --

16 MEMBER BLEY: But is it very easy to point
17 me to the papers that describe that?

18 MR. BASS: We can do that after the fact.

19 MEMBER BLEY: I would appreciate it
20 because I don't have a good feel for that.

21 MR. BASS: Yes, again, we did a whole
22 series of large-scale pressured thermal shock
23 experiments in the eighties, of which I was a part of.
24 And in that particular case, we were very successful
25 in predicting the initiation of surface flaws under

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 pressurized thermal shock loading. And this has all
2 been very well-documented in the literature, and I
3 think we can certainly provide you with whatever we have
4 got --

5 MEMBER BLEY: Yes. That would be helpful
6 to me.

7 MR. KIRK: Actually, I think we will look,
8 but I am pretty sure it is an appendix to NUREG-1807.

9 MEMBER BLEY: That would be great.

10 MR. BASS: Probably the best document to
11 direct him to would be the document that we used for
12 the review with the ACRS back 10 years ago, whatever
13 it was. But that gave the best summary of providing
14 the relevance of LEFM to the FAVOR methodology. But
15 we will make that available.

16 MEMBER BLEY: That would be great.
17 Appreciate it.

18 CHAIRMAN BALLINGER: Any other questions
19 by the Committee members?

20 (No response.)

21 The bridge line is open. Is there anybody
22 on the bridge line that would like to make a comment?

23 MR. LEWIS: Yes, thank you. Marvin Lewis,
24 a member of the public.

25 CHAIRMAN BALLINGER: Yes, Marvin?

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 MR. LEWIS: I just was thinking. I have
2 been listening to all this stuff, the probabilistic
3 risk analysis predictions. I was thinking, you know,
4 there is a lot about metals that turn out to be a
5 surprise. I don't know if anybody noticed about the
6 Liberty ships back in World War II, but they started
7 cracking on the North Ocean, no, North Sea. And it
8 didn't take us long to figure out why.

9 But what I am trying to say is there are
10 surprises hidden in the numbers, and we should really
11 look at them and find out what these numbers are trying
12 to tell us.

13 All right. Thank you.

14 CHAIRMAN BALLINGER: Thank you.

15 Any other comments by people on the bridge
16 line?

17 (No response.)

18 Hearing none, thank you.

19 Comments from people in the audience?
20 Anybody have comments?

21 (No response.)

22 I'm speaking to the choir out there?

23 Okay. One last question. You mentioned
24 several times you are interested in feedback. In what
25 form would you like that?

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 MR. KIRK: I am going to defer to my boss,
2 by boss' boss to tell you that answer.

3 MR. RUDLAND: My name is Dave Rudland. I
4 am the Chief of the Component Integrity Branch in
5 Research.

6 I don't think we need anything real
7 formalized.

8 CHAIRMAN BALLINGER: Okay.

9 MR. RUDLAND: I think we are looking just
10 more for the informal discussions. So, I don't think
11 we need a letter or anything like that.

12 CHAIRMAN BALLINGER: Okay.

13 MR. RUDLAND: And I think the minutes will
14 reflect the information that we need.

15 CHAIRMAN BALLINGER: Thank you.

16 MEMBER BLEY: Just for the record, the
17 only way we can give advice is through a letter.

18 MEMBER SKILLMAN: Anything that has been
19 said in this meeting has absolutely no bearing on ACRS
20 opinions.

21 CHAIRMAN BALLINGER: Okay. Lucky thing
22 the Chairman is sitting here.

23 (Laughter.)

24 MEMBER SKILLMAN: No, that is just a fact.

25 CONSULTANT SHACK: Well, unless you have

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 an official opinion to deliver.

2 MEMBER SKILLMAN: A subcommittee can't
3 deliver an official opinion.

4 CONSULTANT SHACK: Right.

5 MEMBER SKILLMAN: Well, you can decide
6 whether you have an official opinion to deliver or not.

7 CONSULTANT SHACK: And then, you can write
8 a letter.

9 (Laughter.)

10 MR. RUDLAND: I have another thing to add.
11 When we talked about this informally, we talked about
12 leaving the decision up to you whether or not to go to
13 full Committee. So, we will leave that decision up to
14 you, if you think that is necessary.

15 CHAIRMAN BALLINGER: Thank you.

16 I guess we are done, unless there are any
17 other --

18 MEMBER BLEY: I would ask one question.
19 If we don't say anything, what are you going to do next?
20 What you've told us or is it hinging on what we say in
21 any way?

22 MR. KIRK: Well, I mean, like I said, I
23 have tried to be writing. I am hoping my colleagues
24 were taking notes because my job was to talk.

25 But I think you have reminded us of some

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 things that we might have left aside. This is pretty
2 much our short punchlist of things to look at.

3 And I will just say, personally, one thing
4 that I have recognized in preparing for this and talking
5 to you and hearing your comments is in many ways I think
6 we have been looking for one thing that would fix
7 everything. And, well, we haven't found that yet. I
8 think we have fairly convinced ourselves of that, and
9 I hope we have convinced you of that. Perhaps we need
10 to be looking at a combination of factors.

11 MEMBER BLEY: I don't want to put you
12 completely on the spot, but --

13 MR. KIRK: Sure you do.

14 MEMBER BLEY: -- is it fair for us to
15 believe that, if we don't give you any specific advice
16 in a letter, there are items that you have there that
17 are actually going to get attention over the next couple
18 of years?

19 MR. KIRK: Yes. Yes, that's a fair
20 assumption.

21 MEMBER BLEY: Okay. All right.

22 MEMBER RICCARDELLA: I think that is the
23 right list of things. The only thing I might add would
24 be also a relook at surface-breaking flaw distribution
25 and where we could possibly get some other data to

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 support or change that.

2 MR. KIRK: Okay. Thank you.

3 MEMBER RICCARDELLA: But, other than
4 that, I think you have got everything listed.

5 CONSULTANT SHACK: And I think adopting a
6 PRODIGAL model would make the problem go away. I mean,
7 it really is tied to that distribution. Okay? But I
8 have no reason to think why we would do that.

9 (Laughter.)

10 It is a region of uncertainty. I mean,
11 when you are dealing with core distributions that are
12 kind of as sparse as this, it is hard to come up with
13 good answers.

14 MEMBER RICCARDELLA: I mean, you are
15 taking data from one vessel that you have examined and
16 found none of these flaws. And somehow getting that
17 two per vessel are going to be these two breaking flaws.
18 I mean, that might be right, but it needs to be examined.

19 MR. KIRK: Yes, it is a model. It is an
20 approximate model.

21 CHAIRMAN BALLINGER: Any more questions?

22 (No response.)

23 Then, thank you very much for a really
24 great presentation.

25 MR. KIRK: Thank you.

NEAL R. GROSS

COURT REPORTERS AND TRANSCRIBERS
1323 RHODE ISLAND AVE., N.W.
WASHINGTON, D.C. 20005-3701

1 CHAIRMAN BALLINGER: And I think we are
2 adjourned.

3 (Whereupon, at 3:59 p.m., the meeting
4 adjourned.)

5

6

7

8

9

10

11

12

Advisory Committee on Reactor Safeguards

Materials Subcommittee Meeting

Technical Brief on NRR Bifurcation of 10 CFR 50 Appendices G and H Rulemaking and RES Research Efforts on 10 CFR Part 50 Appendix G

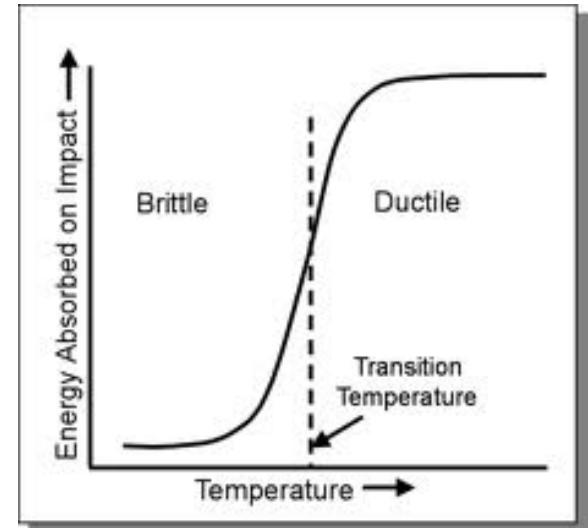
**Thursday, August 21, 2014
NRC Headquarters
Rockville, MD**

Bifurcation of 10 CFR 50 Appendices G and H Rulemaking

Robert O. Hardies
Senior Level Advisor – Materials Engineering
Office of Nuclear Reactor Regulation

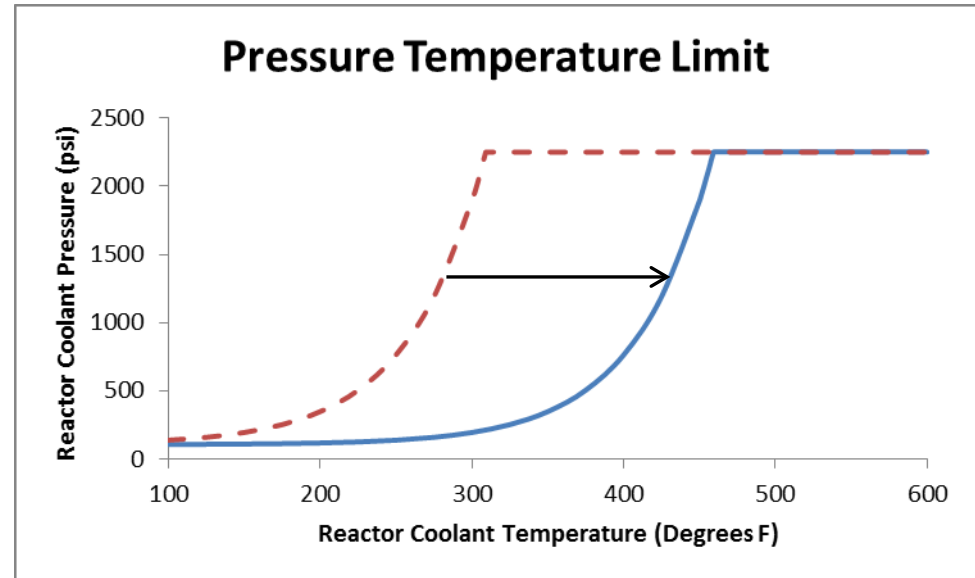
Background

- Title 10 of the Code of Federal Regulations, Part 50, Appendix A, General Design Criteria
 - Fracture Prevention of Reactor Coolant Pressure Boundary



10 CFR 50 Appendices G & H

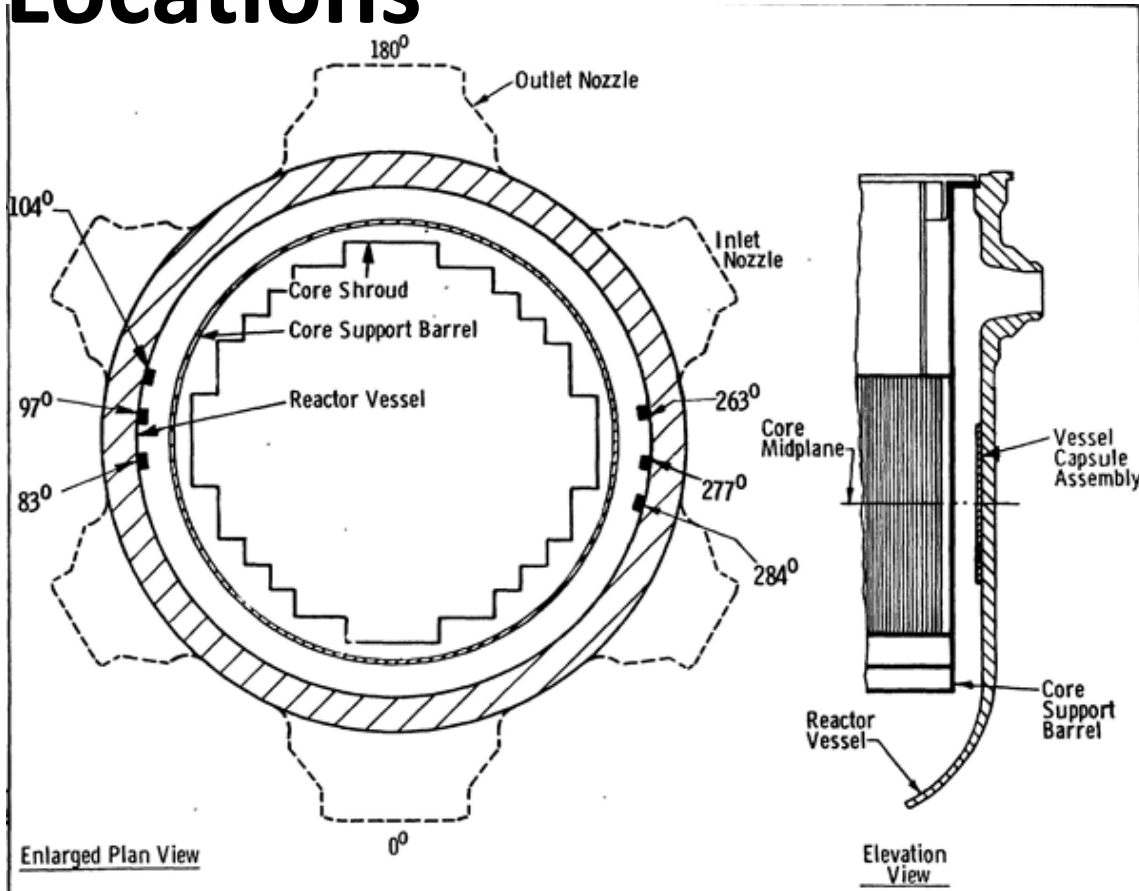
- Appendix G establishes heat up and cool down curves (P-T curves)
 - Shape and initial location
- Appendix H provides data to inform the curve shift due to irradiation



Surveillance Program

- Design
 - Which materials go into the program
 - What kind of specimens
 - How many specimens
 - How many capsules and where to place them
- Implementation
 - When to test
 - Guidance for number and temperature of tests
 - Retention of specimens
 - Evaluation or revision of withdrawal schedule
 - Report description

