



**UNITED STATES  
NUCLEAR REGULATORY COMMISSION  
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS  
WASHINGTON, DC 20555 - 0001**

June 25, 2015

MEMORANDUM TO:           ACRS Members

FROM:                   Christopher L. Brown, Senior Staff Engineer **/RA/**  
                              Technical Support Branch, ACRS

SUBJECT:                CERTIFICATION OF THE MINUTES OF THE ACRS  
                              METALLURGY AND REACTOR FUELS SUBCOMMITTEE  
                              MEETING, APRIL 7, 2015 - ROCKVILLE, MARYLAND

The minutes of the subject meeting were certified on June 25, 2015, as the official record of the proceedings of that meeting. A copy of the certified minutes is attached.

Attachment: As stated

cc w/o Attachment:   E. Hackett  
                              M. Banks

**NUCLEAR REGULATORY COMMISSION  
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS  
WASHINGTON, DC 20555 - 0001**

June 25, 2015

MEMORANDUM TO: Christopher L. Brown, Senior Staff Engineer  
Technical Support Branch, ACRS

FROM: Joy Rempe, Subcommittee Chairman for C-SGTR  
Metallurgy and Reactor Fuels Subcommittee

SUBJECT: CERTIFICATION OF THE MINUTES OF THE ACRS  
METALLURGY AND REACTOR FUELS SUBCOMMITTEE  
MEETING, APRIL 7, 2015 - ROCKVILLE, MARYLAND

I hereby certify, to the best of my knowledge and belief, that the minutes of the subject meeting on April 7, 2015, are an accurate record of the proceedings for that meeting.

|   |                     |
|---|---------------------|
| <u>                    /RA/                    </u>                             | <u>06/ 25 /2015</u> |
| Joy Rempe, Chairman,<br>Metallurgy and Reactor Fuels<br>Subcommittee for C-SGTR | Date                |

**ADVISORY COMMITTEE ON REACTOR SAFEGUARDS**  
**MINUTES OF THE ACRS METALLURGY AND REACTOR FUELS SUBCOMMITTEE**  
**MEETING**

April 7, 2015  
ROCKVILLE, MD

The ACRS Materials, Metallurgy, and Reactor Fuels Subcommittee held a meeting on April 7, 2015, in T2B1, 11545 Rockville Pike, Rockville, MD. The meeting convened at 8:30 p.m. and adjourned at 5:03 p.m.

The meeting was opened to the public.

No written comments were received from members of the public.

**ATTENDEES**

**ACRS Members/Staff**

Joy Rempe, Subcommittee Chairman for C-SGTR  
Charlie Brown, Member  
Ron Ballinger, Member  
Dana Powers, Member  
Michael Corradini, Member (via phone)

Gordon Skillman, Member  
Sanjoy Banerjee, Member  
Dennis Bley, Member  
John Stetkar, Member

Christopher Brown, Designated Federal Official

**NRC Staff**

Mica Baquera  
Istavan Frankl  
Emmett Murphy  
Antonios Zoulis

Kathryn Brock  
Evelyn Gettys  
Michael Salay

Christopher Boyd  
Raj Iynegar  
Jason Schaperow

Kevin Coyne  
Richard Lee  
R. Schneider

**Industry**

Ali Azarm, IESS  
Roy Linthicum, PWROG

**SUMMARY**

The briefing described a multi-discipline effort led by NRC/RES on Consequential Steam Generator Tube Rupture (SGTR). C-SGTR is defined by a leakage area greater than a threshold value occurring before a large vent path in RCS is established; either due to failure of RCS components or intentional depressurization. The staff (and their contractors) have documented their analysis and results in a NUREG entitled, "Consequential SGTR Analysis for Westinghouse (W) and Combustion Engineering (CE) Plants with Thermally-Treated Alloy 600 and 690 Steam Generator Tubes." System analysis tools; such as, MELCOR and SCDAP/RELAP5 are used to predict the system flows and heat transfer. The briefing topics included the following: 1) C-SGTR

scenario description, 2) TH analyses, 3) computational fluid dynamics (CFD), 4) experimental basis, 5) differences between CE and W plants, and 6) CE MELCOR analyses.

The meeting transcript is attached and contains an accurate description of each matter discussed during the meeting. The presentation slides and handouts used during the meeting are attached to the transcript.

| SIGNIFICANT ISSUES  |                               |
|---|-------------------------------|
| Issue (s)   | Reference Pages in Transcript |
| 1. Introduction by Dr. Kevin Coyne and a brief discussion of the staff's scope of work. Preliminary questions were raised by the members that included deliverables, schedule, and public comments. Members also raised a concern relating to the lack of documentation for the CE CFD and MELCOR analyses. See transcript for further discussion of this matter. | 7-26<br>230                   |
| 2. The fast scenario beginning on slide 4 was discussed by RES staff. Subcommittee members asked questions pertaining assumptions related to relief valve (e.g., SRV and PORV) performance when exposed to temperatures expected during a severe accident. See transcript for further discussion of subcommittee member's questions and how the staff responded.  | 28-33                         |
| 3. It was mentioned that the draft NUREG states that C-SGTR can be identified from existing Level 1 PRAs. PRA information doesn't consider conditions that could lead to thermally-induced SGTR. Member Stetkar interjected that clarity on this the misconception is needed. See transcript for detailed explanation from member Stetkar.                        | 35-36                         |
| 4. Staff discussion on reactor coolant system temperatures from the W calculations. Members observed that melting temperature assumptions for Inconel and stainless steel presented by the staff appear high. Additional discussion by members Rempe, Ballinger and Powers on oxidation of stainless steel. See transcript for details on this matter.            | 41-46<br>237-238              |
| 5. Discussion between members and staff on staff slide 11 which shows a counter-current natural circulation and the rate of mixing in the inlet plenum. The pressurizer liquid level was discussed for the analysis. See transcript for additional discussion.  | 51-55                         |
| 6. Discussion on CFD CE sensitivity calculations performed. As was raised many times during the briefing, questions and concerns from members on the need for readily available reports and the lack of proper documentation. See transcript for discussion on this matter.   | 63-65                         |
| 7. Discussion of B&W Plants. Staff stated that these plants have not been part of the recent severe accident induced failure studies because the vigorous natural circulation flows wouldn't be expected in these plants. Key design features of the B&W fleet  | 65-67                         |

|   |                           |
|---|---------------------------|
| <p>were pointed out during the briefing. See transcript for additional features discussed about the B&amp;W fleet.</p>  |                           |
| <p>8. Clarification discussion concerning replacement steam generators for W plants similarities to CE steam generators. See transcript for further on this clarification.</p>  | <p>77-78,<br/>147-148</p> |
| <p>9. The approach taken for the hottest tube analysis for CE plants was discussed by staff. It was noted by member Rempe that the W analyses relied on NUREG 1922; but the CE approach relied on the expert opinion of several NRC staffers. Refer to transcript for detailed discussion of this matter.</p>   | <p>83-91</p>              |
| <p>10. Staff discussed hot leg-surge line model aspects and analysis procedures. Failure times and thermal-mechanic simulation were discussed. Questions were raised by SC members on failure time uncertainties and temperature distribution. See transcript for how the questions were answered by NRC staff and its contractor.</p>  | <p>107-133</p>            |
| <p>11. Discussion on the C-SGTR calculator. Questions, concerns and comments from the subcommittee that the calculator does not correctly account for the uncertainties. See transcript for further discussion of this topic.</p>   | <p>133-138</p>            |
| <p>12. Discussion on updating flaw distribution and questions concerning the flaw data (probability versus flaw depth distribution) in the ISL report. See transcript for further discussion.</p>   | <p>149-154</p>            |
| <p>13. Additional discussion on flaw distribution for Thermally Treated Inconel 600 and 690 (600TT and 690TT). Members discussed the limitations in the NUREG as compared to the ISL letter report. See transcript for further discussion.</p>  | <p>156-173</p>            |
| <p>14. It was stated that the calculator was developed to support the C-SGTR PRA analyses. The calculator estimates the C-SGTR probability for a specific accident scenario and for a set of flaw in the steam generator tubes. Material data for thermally-treated Inconel 600 and 690 (TT600 and TT690) are used for SG tubes modeled. Questions from members Rempe and Bley on PRA, uncertainties, and MELCOR analyses. See transcript for questions raised and how staff and its contractors responded.</p> | <p>183-198</p>            |
| <p>15. Discussion on sources of uncertainties that the calculator tries to handle; e.g., modeling and measurement uncertainties were discussed. Questions were asked by Members Bley, Powers, and Skillman. See transcript for questions raised and how staff and its contractors responded.</p>  | <p>199-206</p>            |
| <p>16. Dr. Coyne summarized how the calculator works.</p>   | <p>212-214</p>            |
| <p>17. Discussion on the probabilistic risk analysis of C-SGTR for severe accidents and DBA accidents and PRAs. Members Stetkar and Bley asked questions about PRA scenarios. See transcript for further details.</p>   | <p>215-229</p>            |
| <p>18. Discussion on the seven steps for a simple PRA for LERF estimation. W results were discussed. Questions were raised by Member Stetkar on uncertainties in temperature and time.</p>  | <p>231-249</p>            |

|  |         |
|--|---------|
| Discussion of the CE results using MELCOR. Subcommittee Chairman Rempe raised related questions concerning differences in the MELCOR analysis versus a SCDAP core heat up analysis. See transcript for further details on these subject matters. |         |
| 19. Discussion on a single flaw of various depths and determining the probability of SGTR before RCS failure. See transcript for further discussion.   | 249-252 |
| 20. Discussions on estimated containment bypass probability for CE and W plants. See transcript for further discussion.  | 252-257 |
| 21. Discussion on simplified LERF model and summary of the results. In particular, summary of pressure induced C-SGTR for W plant and CE plant. See transcript for further discussion.   | 257-270 |
| 22. PRA summary and insights were discussed by the staff. Comment and discussion by member Stetkar concerning are the PRA models capturing all scenarios. See transcript for further discussion.   | 270-280 |
| 23. Office of Nuclear Reactor Regulations perspectives on the draft NUREG and future plans. See transcript for further discussion.   | 283-292 |
| 24. Public comments on draft NUREG. See transcript for further discussion.   | 297-299 |
| 25. Subcommittee comments. See transcript for further discussion.  | 300-309 |

# **Official Transcript of Proceedings**

## **NUCLEAR REGULATORY COMMISSION**

Title:                   Advisory Committee on Reactor Safeguards  
                              Metallurgy and Reactor Fuels Subcommittee

Docket Number:     (n/a)

Location:             Rockville, Maryland

Date:                  Tuesday, April 7, 2015

Work Order No.:     NRC-1503

Pages 1-313

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UNITED STATES OF AMERICA  
NUCLEAR REGULATORY COMMISSION  
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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS  
(ACRS)  
+ + + + +  
METALLURGY & REACTOR FUELS SUBCOMMITTEE  
+ + + + +  
TUESDAY  
APRIL 7, 2015  
+ + + + +  
ROCKVILLE, MARYLAND

+ + + + +  
The Subcommittee met at the Nuclear  
Regulatory Commission, Two White Flint North, Room  
T2B1, 11545 Rockville Pike, at 8:30 a.m., Joy Rempe,  
Chair, presiding.