Surveillance Capsule Locations



Surveillance program design is completed before the vessel is delivered



Proposed Appendix H Changes

- Change ASTM edition control from Appendix H to 10 CFR 50.55a
- Current rule requires ASTM E 185 (1982 version or earlier) for design and implementation of the reactor vessel surveillance program
 - Proposed change to permit later versions
 - ASTM split standard E 185 into two standards, E 185 for design and E 2215 for implementation
 - New E 185 requires fracture toughness specimens
 - New E 185 eliminates a low-fluence capsule
 - New E 2215 provides guidance for life extension withdrawal schedule changes
 - New E 185 and E 2215 eliminate HAZ specimens

Proposed Appendix H Changes (cont'd)

- Current rule requires transmittal of capsule analysis reports within one year of capsule removal
 - Consider increasing to 18 months or two years
 - Integrated programs and shared capsules with multiple participants require more time for reporting
 - There is sufficient fleet-wide and plant-specific data in the database to allow time extension

Bifurcation of Appendices G and H Rulemaking

- Appendix G is a high priority rulemaking
- Appendix H is a medium priority rulemaking
- Appendix G technical basis not yet complete
- As a result, NRR requested, and Commission granted (8/8/2014), bifurcation of these two activities
- NRR/RES will proceed with Appendix H rulemaking

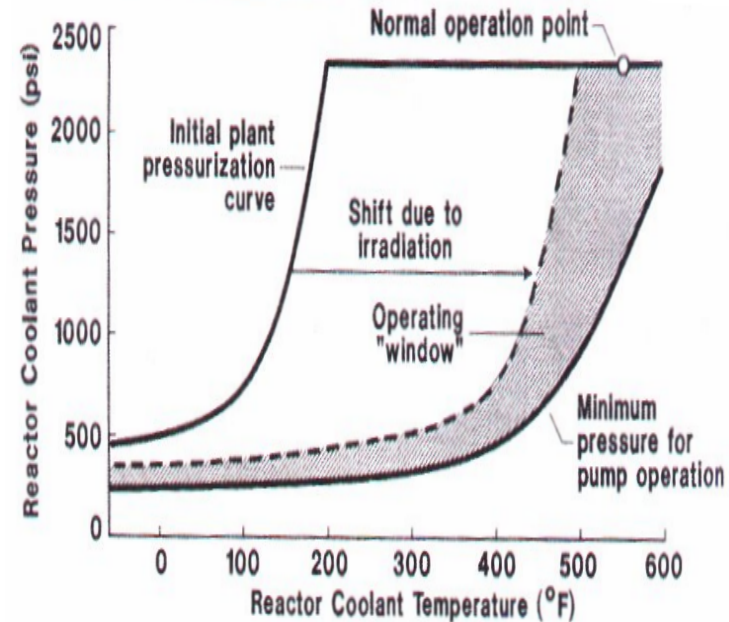
Questions or Comments?

NRR Regulatory Perspective on 10 CFR Part 50 Appendix G

Robert O. Hardies
Senior Level Advisor – Materials Engineering
Office of Nuclear Reactor Regulation

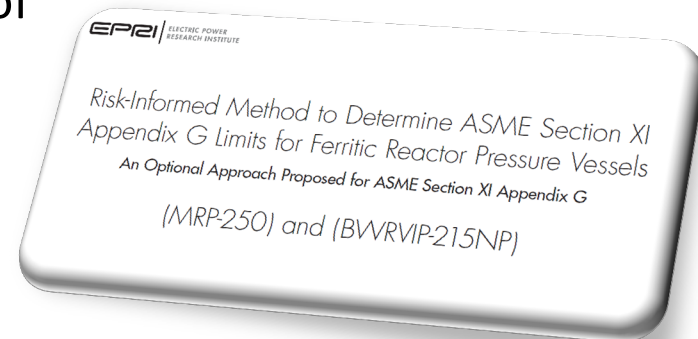
What are P-T Limits?

- Pressure-Temperature (P-T) Limits
 - Prevent non-ductile fracture of the reactor coolant pressure boundary
 - Impose limits on RCS operation
 - Based on LEFM analyses – establish minimum temperature necessary to ensure adequate margins against RPV failure as a function of pressure
 - Operate below/right of curve
 - Curve shifts as plant ages due to irradiation
 - Reside in plant Tech. Specs.
- P-T Limits Regulations and Guidance
 - 10 CFR 50, Appendix G: Fracture Toughness Requirements
 - Invokes ASME Code Section XI Nonmandatory Appendix G methodology for P-T curve development
 - RG 1.99, Rev. 2: Radiation Embrittlement of Reactor Vessel Materials



NRC Research Activities

- 2007: NRR developed User Need Request (UNR) 2007-001 that requested RES to re-evaluate the technical basis of 10 CFR 50 Appendix G
- 2009: Industry publishes MRP-250, following on the investigation of NRC RES
- 2011:
 - MRP-250 recommendations adopted by ASME Code (2011 Addenda) as a “Risk-Informed (R-I) Alternative” in Section XI Nonmandatory Appendix G
 - NRC did not approve at ASME; disapproving in 10 CFR 50.55a Rulemaking
 - NRR requested that RES include an evaluation of the ASME Code R-I Alternative
- Now:
 - NRC staff evaluation of both the “Current ASME Code” and “R-I Alternative” approaches identifies two important issues:
 1. Shallow surface-breaking flaws (SBFs) – not considered in MRP-250 analysis
 2. Leak tests



Current NRR Position

- There are no immediate safety issues warranting any changes to Appendix G
- Working to understand research results
- Appendix G and RG 1.99 technical bases development on-going

Questions or Comments?

NRC Research Efforts on 10 CFR Part 50 Appendix G Reactor Pressure Vessel Fracture Toughness Requirements



**Mark Kirk, Gary Stevens, Eric Focht, Mike Benson,
and Josh Kusnick**

Office of Nuclear Regulatory Research, Component Integrity Branch



Terry Dickson, B. Richard Bass, and Paul Williams

Oak Ridge National Laboratory

Outline

- **Background and Objective**
 - Appendix G project
 - Probabilistic Fracture Mechanics Code “FAVOR”
- **Technical Issues #1 & #2**
 - Shallow inner-diameter surface breaking flaws & the FAVOR cladding model
- **Technical Issue #3**
 - Boiling water reactor leak tests

First, Some Definitions....

Acronym	Description
CPI	Conditional Probability of Initiation. The probability that a pre-existing flaw initiates, conditioned on the occurrence of the loading being analyzed. Crack initiation occurs only by a brittle (cleavage) mechanism. The FAVOR code also checks for the possibility of ductile (upper shelf) initiation (but none has ever occurred for the conditions analyzed).
CPF	Conditional Probability of Failure. The probability that a pre-existing flaw initiates and propagates through the vessel wall, conditioned on the occurrence of the loading being analyzed. The possibility for cleavage, as well as ductile, crack growth, and vessel failure by ligament overload, is considered. A “through-wall” crack is assumed when the crack extends 90% through the vessel wall.
TWCF	Through-wall cracking frequency. TWCF is CPF weighted by the event frequency (yearly occurrence) of the analyzed loadings.
P-T Limits	Pressure -temperature limits. These are reactor operating limits established to prevent non-ductile failure of the reactor pressure vessel in accordance with the requirements of 10 CFR 50 Appendix G.
ASME (Current)	Deterministically-based P-T limits and leak test temperatures calculated according to the provisions of Articles G-2215 and G-2400, respectively, of ASME Code, Section XI, Nonmandatory Appendix G (adopted by ASME in the 1970s).
ASME (R-I)	Risk-informed-based P-T limits and leak test temperatures calculated according to the provisions of Articles G-2216 and G-2500, respectively, of ASME Code, Section XI, Nonmandatory Appendix G (adopted by ASME in 2011).

Background and Objective

THE APPENDIX G PROJECT

Request for Evaluation of 10 CFR 50 Appendix G

- NRR User Need Request 2007-001
 - Requests evaluation of 10 CFR 50 Appendix G **(CFR-G)**, including possibility of risk-informed revision
- 10 CFR 50 Appendix G incorporates Nonmandatory Appendix G to Section XI of the ASME Code **(ASME-G)** by reference unless excluded by 50.55a
 - Effectively makes ASME-G part of Federal law unless excluded by 10 CFR 50.55a
- Joint provisions of CFR-G & ASME-G address
 - **P-T limits for normal operations (heatup, cooldown, leak test)**
 - Minimum temperature requirements for flange
 - Modifications to P-T limits caused by stress concentrations (nozzles)
 - Limits on CVN upper shelf energy

The “Risk-Informed” Alternative

- **2009**: EPRI report providing technical basis for risk-informed alternative cooldown, heatup, and leak test limits
- **2011**: These recommendations adopted by ASME Code (2011 Addenda)
- **Now**: Included evaluation of the R-I alternative as part of NRR-UNR-2007-001 work

EPRI | ELECTRIC POWER
RESEARCH INSTITUTE

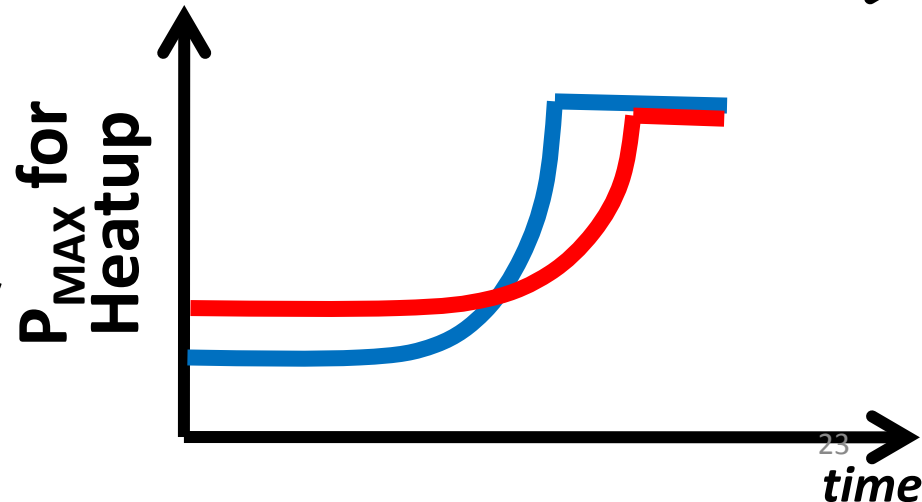
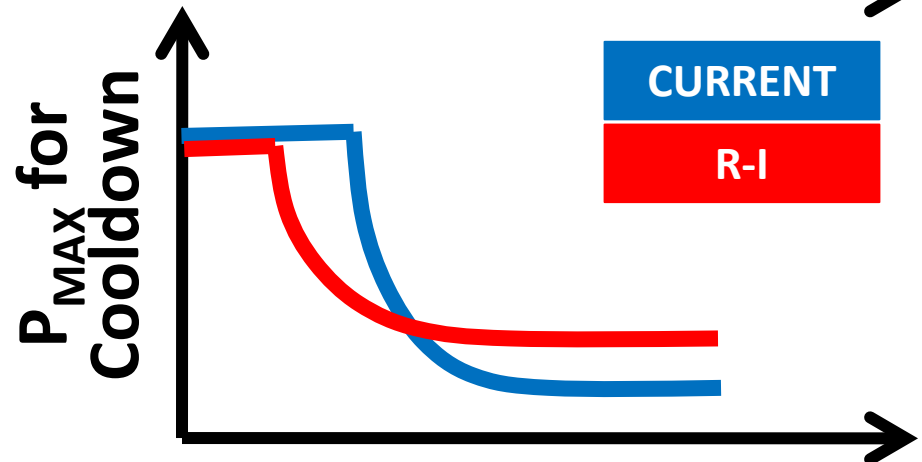
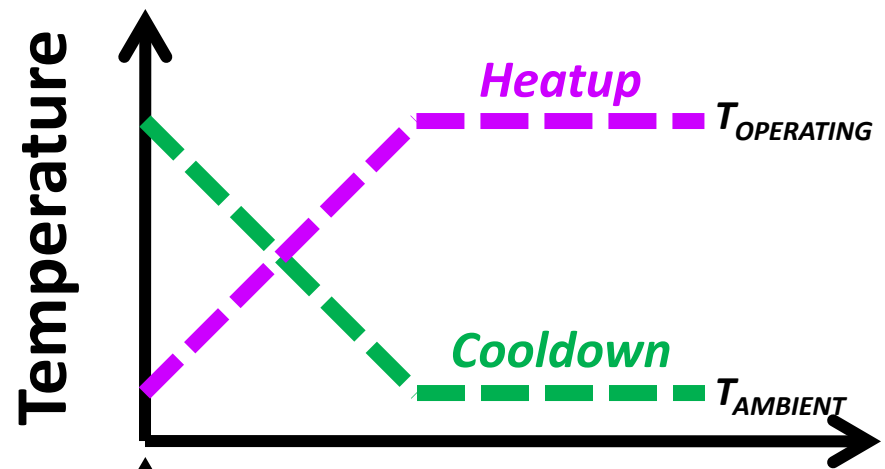
*Risk-Informed Method to Determine ASME Section XI
Appendix G Limits for Ferritic Reactor Pressure Vessels
An Optional Approach Proposed for ASME Section XI Appendix G
(MRP-250) and (BWRVIP-215NP)*

Today's Focus

- One aspect of the FAVOR PFM model (shallow through-cladding flaws) that influences significantly the results
- Operating pressure leak tests, as an example of:
 - The impact of shallow through-cladding flaws
 - A comparison of “current ASME” to “R-I ASME”

Staff's Approach to Evaluation of P-T Limits

- **Model of the RPV: FAVOR**
 - Same as used, reviewed, & approved, in PTS re-evaluation
 - Includes sub-models for flaw populations, embrittlement, toughness, attenuation, etc.
- **Loading**
 - Follows the P-T limits established by CFR-G & ASME-G
 - Recognized to be conservative
 - Based on PTS, failure probabilities believed to be low
 - Same approach used by industry
 - Also modeled actual & plant procedure loadings