1 COMMITTEE MEMBERS:

2 JOY REMPE, Chair

3 RONALD G. BALLINGER, Member

4 SANJOY BANERJEE, Member

5 DENNIS C. BLEY, Member

6 MICHAEL L. CORRADINI, Member\*

7 DANA A. POWERS, Member

8 MICHAEL T. RYAN, Member

9 GORDON R. SKILLMAN, Member

10 JOHN W. STETKAR, Member

11  
12 DESIGNATED FEDERAL OFFICIAL:

13 CHRISTOPHER L. BROWN

1       ALSO PRESENT:

2               EDWIN M. HACKETT, Executive Director, ACRS

3               ALI AZARM, IESS

4               MICA BAQUERA, RES

5               KATHRYN BROCK, RES

6               CHRISTOPHER F. BOYD, RES

7               KEVIN COYNE, RES

8               ISTVAN FRANKL, RES

9               EVELYN GETTYS, RES

10              ACE HOFFMAN\*

11              RAJ IYENGAR, RES

12              KEN KARWOSKI, NRR

13              RICHARD LEE, RES

14              ROY LINTHICUM, PWROG

15              EMMETT MURPHY, NRR

16              MICHAEL SALAY, RES

17              SELIM SANCAKTAR, RES

18              JASON SCHAPEROW, NRO

19              RAY SCHNEIDER, Westinghouse

20              ANTONIOS ZOULIS, NRR

21

22       \*Present via telephone

23

24

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

(8:30 a.m.)

CHAIR REMPE: Okay. This meeting will now come to order. This is a meeting of the Materials and Reactor Fuel Subcommittee of the ACRS. I am Joy Rempe, Chairman of today's subcommittee. Subcommittees in attendance are Sanjoy Banerjee, Dick Skillman, Dana Powers, John Stetkar, Ron Ballinger. In addition we have Mike Corradini on the phone. And we may be joined by Dennis Bley later in the morning.

MEMBER POWERS: Is that Mike Corradini from the losing University of Wisconsin?

CHAIR REMPE: I believe that's the phrase.

MEMBER POWERS: Ah, okay.

CHAIR REMPE: The purpose of this meeting is to receive a briefing from the staff in the Office of Nuclear Reactor, excuse Nuclear Regulatory Research, and the Office of Nuclear Reactor Regulation on consequential steam generator tube rupture.

Specifically we'll hear about information in a draft NUREG entitled Consequential Steam Generator Tube Rupture Analysis for Westinghouse and Combustion Engineering Plants with Thermally Treated Alloy 600 and 690 Steam Generator Tubes.

The subcommittee will gather information

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1 and analyze relevant issues and facts, and formulate  
2 those positions and actions as appropriate for  
3 deliberation by the full committee. At this time the  
4 full committee briefing is scheduled to occur on June  
5 10th. Christopher Brown is the designated federal  
6 official for this meeting.

7 The rules for participation to be in  
8 today's meeting have been announced as part of the  
9 notice of this meeting previously published in the  
10 Federal Register on March 31st, 2015. A transcript of  
11 the meeting is being kept, and will be made available  
12 as stated in the Federal Register notice.

13 It's requested that speakers first  
14 identify themselves, and speak with sufficient clarity  
15 and volume so that they can be readily heard. Also,  
16 please silence all phones or other widgets that make  
17 noise.

18 We have not received any comments or  
19 requests for members of the public to make oral  
20 statements or written comments. A bridge line has been  
21 set up for public participation, which will occur at  
22 the end of the meeting.

23 So let's now proceed with the meeting.  
24 And I'd like to start by calling upon Dr. Kevin Coyne,  
25 the Branch Chief RES, to introduce the speakers and give

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1 us a short introduction.

2 DR. COYNE: Okay. Thank you, Dr. Rempe.  
3 Again, Kevin Coyne from the Office of Nuclear  
4 Regulatory Research. Thanks again for the opportunity  
5 to brief to the joint subcommittee. Raj Iyengar will  
6 go through a quick summary of the previous interactions  
7 we've had. But we've had several interactions with the  
8 full committee and subcommittees on this work.

9 Just to go through briefly some of the  
10 history. We had the steam generator action plan that  
11 ran well over a decade. And it closed in 2009. One  
12 of the items that was left remaining for the steam  
13 generator action plan was some resolution on some  
14 consequential steam generator tube rupture issues.

15 A decision was made in 2009 to close the  
16 steam generator action plan, with the rest of the  
17 remaining work to go under our normal work process.  
18 That included things like doing more detailed work for  
19 the Combustion Engineering type designs. And  
20 developing a simple but realistic PRA method, no small  
21 challenge, to support severe accident licensing  
22 reviews from a PRA perspective, and also support the  
23 reactor oversight process.