Background and Objective

THE PFM CODE “FAVOR”

FRACTURE ANALYSIS OF VESSELS, OAK RIDGE

History of FAVOR

Timeline

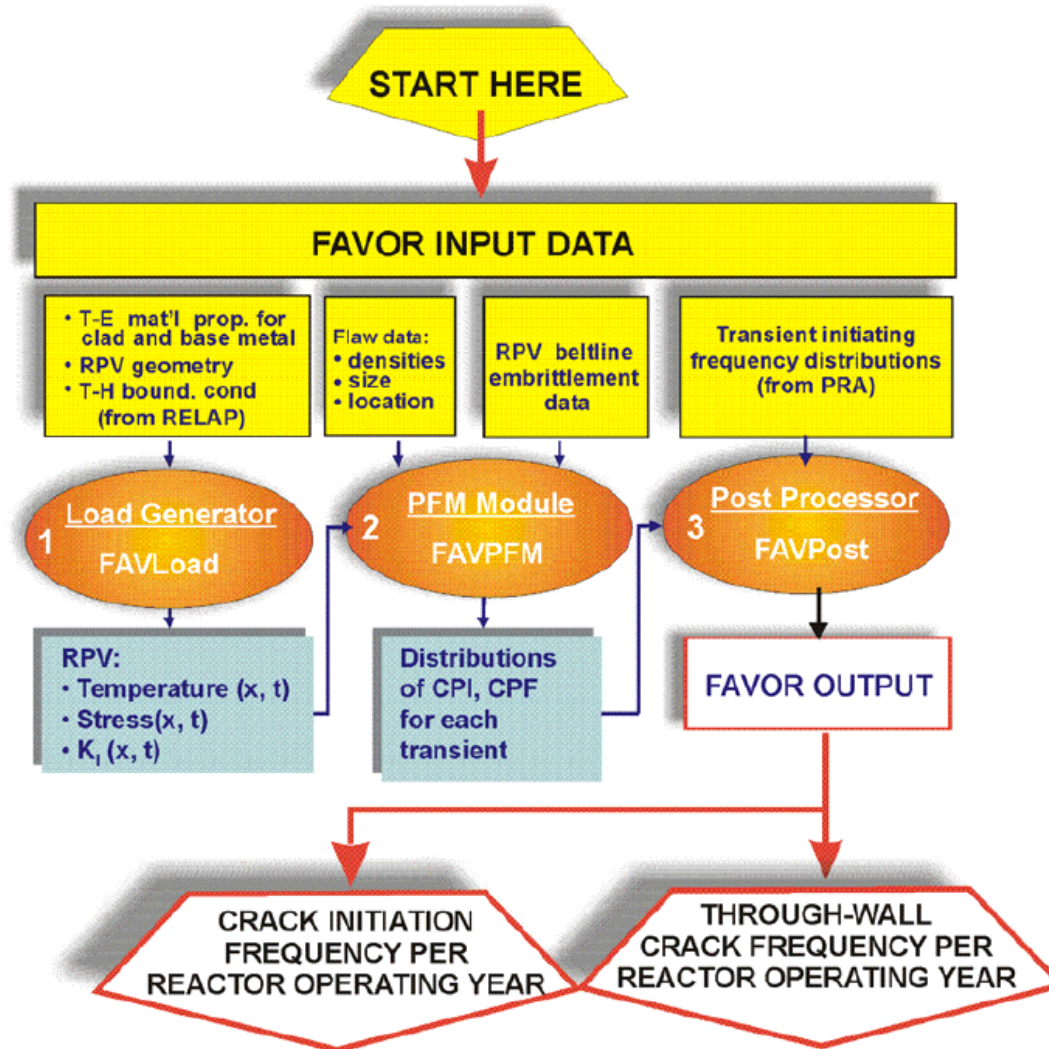
- Finds origin in PFM codes used for IPTS (80s) & Yankee Rowe (90s)
- 1995: 1st release of FAVOR
- 1999-2005: Significant development to support PTS project
 - Thorough evaluation of all models
 - Aleatory / epistemic distinction
 - Warm pre-stress
- 2009: Expanded to address
 - BWR geometries
 - Heatup (& leak test)
 - Flaws on or near the OD
- 2012: Most recent full release

Review, V&V, etc.

- 1999-2007: PTS re-evaluation
 - Thorough internal reviews of code and all models
 - 2007: V&V report (NUREG-1795)
 - 2007: External expert panel review (NUREG-1806, App. B)
- 2011: CNWRA/SWRI review
- Papers provide benchmarking of K solutions to ABAQUS (1995, 2000, 2004, 2010)

Structure of FAVOR

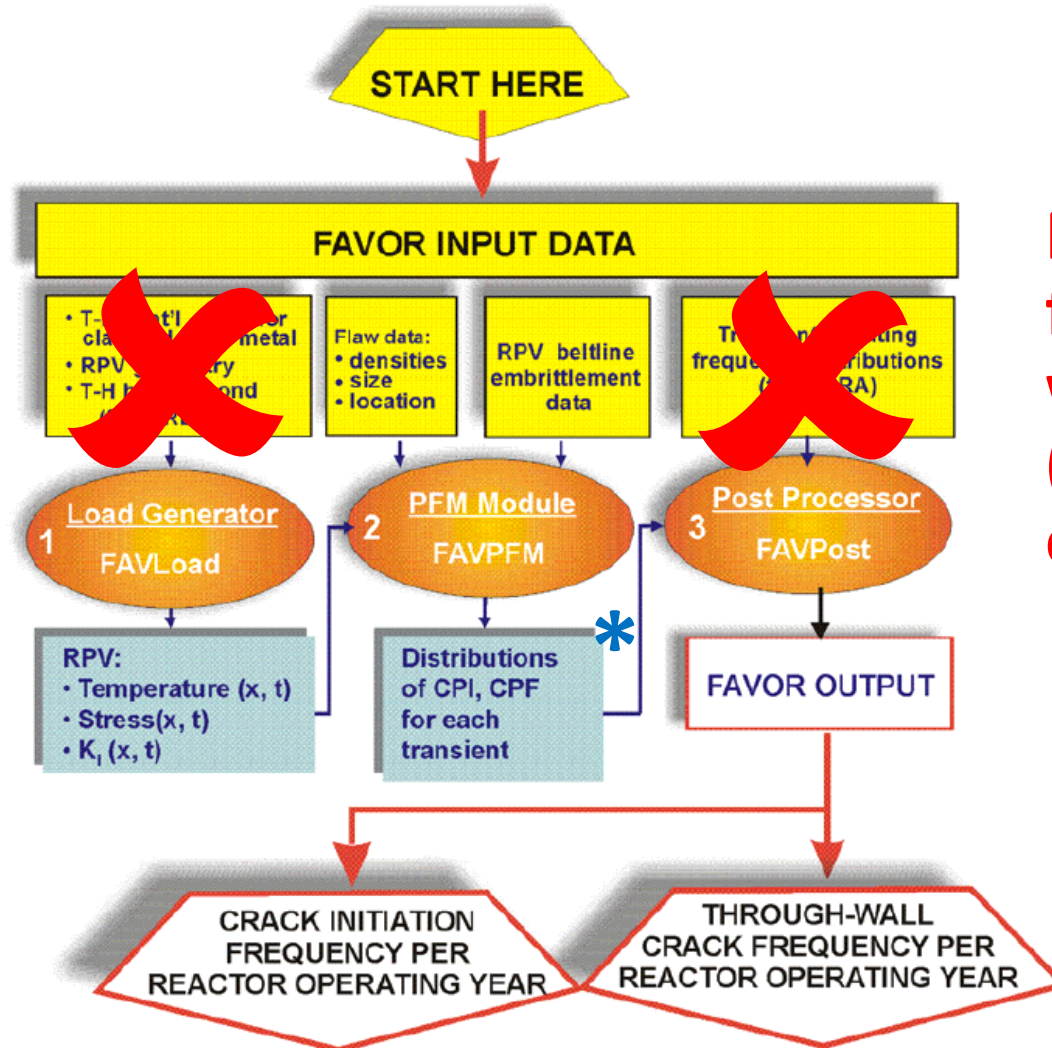
As used for PTS



Structure of FAVOR

As used in this study

Loading
follows
allowed P-T
limits

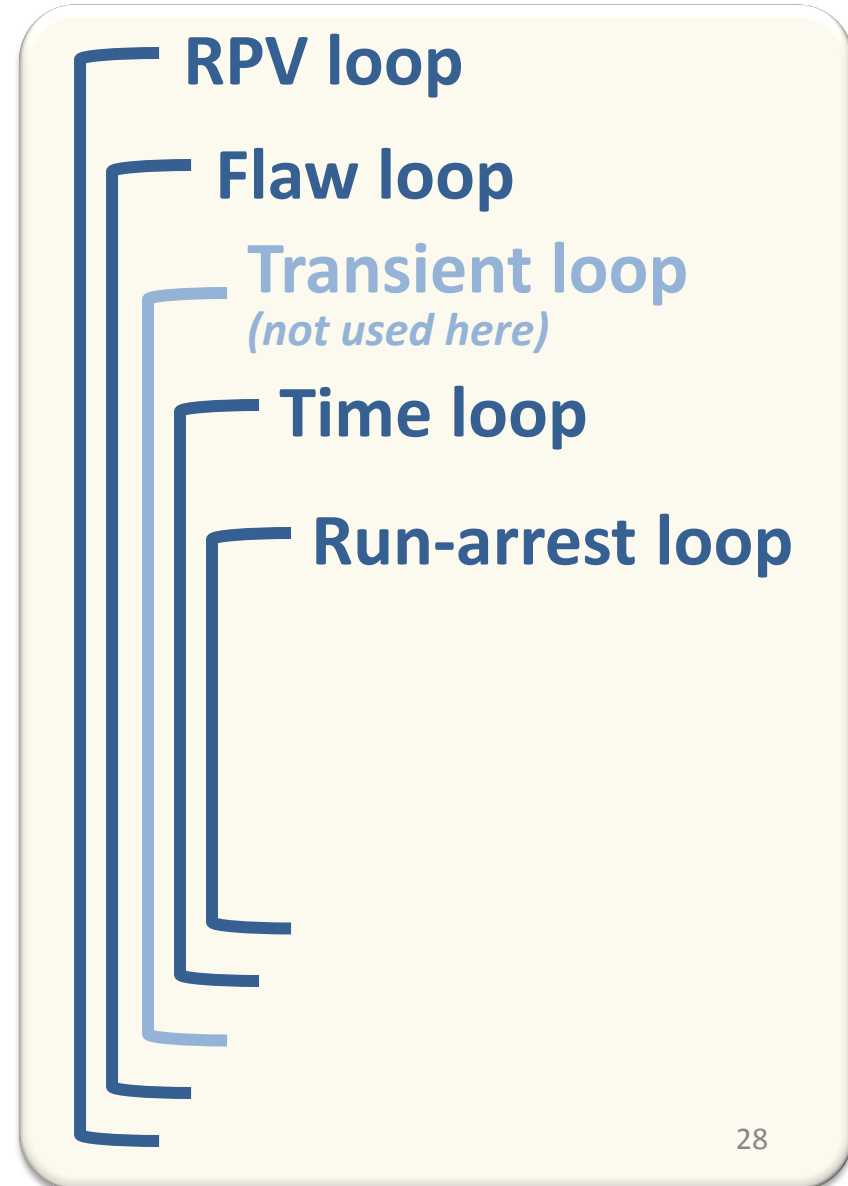


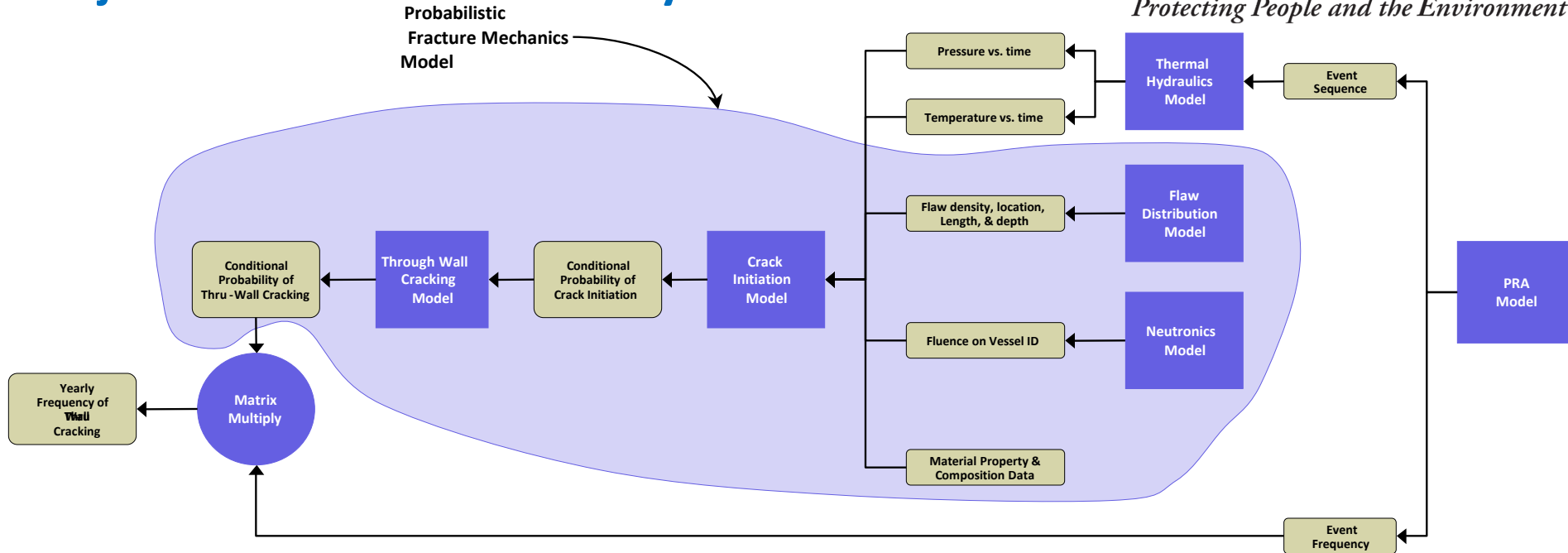
No event
frequency
weighting
(at project
outset)

* CPI = Conditional probability of crack initiation
CPF = Conditional probability of vessel failure

FAV-PFM Module

- Nested loop structure
- Monte Carlo simulation





• Treatment of uncertainties

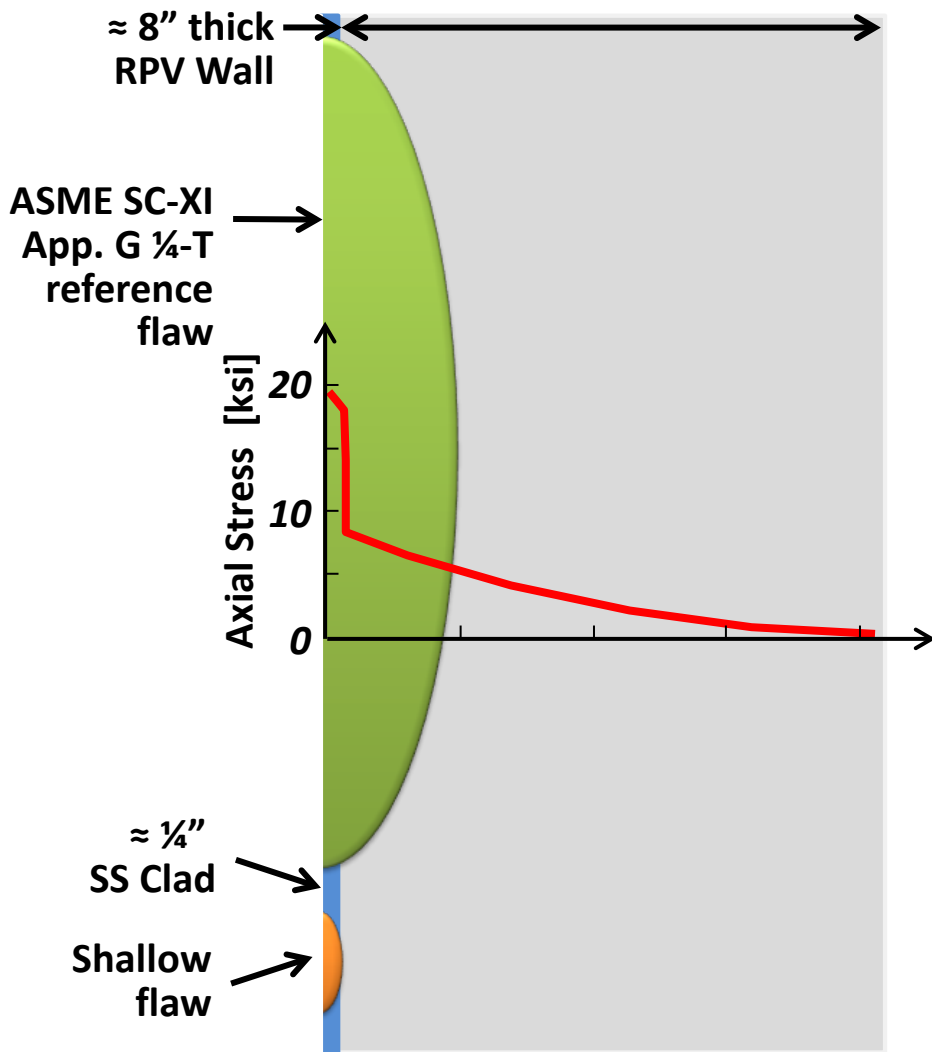
- Assessed in all cases
- Modeled if important/significant, aleatory or epistemic as appropriate
- If less significant: represented as a constant
- If not enough data: treated conservatively

Technical Issues #1 and #2

SHALLOW ID SURFACE BREAKING FLAWS (SBF) AND THE FAVOR CLADDING MODEL

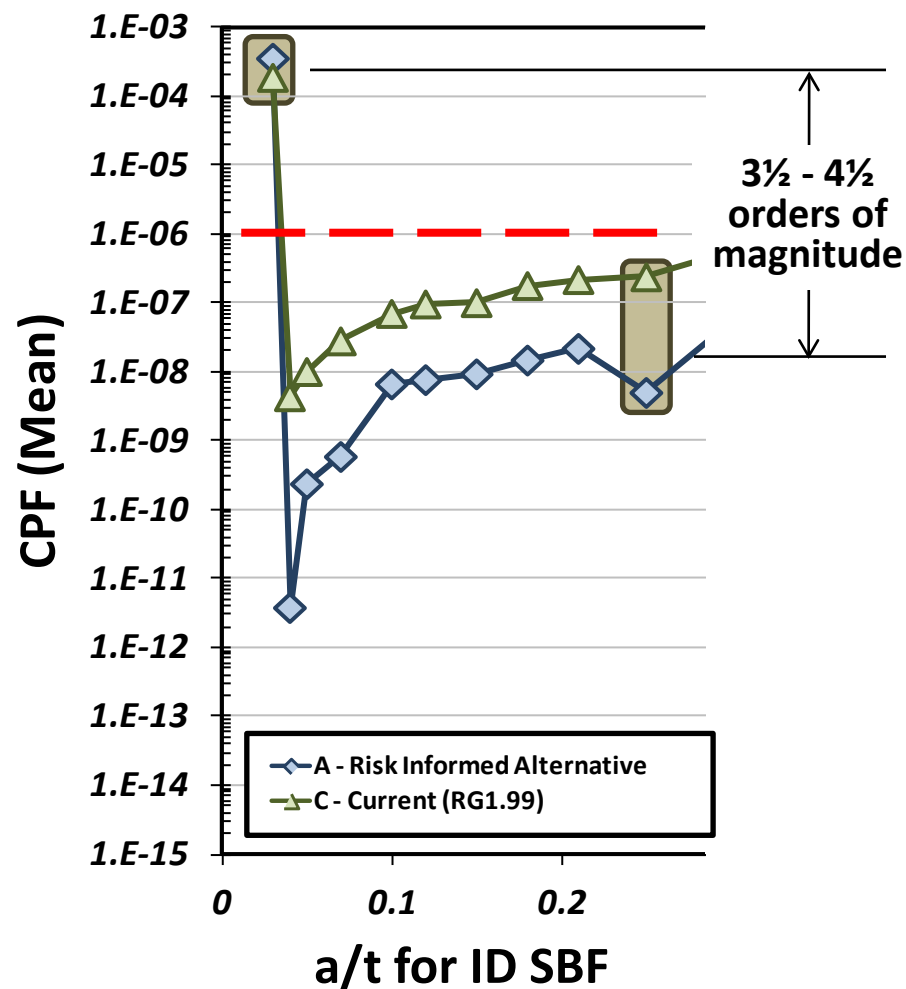


Reason for Detailed Evaluation of Clad Model (& SBFs)



PWR Plant A

Cooldown @ 100 °F/hr, $RT_{MAX(AW)} = 247$ °F



Clad Model & SBFs

Outline

- ORNL/TM-2012/489 provides full details
- Topics discussed here
 - **Flaws**: Basis for including SBFs in FAVOR's population of flaws sampled
 - **Stresses**: Additional stress generated by the cladding
 - Analytical representation
 - Experimental basis
 - **Probability**: Effect on FAVOR calculated initiation and failure probabilities
 - Normal cooldown following P-T limits
 - Normal cooldown following plant P-T records
 - Rapid (PTS) cooldowns

ORNL/TM-2012/489

The Effect of Shallow Internal Surface-Breaking Flaws on the Probability of Brittle Fracture of Reactor Vessels Subjected to Normal Cool-Down Transients

Prepared by

Terry L. Dickson, B. Richard Bass, and Paul T. Williams
Oak Ridge National Laboratory

Robert H. Dodds, Jr.
Professional Consulting Services
1416 Brookmeade Avenue
Maryville, TN 37804

Prepared for
U.S. Nuclear Regulatory Commission

Prepared by
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831-6285
Managed by
UT-BATTELLE, LLC
For the
U.S. DEPARTMENT OF ENERGY
Under contract DE-AC05-00OR22725

SBFs in Cladding

Basis

Nondestructive & destructive evaluation of PVRUF RPV



46 sq-ft of cladding

[1998-2000]

Welding simulations using the PRODIGAL code

[Chapman & Simonen, 1998]

Cladding exams at Bettis

[Li & Mabe, 1998]

NRC Expert Elicitation

[Jackson & Abramson 2000]

ORNL/TM-2012-489 (Section 2.1)

- Reviews CR6817 & operating experience
 - IGSCC in Quad Cities 2
 - IGSCC in Japan Power Doubling Reactor
- No significant new data/knowledge on this topic has become available since 2003

NUREG/CR-6817, Rev. 1,
Simonen, et al., "A
*Generalized Procedure for
Generating Flaw Related
Inputs for the FAVOR Code,*"
[2003]

FAVOR Clad SBF Model

- All flaws oriented circumferentially
- All flaws of depth = cladding thickness (rounded up to nearest 1/100th of wall thickness)
- Distribution of aspect ratios from 2:1 to ∞
- 0.0037 flaws/ft² of ID area (\approx 2-3 per vessel)

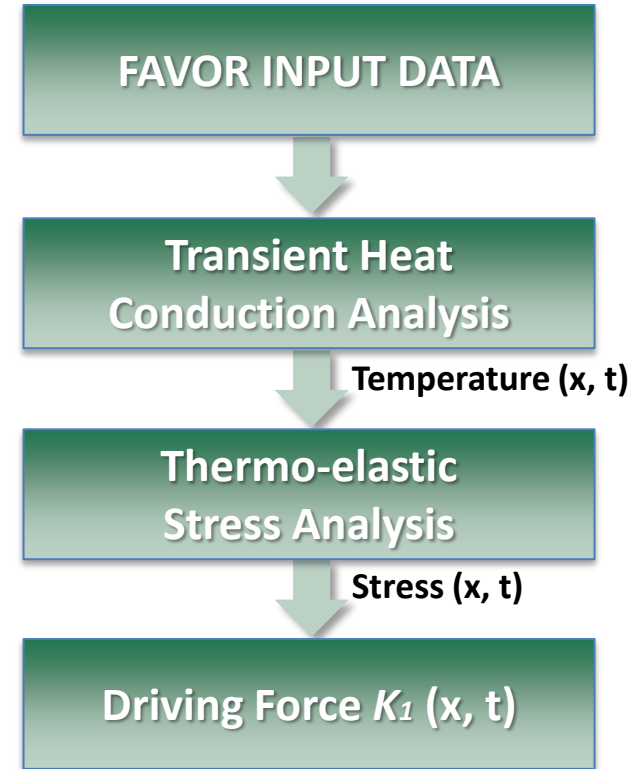
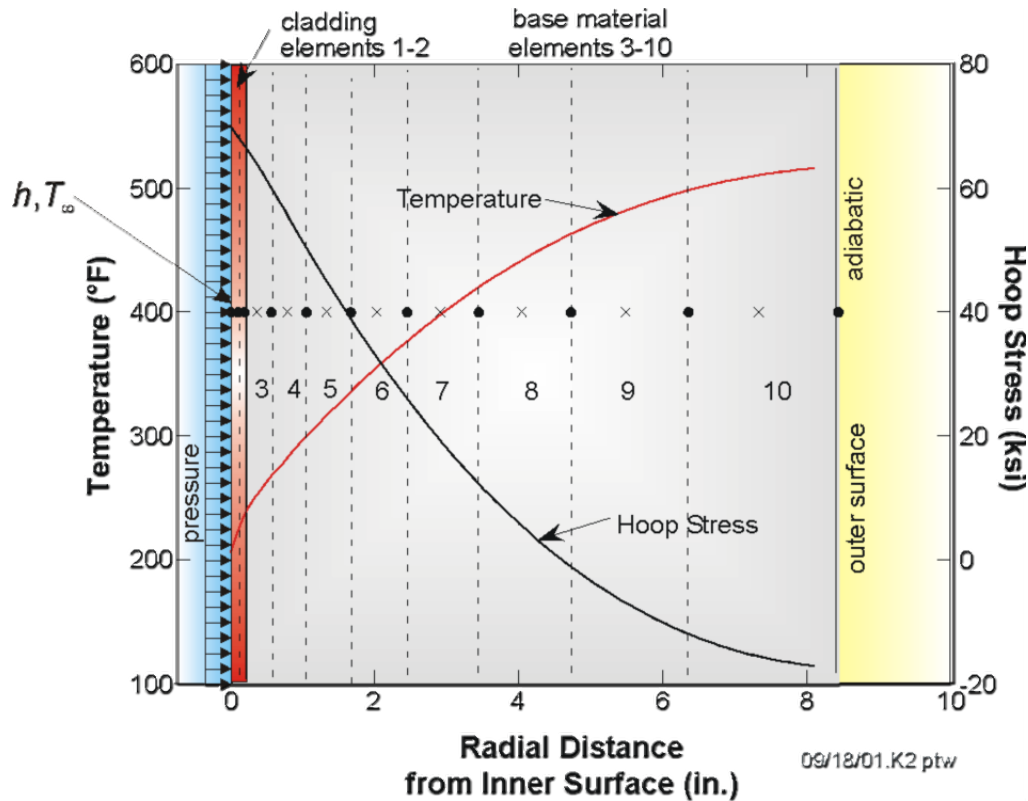
SBFs in Cladding

Current Evaluation

- Based on NUREG/CR 6817(R1) & ORNL/TM-2012-489, the staff finds the model of SBFs size and density in FAVOR acceptable
- The industry's model supporting the R-I additions to ASME SC-XI App. G [EPRI MRP-250] did not consider SBFs
- For SBFs, FAVOR calculates high CPI/CPF values for both the R-I and current ASME methods