24 So it's a complex project. It's had the  
25 involvement of all three research divisions,

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1 thermal-hydraulics, computational fluid dynamics,  
2 operating experience for flaws and flaw distribution  
3 analysis, structural work for the reactor coolant  
4 system, and obviously PRA work.

5 In addition, since 2010 we've had some  
6 diversion of resources, I think it would be safe to say,  
7 with the Fukushima event, dealing with some budget of  
8 challenges with sequestration. And this work has  
9 always been considered important. But it hasn't  
10 always been our highest priority in research. But  
11 we've made steady progress over the last five years.

12 But that has caused us to extend the  
13 schedule for the work a bit longer than I think we  
14 originally anticipated when we first put this on. But  
15 the good news is the technical work is now complete.  
16 We have a first draft report that's been provided to  
17 the subcommittee.

18 Our focus has been on getting the technical  
19 work right. So we recognize there is some smoothing  
20 and some editing details in the report that still need  
21 to be worked out. But we want to get the technical  
22 information down correct, and any comments from the  
23 committee incorporated in the report before go through  
24 that process.

25 So looking ahead our plan is to get

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1 feedback from the committee. We plan to incorporate  
2 that into the draft report. Then we'll prep the report  
3 for issuance as a draft NUREG for public review and  
4 comment. We hope to get that published as a draft NUREG  
5 by the end of the year, with a target of publishing the  
6 report as a final in 2016. And with that --

7 CHAIR REMPE: Since you brought up  
8 schedule, let me see if I can understand, just to make  
9 sure. You are planning to, if there's -- For example,  
10 if there were a lot of technical changes you are  
11 planning to incorporate those changes, and then by the  
12 end of the fiscal year or the calendar year you will  
13 issue, update the report and issue it for public comment  
14 after you incorporate our comments?

15 DR. COYNE: Correct.

16 CHAIR REMPE: But you would, it's  
17 currently scheduled to have a full committee meeting  
18 in June right now. Is there any flexibility? I mean,  
19 maybe there won't be a lot of technical comments. But  
20 if there were, would there be interest in maybe having  
21 a second subcommittee meeting? Or are you pretty  
22 fixed, no, I want just one committee meeting? Or,  
23 what's your idea?

24 DR. COYNE: I guess we'd defer to the  
25 preference of the committee on that as to whether you

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1 wanted us to come back, say after we finish the public  
2 comment period, to --

3 CHAIR REMPE: Before, if there were some  
4 substantial changes.

5 DR. COYNE: Right. Before we issue it as  
6 final. We could work out those details as we got closer  
7 to that date.

8 MEMBER CORRADINI: So, may I ask a  
9 question about full review?

10 CHAIR REMPE: Sure.

11 MEMBER CORRADINI: Okay. I guess my  
12 question is, and I wanted Kevin to correct me if I  
13 misunderstand him. But already there's a process  
14 under, to use some analysis for consequential steam  
15 generator tube rupture. And this work by RES is  
16 essentially reducing the (coughing) in an already known  
17 process that is used in risk assessment. Is that a  
18 correct assumption?

19 DR. COYNE: Well, yes and no. The part  
20 we'll decide today goes through some additional efforts  
21 for prioritizing steam generator flaws, and coming up  
22 with better distributions.

23 There's been previous work on  
24 characterization of flaws, which we'll discuss later,  
25 as a very key input into the PRA analysis to have the

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1 distribution of flaws, and the depth of those flaws  
2 correct.

3 So there's been more work done recently as  
4 a part of this study, to develop the flaw distributions  
5 for alloy 690 steam generator tubes. The earlier work  
6 focused on alloy 600 tubes. We also have some better  
7 tools available.

8 We'll talk about the steam generator  
9 calculator, which really is just a fancy way to bring  
10 together what we know about steam generator tube crack  
11 growth and creep rupture failure, to combine that with  
12 the thermal-hydraulic analysis, and do a better  
13 prediction of severe accident induced containment  
14 bypass events.

15 So I think, and others here can correct me  
16 if I'm wrong. But I think the essence of how we  
17 approach consequential steam generator tube rupture is  
18 essentially unchanged. But some of the details and the  
19 technical inputs have been refined.

20 Additionally, Dr. Mike Salay will talk  
21 about additional thermal-hydraulic work that was done  
22 for Combustion Engineering plants, which was an input  
23 that we did not have previously.

24 MEMBER CORRADINI: So, but then, I guess  
25 the way you describe it, if I were to characterize it

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1 what you're really saying is you have a process, you're  
2 using process to include a risk assessment, and now  
3 you're improving the process.

4 MEMBER STETKAR: Hey, Mike, you're  
5 breaking up.

6 MEMBER CORRADINI: Well, I can barely hear  
7 from papers rattling. But let me try it again.

8 MEMBER STETKAR: No, you're breaking up.

9 MEMBER CORRADINI: Well --

10 MEMBER STETKAR: Coming this way.

11 MEMBER POWERS: You're better, Mike, as  
12 you get closer to the microphone.

13 MEMBER CORRADINI: Okay. Well then, let  
14 me try --

15 CHAIR REMPE: That's it.

16 MEMBER POWERS: Much better.

17 MEMBER CORRADINI: Is that good enough  
18 now?

19 CHAIR REMPE: That's much better.

20 MEMBER CORRADINI: Okay, fine. So, let  
21 me just make sure I'm clear. There's a current process  
22 in use. The process is being improved relative to  
23 certain alloys and flaw distribution. Also the  
24 process is being improved considering combustion steam  
25 generators. But by and large the process is being

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1 improved. So I would appreciate it if you go through  
2 the process by --

3 MEMBER STETKAR: You're breaking --

4 MEMBER CORRADINI: -- and how that changed  
5 relative to the current analysis. And where, if  
6 they're increased or decreased.