FAVOR Clad Stress Model

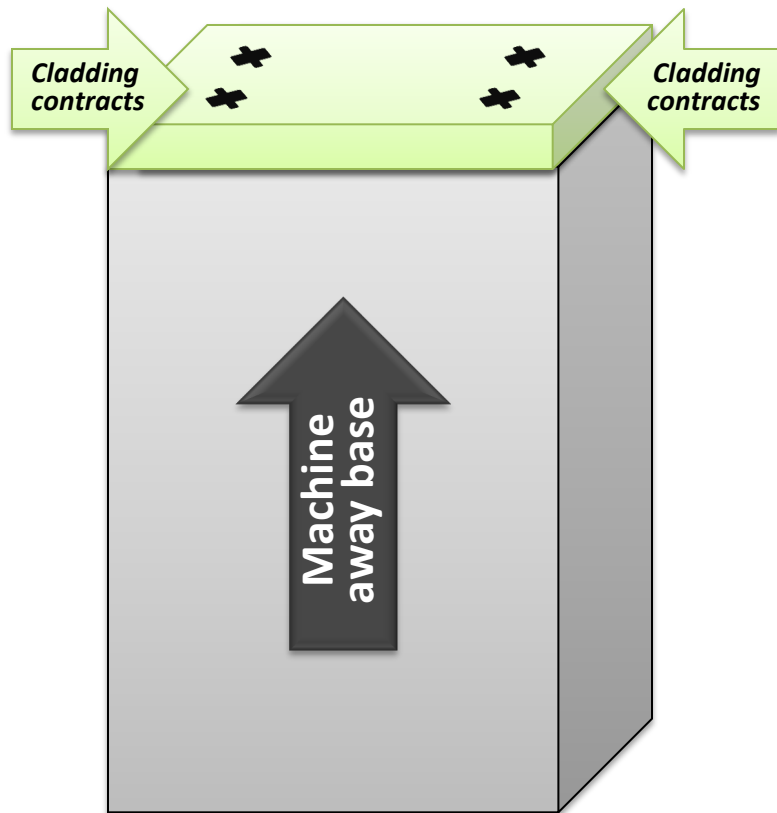
Transient heat conduction & thermo-elastic stress analyses performed using 1D axisymmetric finite element model of un-cracked RPV wall.



$$\sigma_{\theta\theta} = \frac{E}{(1+\nu)(1-2\nu)} \left[(1-\nu)\epsilon_{\theta\theta} + \nu\epsilon_{rr} \right] - \frac{\alpha E}{1-2\nu} (T - T_{ref})$$

Next: Determine T_{ref} from measurements

Determine T_{ref} from Measurements on PVRUF



Measured Displacements from Test Blocks at 70°F

Displacements used as Inputs to Finite Element Analysis

Produces 21.3 ksi Tensile Stress in Clad at 70 °F due to Differential Thermal Expansion

Model RPV with Assumed Uniform Temperature at 70°F

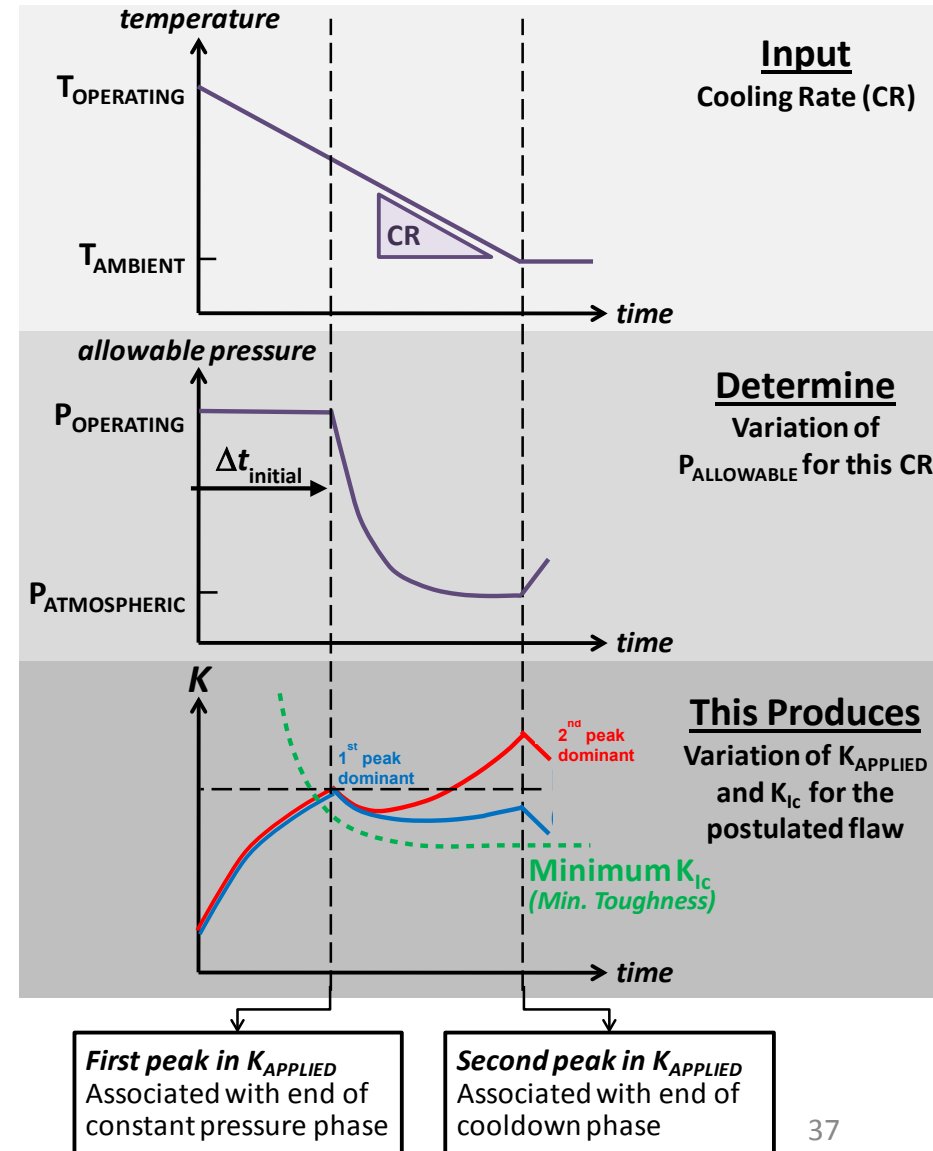
Stress Free Temperature of 488 °F Produces Tensile Stress of 21.3 ksi in Clad at 70 °F *

* Clad stresses, and therefore applied-K, are maximum when the RPV is cold.

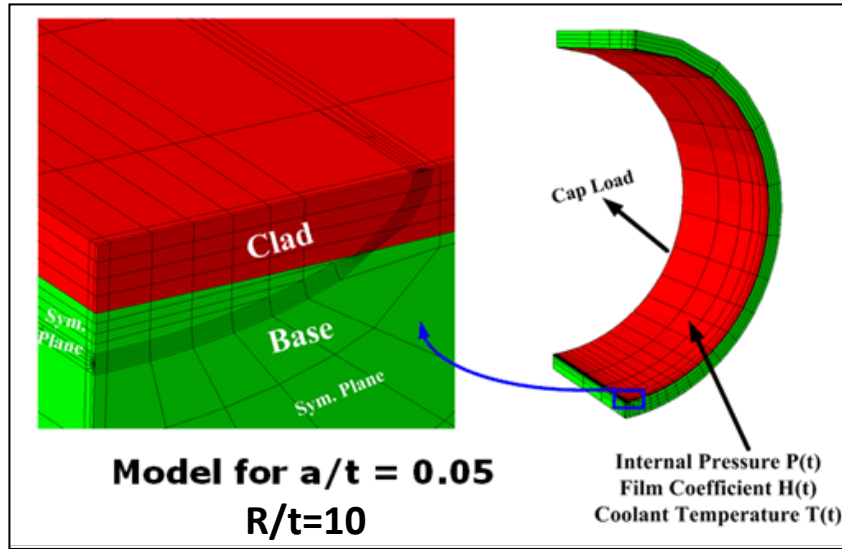
Applied K During a Cooldown

Schematic

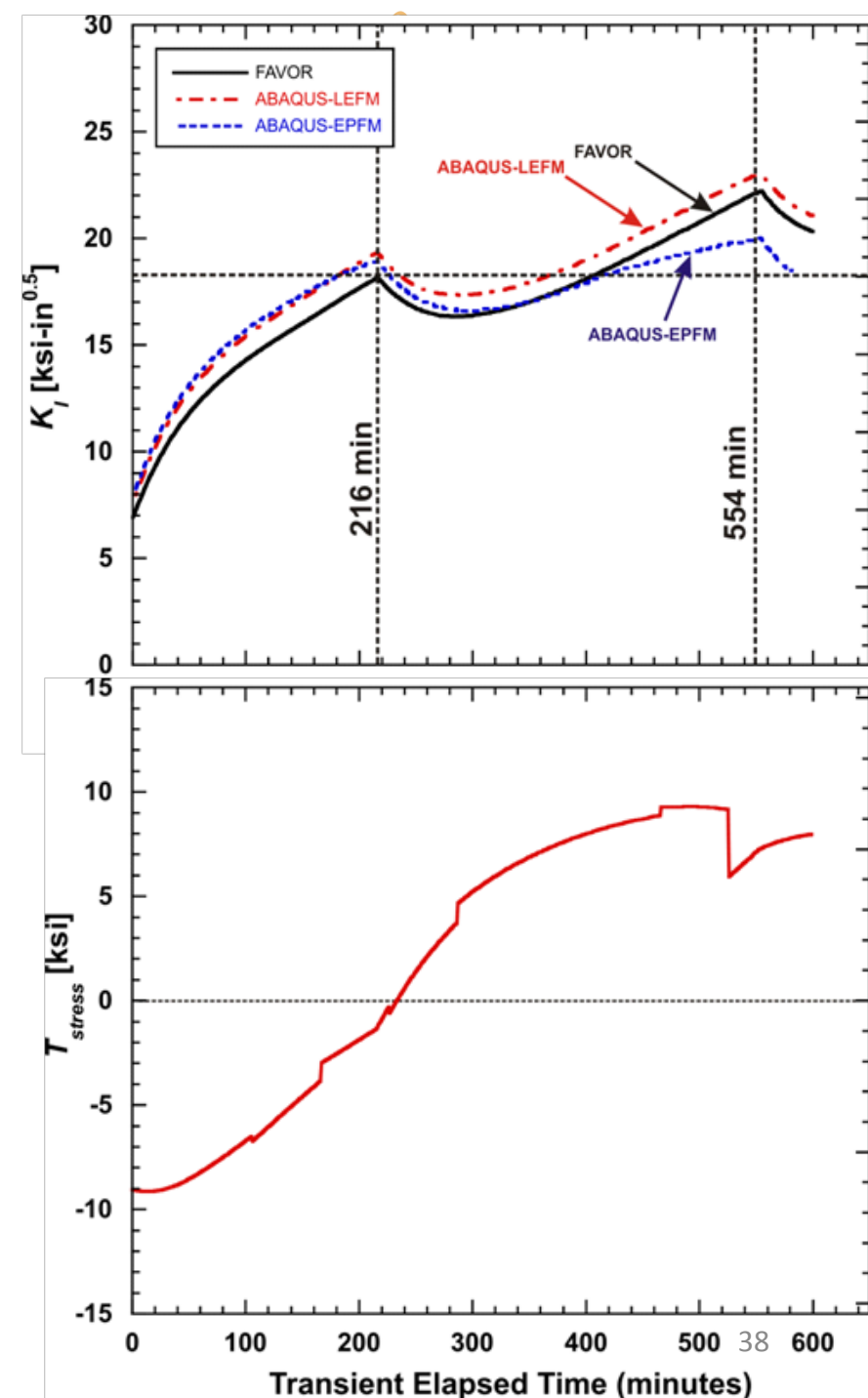
- Greatest ΔT from stress free temperature of 488 °F occurs at room temperature
- Depending on specific
 - Flaw,
 - Cooling rate,
 - Geometry, etc.this can generate the peak K for the transient
- If peak K exceeds minimum toughness, this controls failure probability



FAVOR K Solutions Compared to ABAQUS

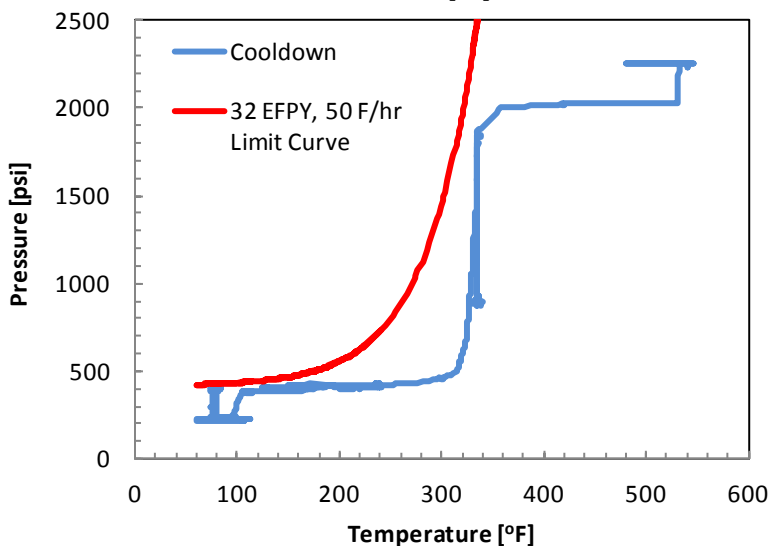
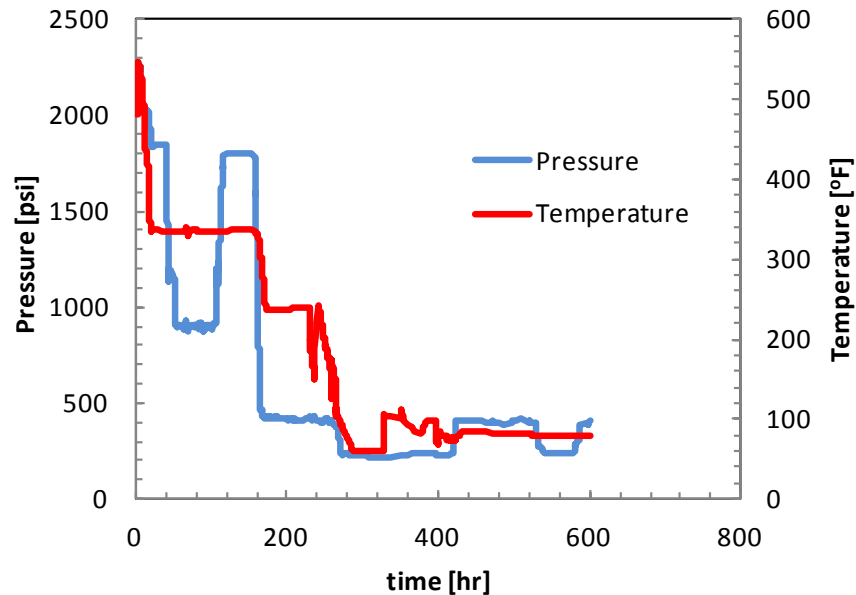


- **LEFM**: FAVOR within 4% of ABAQUS (much less difference when crack depth not interpolated)
- **EPFM**
 - FAVOR within 13% of ABAQUS
 - Plasticity mitigates, but does not eliminate, the 2nd peak
- **Constraint loss?**: Even shallow flaws have high constraint at 2nd peak, so single parameter flaw assessment as done in FAVOR remains appropriate



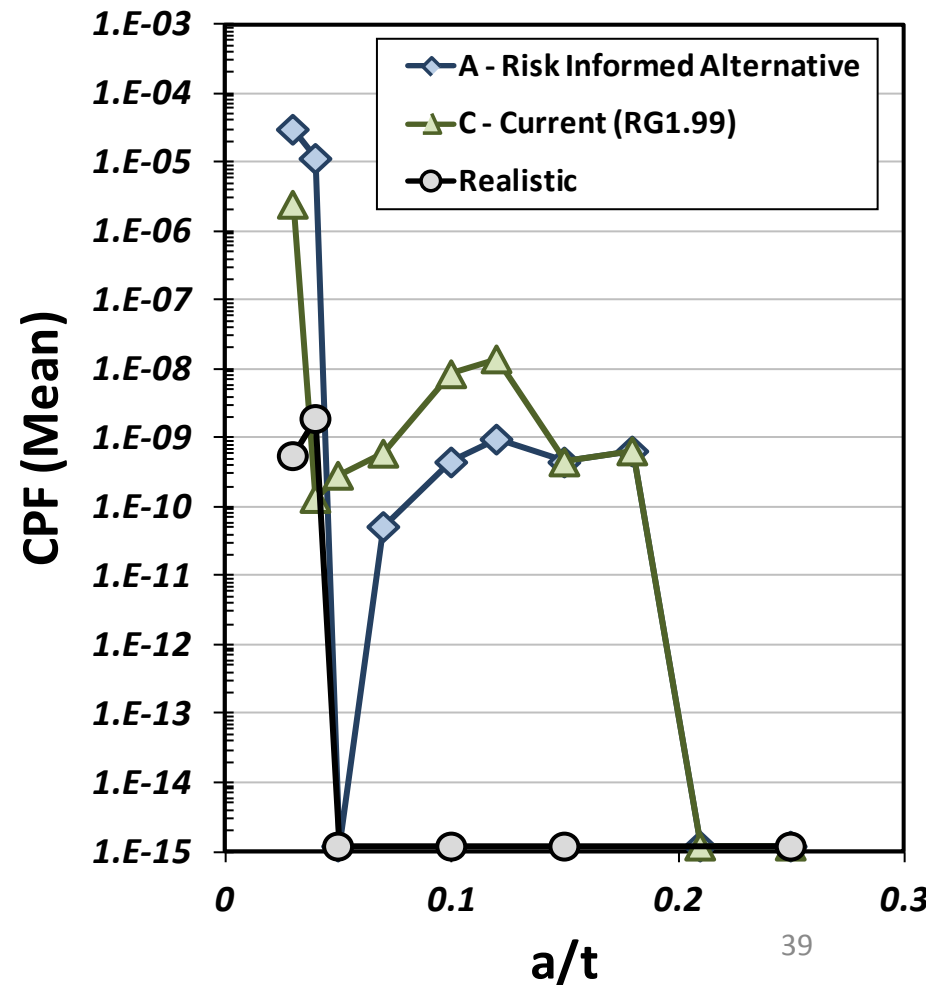
Comparison of CPF for Actual vs. P-T Limit Cooldowns

Analysis of one transient (from ≈ 50 available)



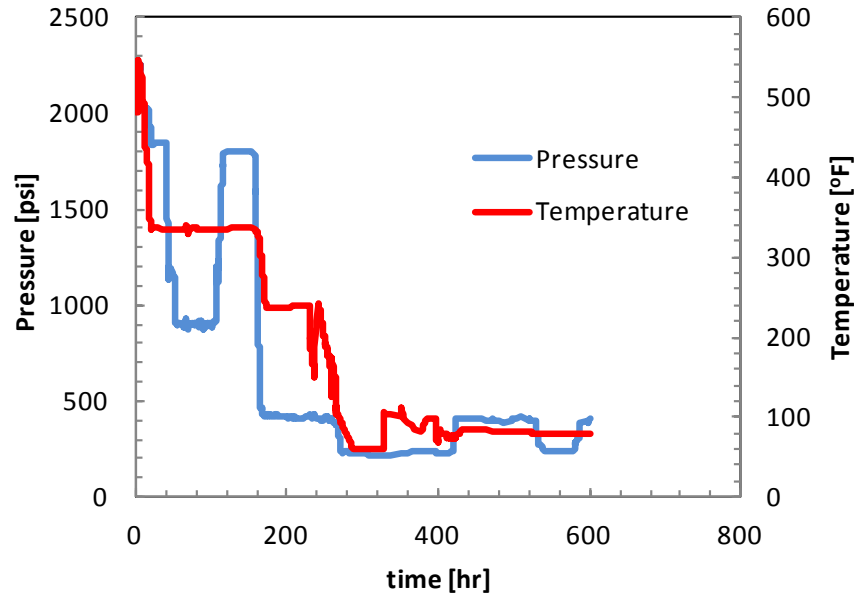
PWR Plant A

50 °F/hr, $RT_{MAX(AW)} = 222$ °F



Comparison of CPF for Actual vs. P-T Limit Cooldowns

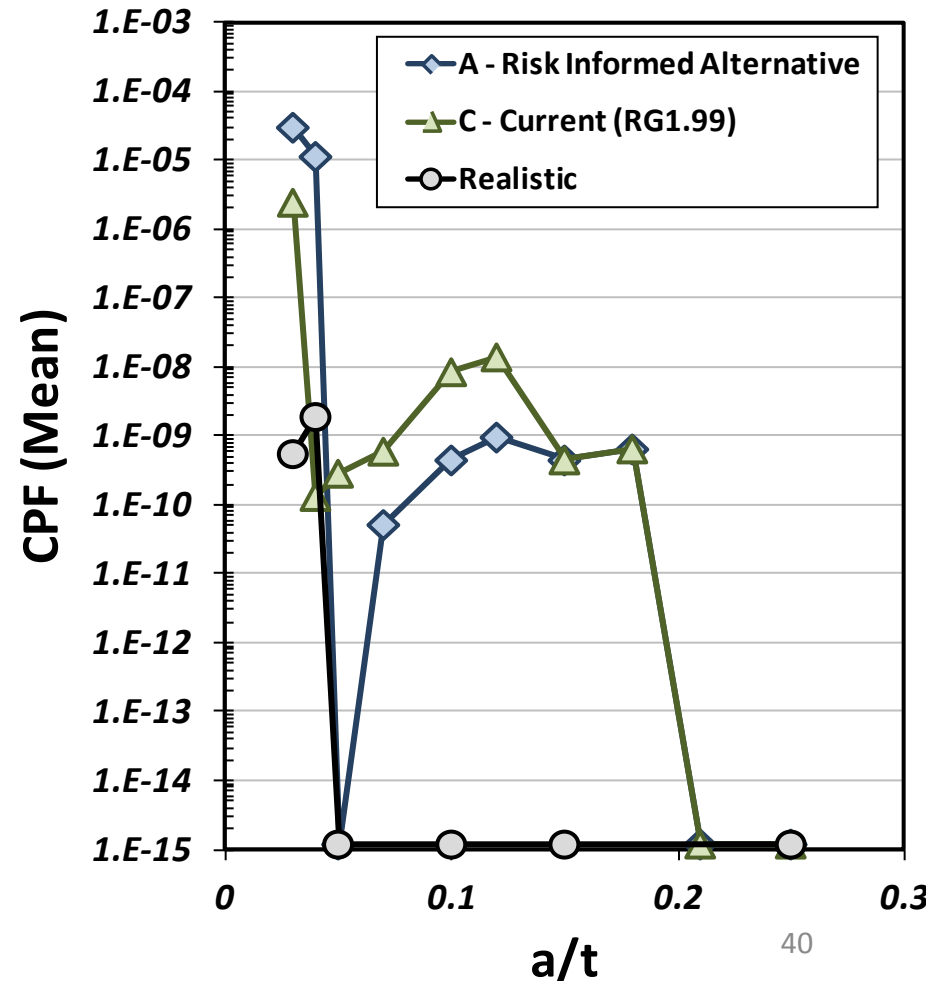
Analysis of one transient (from ≈ 50 available)



- Only shallow SBFs have non-zero CPF
- R-I transient has higher CPF than actual transient
- Current practice transient has CPF about the same as actual transient

PWR Plant A

50 °F/hr, $RT_{MAX(AW)} = 222$ °F



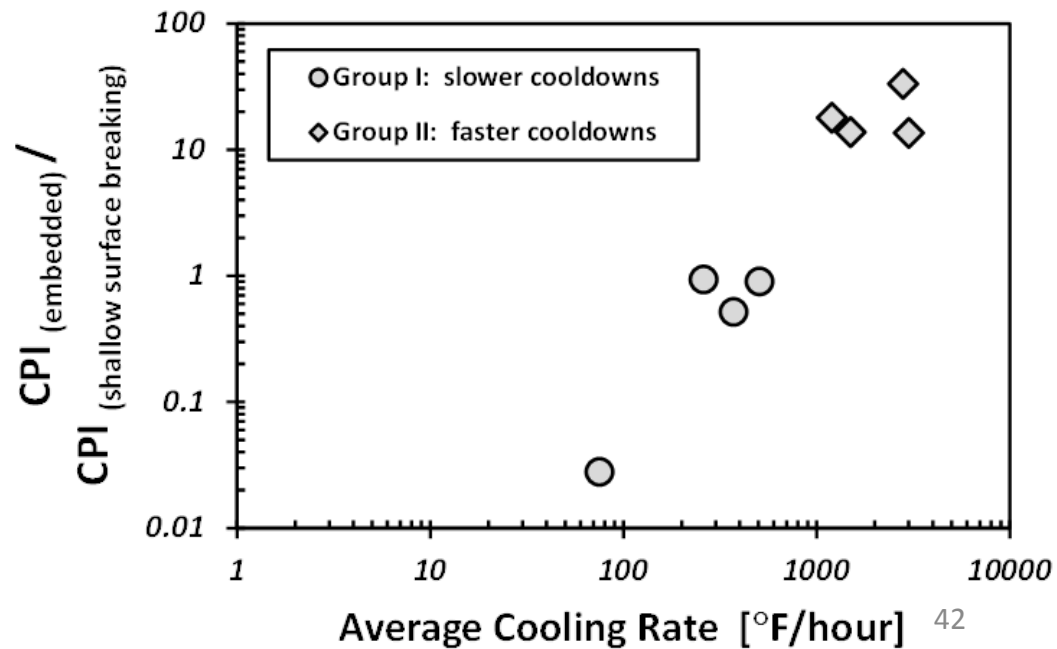
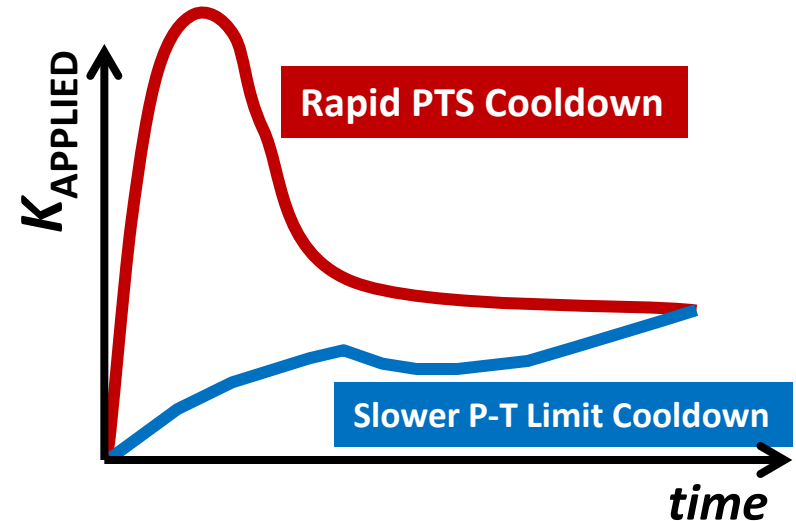
Comparison of CPF for Actual vs. P-T Limit Cooldowns

Summary

- **Considerable difference between P-T limits and actual cooldowns**
 - Other plant specific factors place constraints upon the actual cooldown curve in addition to those imposed by the CFR-G & ASME-G P-T limits
 - The CFR-G & ASME-G P-T limits are the current regulatory requirements
- **From these analyses**
 - Actual cooldowns have much lower CPF than cooldowns following P-T limits
 - 2nd peak in applied K still generates CPF for shallow flaws
 - Maximum calculated CPF = 10^{-9}