7 CHAIR REMPE: Mike, you're not on a cell  
8 phone, are you?

9 MEMBER CORRADINI: Yes.

10 MEMBER STETKAR: Yes, well --

11 (Simultaneous speaking)

12 MEMBER STETKAR: Do the land line, please.

13 MEMBER POWERS: Because we can understand  
14 about a third of what you're -- Well, we can't  
15 understand anything.

16 CHAIR REMPE: But I think that you said you  
17 would like them to emphasize differences in the new  
18 process versus the old one. Isn't that what you said,  
19 Mike?

20 MEMBER CORRADINI: Yes. Can you hear me  
21 now better?

22 CHAIR REMPE: Yes, yes.

23 MEMBER CORRADINI: Okay, fine. So, I  
24 guess what I'm trying to get at is, as I looked through  
25 the documents, and I now have the NUREG. I'm trying

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1 to make sure the staff clearly identifies what's new,  
2 what's not new, where the uncertainty is reduced, where  
3 things remain the same.

4 CHAIR REMPE: Got it.

5 DR. COYNE: Kevin Coyne from the Office of  
6 Research. I think we understand. And another point  
7 that I failed to mention is there's a previous NUREG  
8 on this topic, NUREG-1570, that many of the members may  
9 be familiar with that provided a process for looking  
10 at consequential steam generator tube rupture from a  
11 PRA context.

12 So I think the best way to view the current  
13 work that we're going to discuss today is an extension  
14 of some of those methods, and an improvement in some  
15 of those methods.

16 So, I think the overall point is correct.  
17 There are existing methods. But this work has refined  
18 them and brought them up to date with some of the modern  
19 materials that were being used in the steam generators.

20 MEMBER CORRADINI: Okay. Thank you.

21 CHAIR REMPE: So I have another question  
22 about Schedule 2. The user needs talked about  
23 regulatory guidance and updated handbook section for  
24 the risk assessment standardization project, and all  
25 these other things.

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1           Those are going to be after the end of the  
2           year, or after you do the public comment? And then  
3           you'll start doing those types of interactions? Or,  
4           I know there's a slide at the very end that talks about  
5           a different type of process. But what's your vision  
6           on that, just so we know up front.

7           DR. COYNE: Yes. Some of those details  
8           don't really work out. We'd like to refresh our user  
9           needs at least every five years, if not sooner. So,  
10          this one is getting to the five year point. In fact,  
11          it may have already passed the five year point just  
12          barely.

13          In discussions with NRR the preliminary  
14          agreement we have is, once this report is issued then  
15          we're going to revisit the user need, and better focus  
16          the topics on what deliverables NRR would need to  
17          implement the process. And there would be a follow-on.  
18          We'll essentially close the existing user need, and  
19          then potentially generate a new user need to focus on  
20          development of those regulatory tools.

21          CHAIR REMPE: Okay. Any more preliminary  
22          questions? Thank you. Sorry, but it's good to get  
23          these things out up front. Raj.

24          DR. IYENGAR: Good morning to all of you.  
25          I'm pretty happy and honored to be here to present some

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1 of our almost nearing conclusion efforts on the  
2 consequential steam generator tube rupture program.

3 As we had this preliminary discussion you  
4 could see that was perhaps the harbinger of what's to  
5 come in terms of lively discussion throughout the day.  
6 You will encounter several presentations from our staff  
7 which will outline and disclose some of the most, the  
8 more important sophisticated analysis that we have  
9 done, both in terms of thermal-hydraulics, as well as  
10 in terms of structural analysis, which will offer  
11 credence to the simplified calculator calculations  
12 that you will see here in the afternoon.

13 Just as a background, I think Kevin covered  
14 most of the background behind this effort. I just  
15 wanted to mention a couple of things in addition, is  
16 that we have been repeatedly engaging the ACRS members,  
17 both informally as well as through subcommittee  
18 briefings, and full committee briefings, through the  
19 past four years.

20 So, we've had the benefit of their feed,  
21 their comments and feedback, and advice and insights  
22 into the product that you probably are reviewing. So,  
23 that's been extremely helpful. So this is not a total  
24 surprise to most of you, I believe.

25 I think Dr. Powers had been a driving force

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1 behind this effort from the initial get go. And Dr.  
2 Rempe has been extremely engaged and very helpful, and  
3 offered key advice and insights for this effort.

4 So, without much ado, I just wanted to make  
5 one personal remark for the record. Any project of  
6 this complexity and interdisciplinary nature will  
7 always have some issues and problems. But it requires  
8 a singular driving force to bring it to conclusion.

9 In that regard I want to acknowledge the  
10 effort of Dr. Kevin Coyne, who has been very helpful  
11 and persistent, undeterred, throughout the number of  
12 other events and overriding priorities, mainly  
13 Fukushima.

14 And in addition to all the major  
15 significant projects he and his branch staff do. So,  
16 I really am pleased. And without his singular effort  
17 we would not be here today at this. Thank you very  
18 much.

19 (Simultaneous speaking)

20 CHAIR REMPE: I have this one question  
21 too. Where the, is this is too preliminary to try and  
22 use it yet. So there's been no thoughts of even trying  
23 to use any of the insights. Or have any of the insights  
24 from this work been used in the Vogtle III Level 3 PRA,  
25 for example?

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1 DR. COYNE: Kevin Coyne from research.  
2 We have applied the methodology to the Vogtle project,  
3 so it can be -- You want to step to the microphone and  
4 add something to that?

5 MALE PARTICIPANT: Yes.

6 DR. COYNE: Yes. Enough said. So we  
7 have --

8 CHAIR REMPE: We're starting to use it  
9 already.

10 DR. COYNE: Yes. We've used the  
11 calculator and the flaw distributions with the  
12 thermal-hydraulic analysis that we've done for Vogtle,  
13 and applied the same methodology that will be described  
14 today for the Level 3 project.

15 CHAIR REMPE: Okay. Thanks.

16 DR. SALAY: Mike Salay. And I'll talk a  
17 little bit about the sequence and some of the  
18 thermal-hydraulic work that's been done. I'm going to  
19 go over the scenario description, the  
20 thermal-hydraulic analysis, how we're going about  
21 solving the problem, a little bit of the experimental  
22 basis for the CFD, some differences between CE and  
23 Combustion Engineering plants. And then I'll show  
24 some of the results of some of the Combustion  
25 Engineering Analyses.

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1 CHAIR REMPE: Mike, can you go back a  
2 little bit? I'm sorry. First of all, the ARTIS. I  
3 looked through your few graphs in advance. And I  
4 appreciate you guys them to me so I could. But the  
5 ARTIS input was not at all used in this program.

6 DR. SALAY: We didn't focus on releases.

7 CHAIR REMPE: Right.

8 DR. SALAY: So we ended up not calculating  
9 releases, so we can -- Well, we did calculate it  
10 partially. But it was never part of -- We didn't end  
11 up going --

12 We were initially intending to come up with  
13 releases as part of the guidance. But we didn't go  
14 there. So we never got to the point where we never  
15 added the ARDS stuff.

16 CHAIR REMPE: And just checked to see it  
17 in the work. It doesn't matter. But it actually was,  
18 again, this is before my time on ACRS. But it was an  
19 action item for the SGAP effort. It was closed out  
20 because the staff agreed to use it in this effort. And  
21 just what, the rules of the game here, what does that  
22 mean that it has not been done? Will it be done later?  
23 Or does that matter that it --

24 DR. SALAY: Well, if you're actually using  
25 the releases for something, yes, it would be good to

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1 calculate the retention.

2 CHAIR REMPE: So it's going to be to put  
3 it in at some point later into MELCOR?

4 MEMBER POWERS: Well, it is in MELCOR.

5 CHAIR REMPE: It is? But it just has not  
6 been used.

7 DR. SALAY: This was done before it was in  
8 there. So it's --

9 MEMBER POWERS: Well, if you're asking if  
10 the ARDS' results were in MELCOR, yes. For the SOARCA  
11 effort, I mean, I did it. I took the ARDS' results and  
12 generated for them a model that they had implemented  
13 into MELCOR.

14 CHAIR REMPE: Okay.

15 MEMBER POWERS: And what they -- I did a  
16 Stokes number scaling on it, and they chose not to take  
17 that Stokes number scaling into MELCOR for reasons  
18 you'll have to ask them.

19 But basically it's, the model consists of  
20 a decontamination and by the quakes within the steam  
21 generator, and the decontamination by the separator and  
22 dryer at the top.

23 CHAIR REMPE: And I believe someone  
24 reported, mentioned that you thought that the use of  
25 ARDS' input would reduce the releases by a factor of

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1 five.

2 MEMBER POWERS: About.

3 CHAIR REMPE: So, if you were going to do  
4 something like the Vogtle III PRA, you'd have it in  
5 MELCOR, and you'd have that reduction, but you'd also  
6 use the calculator. So, the fact that it wasn't done  
7 as part of this --

8 MEMBER STETKAR: By the way --

9 CHAIR REMPE: -- it not a problem.

10 MEMBER STETKAR: For the record it's not  
11 Vogtle III, it's the Level 3 PRA for Vogtle Unit I.

12 CHAIR REMPE: Yes, okay. I'm sorry.

13 MEMBER STETKAR: It's just really  
14 important.

15 CHAIR REMPE: Yes, sorry.

16 (Simultaneous speaking)

17 CHAIR REMPE: But anyway, so it has, the  
18 methodology can accommodate the ARDS' work now. Is  
19 that a true statement?

20 MEMBER POWERS: Let me also be clear. It  
21 depends on where your break is, how much reduction --

22 MEMBER STETKAR: Yes.

23 CHAIR REMPE: Right.

24 MEMBER POWERS: I do, the original 1150  
25 kinds of analyses were kind of independent of break

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1 location. But the model that's in MELCOR now, very  
2 definitely depend on where the break occurs.

3 And based on our empirical data we are  
4 generally recommending a uniform distribution for the  
5 location of break within a tube. That's based on  
6 historical data that does not have to do with these ally  
7 600, 690 tubes.