Effect of Cooldown Rate on CPI & CPF of SBFs

- SBFs not significant for PTS cooldowns (generally rapid)
- Rapid cooldown associated with accident transients produces high applied-K early, suppressing dominance of late peak in applied-K produced by cladding
- Assessment of PTS cooldowns in ORNL/TM-2012/489
 - below ≈ 100 °F/hr shallow flaws in cladding dominate CPI & CPF relative to embedded flaws



Clad Model & SBFs

Summary

- **Flaws**
 - Model established in NUREG/CR 6817(R1)
 - Staff continues to find this model acceptable
- **Stresses**
 - Simplified model, based on experiments
 - Benchmarked successfully to ABAQUS
 - Clad stresses maximum at room temperature
- **Probability**
 - Higher for cooldowns along P-T limits
 - Lower for actual cooldowns
 - SBFs significant only at slow cooling rates

ORNL/TM-2012/489

The Effect of Shallow Internal Surface-Breaking Flaws on the Probability of Brittle Fracture of Reactor Vessels Subjected to Normal Cool-Down Transients

Prepared by

Terry L. Dickson, B. Richard Bass, and Paul T. Williams
Oak Ridge National Laboratory

Robert H. Dodds, Jr.
Professional Consulting Services
1416 Brookmeade Avenue
Maryville, TN 37804

Prepared for
U.S. Nuclear Regulatory Commission

Prepared by
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831-6285
Managed by
UT-BATTELLE, LLC
For the
U.S. DEPARTMENT OF ENERGY
Under contract DE-AC05-00OR22725

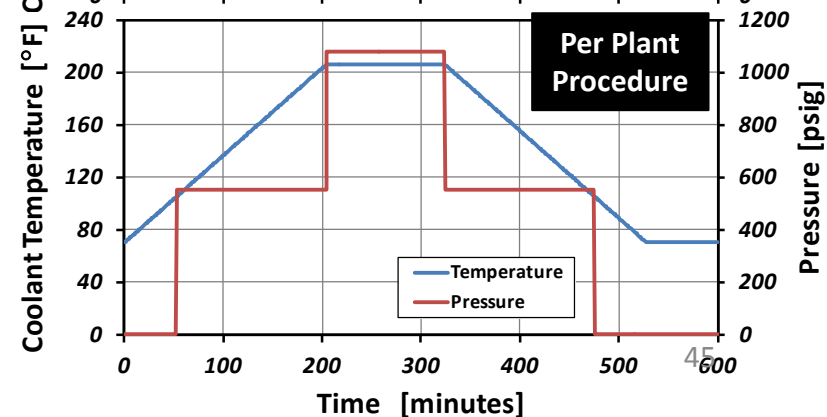
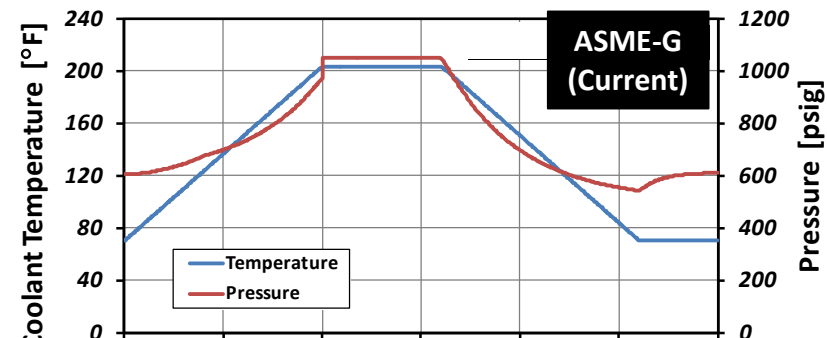
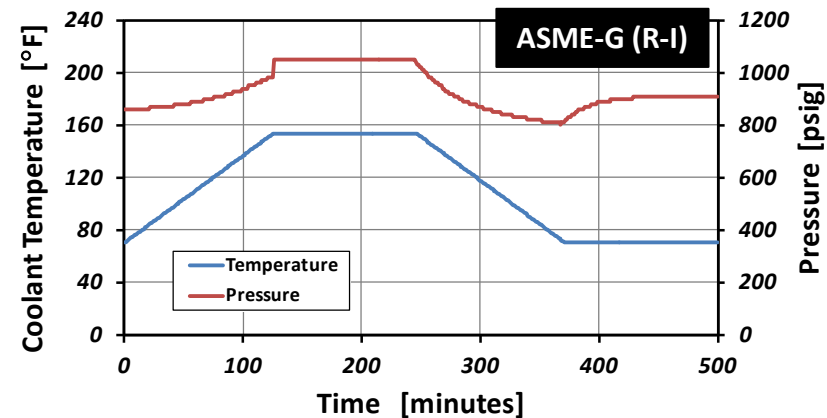
Technical Issue #3

OPERATING PRESSURE LEAK TESTS IN BOILING WATER REACTORS

Examination of Leak Tests in BWRs

TLR-RES/DE/CIB-2014-009

- Used as an example of the challenges presented by SBFs
- Leak tests include both heatup and cooldown
- In BWRs, leak tests occur at the start of every operating cycle
 - Between 1/year and 0.5/year
- So for leak tests, $CPF \approx$ through wall cracking frequency
 - 10^{-6} /year limit on TWCF used in PTS re-evaluation project



Loadings Examined

Leak Test Temperature

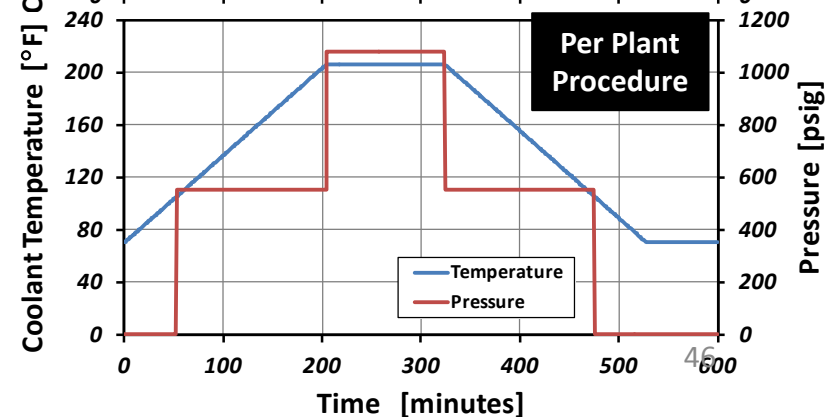
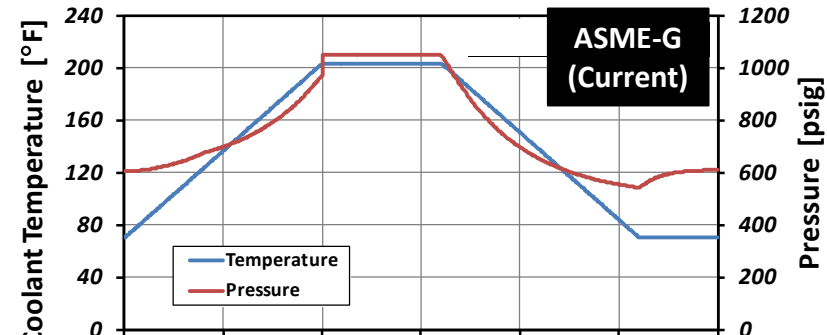
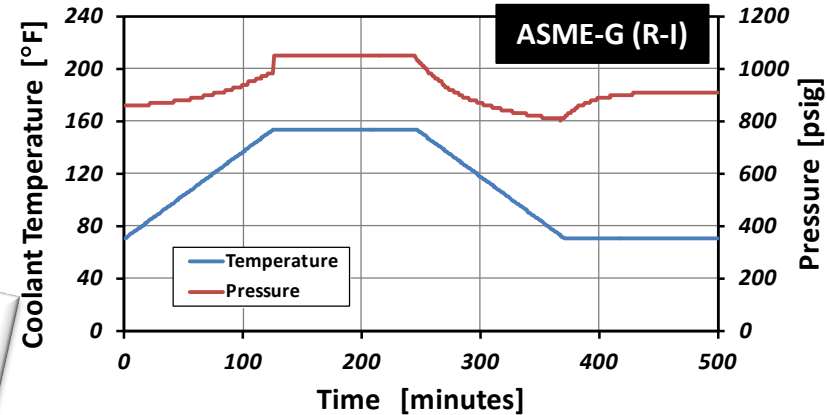
$$T_{LEAK} - RT_{NDT(I)} = Margin + \beta + \frac{1}{0.02} \times \ln \left\{ \frac{F_2 \times Rate \times t^{2.5} + \frac{\alpha \times F_1 \times P_{OPER} \times R_i}{\sqrt{t}} - 33.2}{20.734} \right\}$$

Max Pressure

$$P_{MAX} = [33.2 + 20.734 \exp[0.02(T - \{RT_{NDT} + \beta\})] - F_2 \times Rate \times t^{2.5}] \times \left[\frac{t}{R_i} \right] \times \left[\frac{1}{\alpha F_1 \sqrt{t}} \right]$$

		Current	R-I
Leak	α	1.5	1
	β	0	60
ETC		RG1.99	50.61a
Margin		RG1.99	zero

Following P-T Limits



	Plant Procedure
ETC	RG1.99
Margin	RG1.99

Following BWR Plant Procedure

Flaws, or Flaw Populations, Examined

- Flaw populations that formed the basis of 10 CFR 50.61a
 - NUREG/CR-6817(R1) (i.e., FAVOR) embedded flaw population
 - NUREG/CR-6817(R1) (i.e., FAVOR) population of cladding SBFs on the vessel ID
- The single $\frac{1}{4}$ -t 6:1 surface breaking flaw that establishes P-T limits
 - For comparison to failure probabilities for flaws that formed the basis of 10 CFR 50.61a
 - To assess the current ASME approach

CPI and CPF Results

- Table summarizes results for the condition examined
- Results for other plants (other R/t) and lower embrittlement levels similar
- Following slides examine each flaw population individually

Loading Method	Surface breaking flaw population ⁽¹⁾		Embedded flaw population		Individual 6:1 ¼t surface breaking flaw	
	CPI ⁽²⁾	CPF ⁽³⁾	CPI	CPF	CPI	CPF
ASME-G (R-I)	1.8E-4	1.6E-4	5.7E-8	5.7E-8	7.2E-5	7.2E-5
ASME-G (Current)	6.7E-5	4.3E-5	1.0E-14	1.0E-14	1.7E-6	1.7E-6
Per Plant Procedure	8.6E-6	2.9E-6	2.5E-13	2.3E-13	1.7E-6	1.7E-6

Notes:

(1) The surface flaw depth is 0.04t as this is the flaw depth that penetrates the cladding thickness (rounded up to the nearest 1/100th of the total vessel wall thickness). This depth conforms to the FAVOR flaw model used in the development of 10 CFR 50.61a [15].

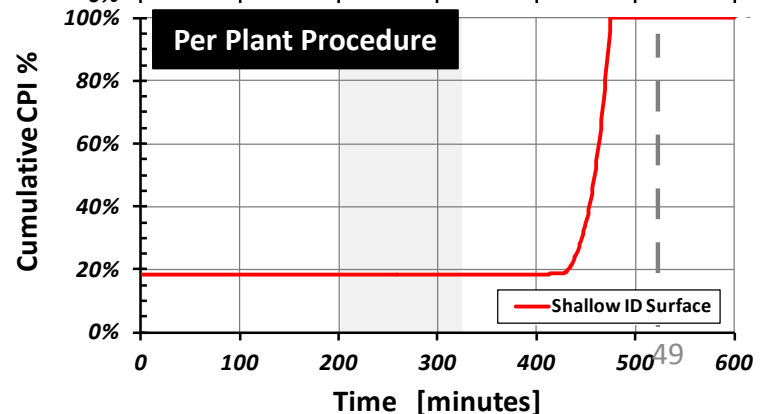
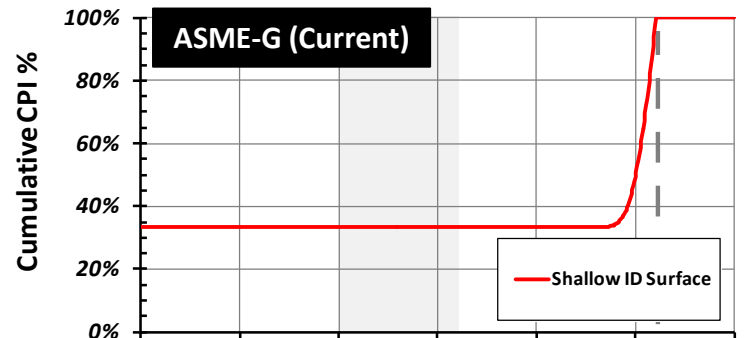
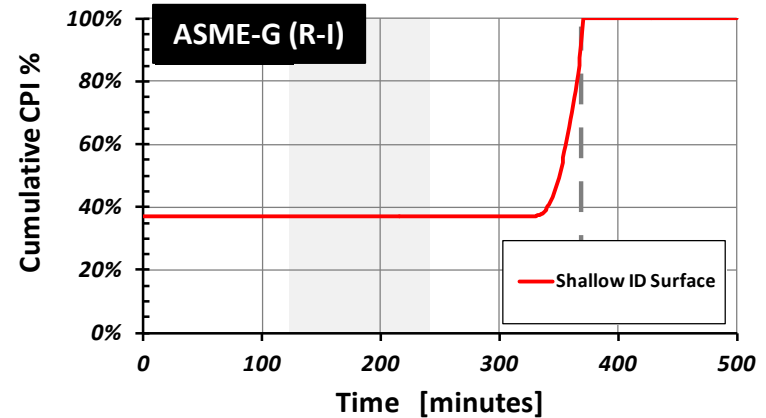
(2) CPI: Conditional probability of crack initiation.

(3) CPF: Conditional probability of vessel failure (i.e., through-wall cracking).

SBFs

Time of CPI/CPF Accumulation

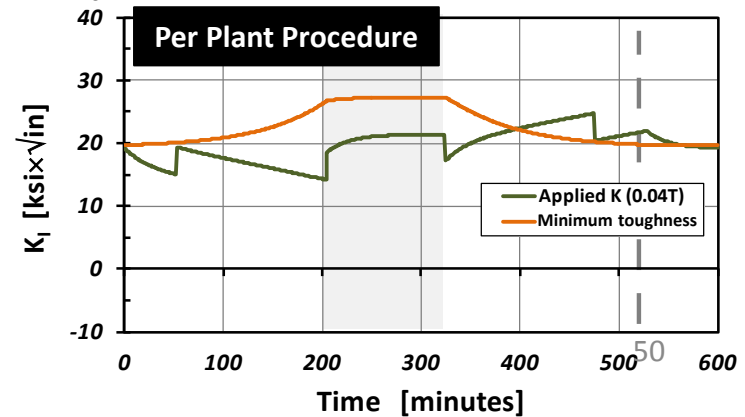
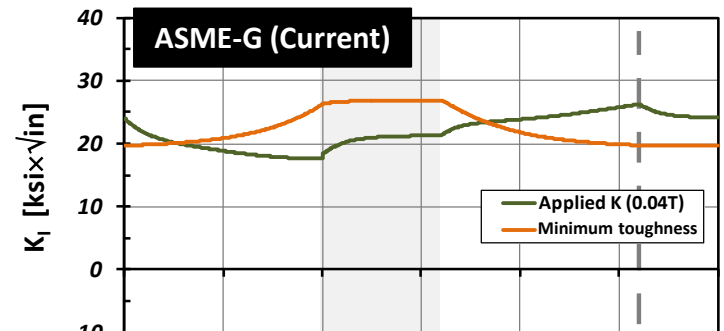
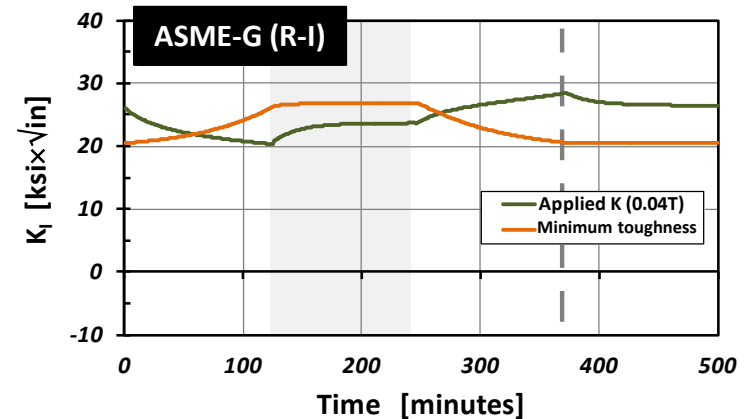
- Irrespective of loading method, all CPI/CPF accumulates when the RPV is near room temperature



SBFs

Applied K vs. time

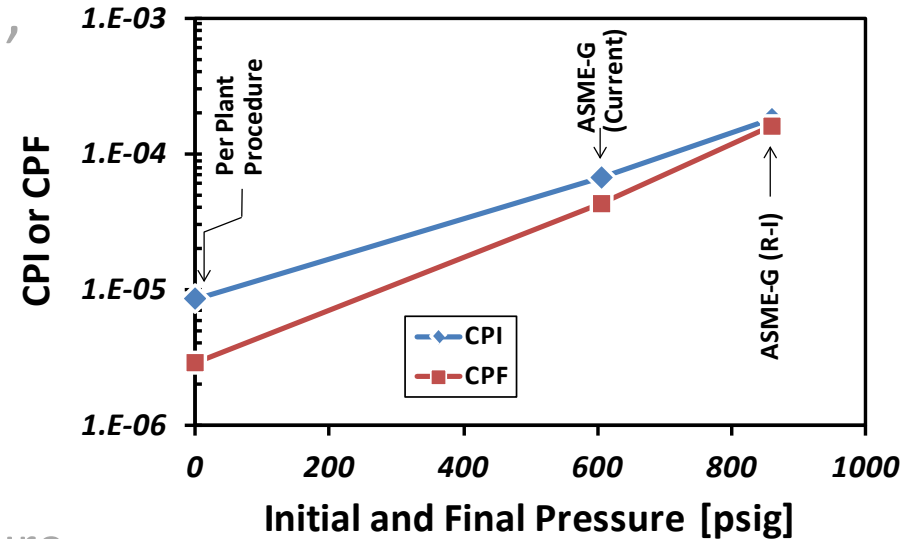
- Irrespective of loading method, all CPI/CPF accumulates when the RPV is near room temperature
- Applied K exceeds toughness only at these times, not during the pressure hold that constitutes the leak test
 - Changing the leak test temperature and/or pressure will not change this result



SBFs

Effect of Initial/Final Pressure

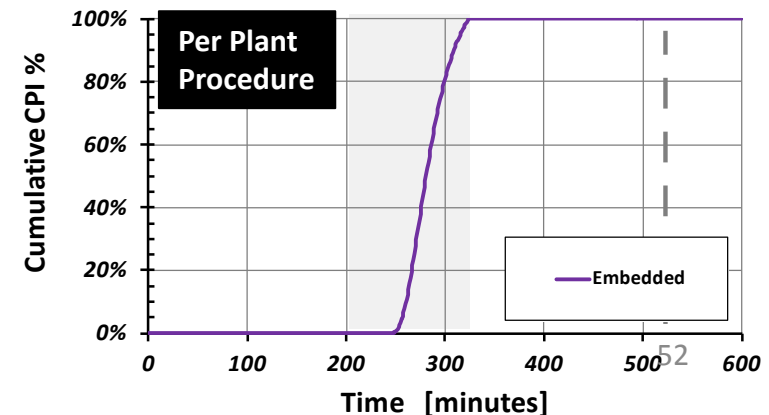
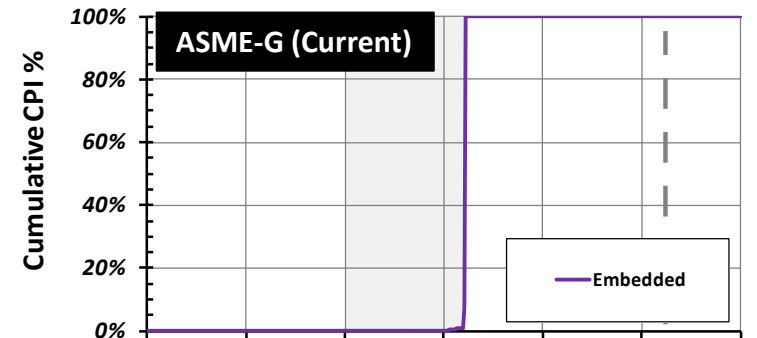
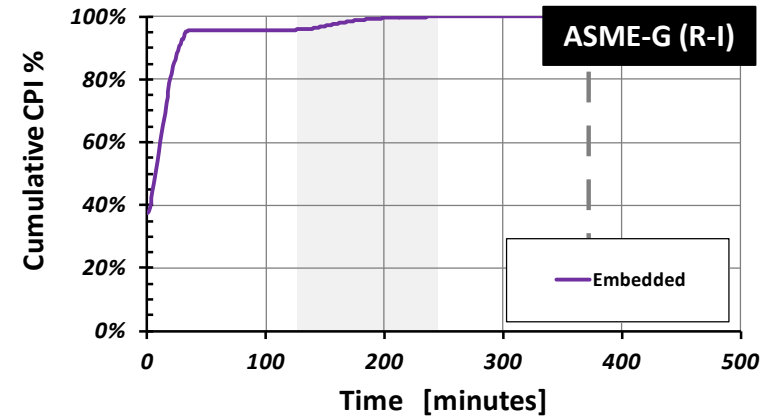
- Irrespective of loading method, all CPI/CPF accumulates when the RPV is near room temperature
- Applied K exceeds toughness only at these times, not during the pressure hold that constitutes the leak test
 - Changing the leak test temperature and/or pressure will not change this result
- Initial / final pressure
 - Increased pressure allowed by R-I increases CPI/CPF
 - Even at the lower pressures allowed by current practice (or zero pressure following plant procedure) CPI/CPF remain above 10^{-6}



Embedded Flaws

Time of CPI/CPF Accumulation

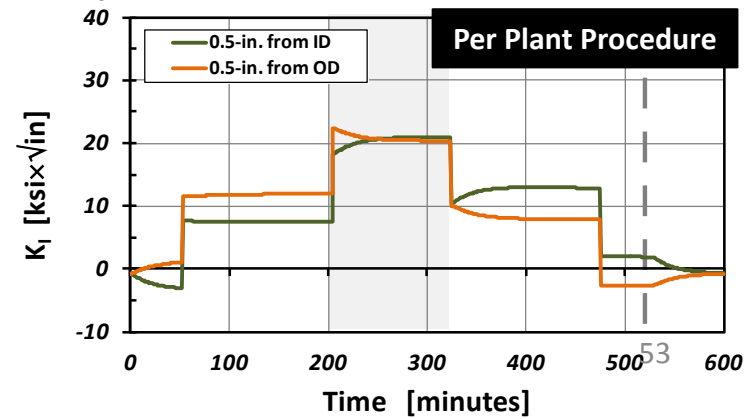
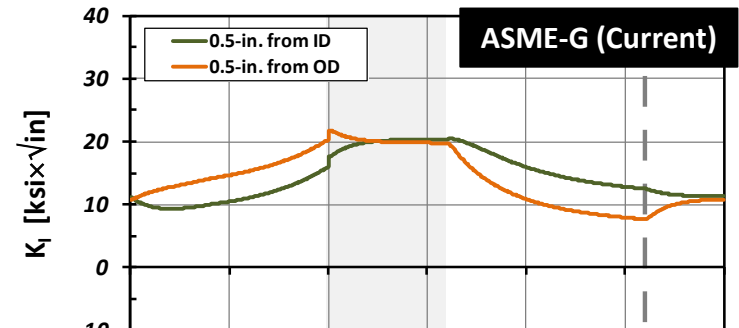
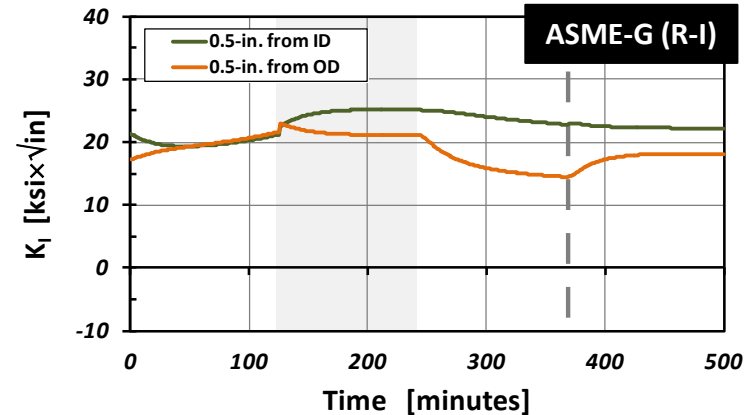
- Time of CPI accumulation depends on loading method



Embedded Flaws

Applied K vs. time

- Time of CPI accumulation depends on loading method
- K vs. time plots provide insights regarding which embedded flaws contribute
 - R-I: both flaws near ID & OD
 - Current: only near ID
 - Plant Procedure: Only near ID
- Plots also show that R-I loading shifts portion of transient responsible for CPI/CPF to the heatup portion, not the leak test



Embedded Flaws

CPI/CPF Values

- Loading along R-I P-T limits
 - Increases CPI/CPF versus current P-T limits
 - Changes time during the transient that produces CPI/CPF to that leading up to the leak test, not the duration of the leak test itself
- CPI and CPF values remain well below 10^{-6} for embedded flaws

Loading Condition	Pressure at T=0 [psi]	Leak Test Temperature [°F]	CPI				
			Total	% before leak test	% during leak test	CPI at T=0	CPI at leak test
ASME-G (R-I)	860	154	5.7E-8	95.5%	4.5%	5.7E-8	3E-9
ASME-G (Current)	606	204	1E-14	0%	100%	0	1E-14
Per Plant Procedure	0	204	2.5E-13	0%	100%	0	2.5E-13

Leak Tests of BWRs

Summary

- **SBFs**
 - CPI / CPF increased by R-I alternative
 - CPI & CPF $> 10^{-6}$ for all loading conditions evaluated, including plant procedure and current limits
 - Changing the leak test temperature or pressure will not alter these results
- **Embedded flaws**
 - CPI & CPF increased by R-I alternative
 - CPI & CPF $< 10^{-6}$ for all loading conditions evaluated
 - R-I alternative changes the time of transient that produces CPI/CPF to that occurring before the leak test

Technical Letter Report
TLR-RES/DE/CIB-2014-009

***Probabilistic Fracture Mechanics Analyses of
Operating Pressure Leak Test Transients for
Boiling Water Reactors***

Date: July 30, 2014

Prepared by:

Mark T Kirk
Senior Materials Engineer
Component Integrity Branch

Gary L. Stevens
Senior Materials Engineer
Component Integrity Branch

Terry L. Dickson
Oak Ridge National Laboratory

NOTE: While NRR staff have been briefed on the contents of this report they have not yet had the opportunity to review the report due to resource constraints. This report has been reviewed by RES management.

Division of Engineering
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001



Wrap Up

NEXT STEPS

Next Steps

- **Receive ACRS feedback and comments**
- **Complete documentation of existing work**
 - 12 technical letter reports
 - 1 NUREG
- **Comprehensive review of conservatisms in the FAVOR model. Builds off a similar examination during PTS project [NUREG-1808, 2006].**
- **Detailed investigations of factors identified as significant**
 - Currently: FAVOR cladding stress model
 - Others topics will be investigated as identified, contingent on resources, for example
 - Elastic plastic effects
 - Load history effects
 - Actual loading instead of loading along P-T limits
 - Effects of corrosion on crack driving force
 - Measurement of cladding residual stresses
 - Peer review will be sought in various forums
- **These and other research plans are consistent with NRR needs, and the current User Need Request (NRR-2014-007)**

Questions or Comments?