8 CHAIR REMPE: And then the last thing I  
9 wanted to bring up on this slide is, for the record,  
10 there was earlier documents that reported the earliest  
11 ISL SCDAP analyses. There were documents that talked  
12 about the CFD work for the Westinghouse plant. But  
13 when you talk about the CE CFD work and the CD MELCOR  
14 analyses there are no standalone documents?

15 DR. SALAY: There are standalone  
16 documents. I thought we provided those.

17 DR. COYNE: Yes. There's NUREG reports  
18 for the Westinghouse analysis.

19 CHAIR REMPE: For the Westinghouse. But  
20 CE --

21 DR. SALAY: No. CE, Sandia did some  
22 stuff, and I did some stuff.

23 MEMBER CORRADINI: Let me get that clear.  
24 Those were provided to us? I guess, I'm looking, and  
25 I don't, I'm not aware of that.

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1 DR. SALAY: Were they? Were they not?

2 CHAIR REMPE: And I, actually the draft  
3 NUREG I reviewed didn't have any references. And  
4 that's why I'm asking that question. I mean, it talks  
5 about an older CE plant analysis.

6 But it -- So, you made some changes and it  
7 reports those, but not in the level of detail where you  
8 could review them. And so, are there standalone  
9 documents? And they should be referenced in the draft  
10 NUREG if there are.

11 DR. SALAY: Well, yes. I wrote  
12 something. It was in draft form. It was decided not  
13 to be included in as a reference.

14 MEMBER CORRADINI: So, just to be clear,  
15 we do or don't have those auxiliary documents if we want  
16 to look at details?

17 MEMBER STETKAR: We don't.

18 CHAIR REMPE: Okay. That probably will  
19 come up again. I just wanted to make sure. And so,  
20 was there a reason why they weren't even referenced in  
21 the document?

22 DR. COYNE: I'll ask Dr. Lee to address  
23 that, if you could?

24 DR. LEE: About what?

25 DR. COYNE: The standalone references for

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1 the CE work that was done for the study.

2 DR. LEE: And why do you need the  
3 standalone?

4 CHAIR REMPE: Well, there's a lot of  
5 details for the Westinghouse analyses that we can  
6 review. And then it talks about the CE work, and it  
7 doesn't have that level of detail. And I am, was just  
8 wondering why it wasn't there. And then I hear that  
9 there are references, we just didn't want to reference  
10 them. And I'm just surprised.

11 DR. LEE: No. I think maybe we should go  
12 through this whole entire presentation then, so you can  
13 see whether the thermal-hydraulics analysis relative  
14 to other analyses in this whole entire process. And  
15 see how important that we need to keep on refining the  
16 thermal-hydraulics analysis.

17 CHAIR REMPE: So, you're saying that the  
18 documents are drafted. They're being --

19 DR. LEE: I didn't draft anything. If  
20 Mike had draft something -- What we need to, what we  
21 have agreed to do for this report is that report  
22 whatever we needed to support the closing of what Kevin  
23 needs to do for this issue. Okay.

24 CHAIR REMPE: Well --

25 DR. LEE: We don't have enough time to do

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1 also, do more things that that we can do. Because Mike  
2 has many other activities he has to do. So that's the  
3 reason.

4 CHAIR REMPE: Well, throughout this  
5 document, like, you talked about the flaw distribution,  
6 those ISL documents that are in the system, and we can,  
7 the NUREG relies on information that's already  
8 documented other places.

9 And so, if you're a curious reviewer you  
10 can go to those other documents. In the case of the  
11 CE MELCOR analysis and the CFD analysis for the CE  
12 plant, there wasn't even any citation to references.  
13 And so, it makes it a little more difficult for the  
14 reviewer.

15 DR. LEE: Are you saying that within the  
16 document itself there's not enough details in there to  
17 --

18 CHAIR REMPE: I thought that way.

19 DR. LEE: -- make some conclusion on it?

20 CHAIR REMPE: I thought that way.

21 DR. LEE: What do you think is going to  
22 change?

23 CHAIR REMPE: Mike, I think you felt that  
24 way too, right?

25 MEMBER CORRADINI: Well, I guess I think

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1 we want to listen to what Mike has to say. But I just  
2 wanted to make sure that everything that you want to  
3 present on the CE plants is, ought to be in the document.  
4 So, if we're looking for more we should speak up when  
5 we get to that point in the presentation. Is that  
6 correct?

7 CHAIR REMPE: Sounds good to me.

8 DR. LEE: Correct.

9 CHAIR REMPE: Okay. Sorry. You can go  
10 ahead with the -- DR. SALAY: So second, I  
11 guess second slide. Yes. So the reason that there's  
12 an interest in this project is, the main reason is that  
13 it could lead to a scare that is called a bypass, a  
14 containment bypass.

15 And this is where your fission products,  
16 instead of being attenuated and reduced in containment,  
17 they go, they bypass the containment and can reach the  
18 environment now. And the scenario that it happens is  
19 a station blackout, where you lose your diesel  
20 generators.

21 And then so then what happens is, the  
22 reactor inventory boils off. You have a release of  
23 fission products. Your pressure stays at your PRV or  
24 SRV setpoint, and your temperature goes up. And sooner  
25 or later something is going to fail.

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1                   And what fails depends, effects whether  
2                   you have a bypass or not. If your tubes fail, your  
3                   steam generator tubes fail first, the fission products  
4                   can go into the secondary side, and then potentially  
5                   to the environment.

6                   However, if any other component fails, the  
7                   RCS blows down into containment. So determining  
8                   whether one of the steam generator tubes fails relative  
9                   to other RCS components is important in determining the  
10                  consequences.

11                  So here's a fast, demonstration of a fast  
12                  scenario that was based on Westinghouse analyses. So  
13                  you have a loss of offsite power, failure of diesels  
14                  and failure of auxiliary feedwater systems. And then  
15                  the primary inventory gets lost through the reactor  
16                  coolant pump seals. The secondary side boils off.  
17                  And the secondary side dries out.

18                  Your primary inventory, you start losing  
19                  your primary inventory through your safety valves.  
20                  And you continue to lose stuff through pump seals.  
21                  Your loop natural circulation stops as the primary  
22                  inventory falls in the steam generator tubes. And the  
23                  natural circulation of superheated steam begins as  
24                  inventory falls below the hot leg.

25                  So the core and system heat up. Core

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1 uncovers, core oxidizes and produces a lot of power.  
2 The system heats up and accelerates. And then you get  
3 a failure somewhere.

4 And this is a scenario from Westinghouse  
5 where your turbine driven auxiliary feedwater was not  
6 operational. It's more likely that some feedwater,  
7 some actions would get some water in the secondary side  
8 to prevent that from happening.

9 MEMBER BANERJEE: Let's go --

10 DR. SALAY: Sorry.

11 MEMBER BANERJEE: So the scenario, this is  
12 a scenario, but there would be failures which would  
13 occur, right?

14 DR. SALAY: Yes.

15 (Simultaneous speaking)

16 DR. SALAY: It's either the tubes or  
17 something else. If something else fails, the surge  
18 line, the hot leg. You could have --

19 MEMBER BANERJEE: It depends on the  
20 timing, as we've seen in the past, right?

21 DR. SALAY: Yes. And even, this is  
22 actually initially made for Westinghouse. Yes. So if  
23 your tubes fail first -- Well, let's go -- If your RCS,  
24 other RCS components fail first you --

25 MEMBER BANERJEE: Then you're home free,

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1 right?

2 DR. SALAY: Then you're fine, yes. If  
3 your tubes fail first, it depends. If enough, if one  
4 tube fails your pressure stays high. And it's likely  
5 that it will remain high enough for other components  
6 to fail, and then depressurize.

7 And so you, which reduces the driving force  
8 to the, for fission products to the environment.  
9 However, if a lot of tubes fail you could depressurize  
10 sufficiently to prevent another RCS component from  
11 failing by --

12 MEMBER BANERJEE: So the calc, this is not  
13 necessarily the motivation. But when you look at this  
14 scenario, the timing of these failures becomes --

15 DR. SALAY: Yes, the timing. You want to  
16 know which fails first.

17 MEMBER BANERJEE: Yes.

18 DR. SALAY: And if one or two tubes fail  
19 first does your pressure, when, how long after will  
20 your, will another RCS component fail?

21 MEMBER CORRADINI: So, if Sanjoy's done I  
22 had a question, a couple of questions just for  
23 clarification. So, the assumptions are of course loss  
24 of off site power, failure of diesels, failure of aux  
25 feed. And also, there is no estimate of cycling the

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1 PORV. And it's essentially leakage. And then  
2 depressurization that way?

3 DR. SALAY: Well, there's assumptions  
4 that PORV operates until batteries fail. And that's  
5 typically assumed to occur four hours in. And so, at  
6 that point the PORV no longer opens. And it goes up  
7 to the SRV pressure.

8 MEMBER CORRADINI: And then there's  
9 continued cycling.

10 DR. SALAY: Yes.

11 MEMBER CORRADINI: So, where I'm getting  
12 at eventually is, in the analyses of the Fukushima  
13 reconstruction it was assumed or decided that somewhere  
14 between some sort of hot leg failure or SRV failure,  
15 due to continued cycling at high temperature.

16 And I'm curious, in the RES analysis for  
17 this, was there a re-investigation of SRV cycling or  
18 PORV cycling that essentially led to it failing open,  
19 or failing with leakage that would depressurize?

20 DR. SALAY: We didn't look into that. I  
21 don't know if the rest of the --

22 MEMBER POWERS: Since that's a boiler, and  
23 this is a PWR --

24 DR. SALAY: Yes.

25 MEMBER POWERS: It's my impression that if

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1       you fail to open the PORV you're still pressurized for  
2       a very long time.

3                     DR. SALAY:  Oh.

4                     MEMBER POWERS:  And that, I mean, as you  
5       come down in pressure eventually you're going to drop  
6       the accumulators.  And that's going to take you right  
7       back up in pressure.  So you're not out of the woods.  
8       I mean, it's just hard to depressurize.

9                     MEMBER CORRADINI:  Well, I guess I'm  
10      asking, so at least in this analysis that was not  
11      reconsidered at all?

12                    DR. SALAY:  No.

13                    DR. COYNE:  Mike, if I could add.  What  
14      Dr. Salay's going though is an example scenario to  
15      highlight some of the pertinent points with a severe  
16      accident induced steam generator tube rupture.  
17      Station blackout is certainly one of the scenarios we  
18      look at.

19                    In general, the PRA method will pull out  
20      any scenarios that leave you with high RCS pressure,  
21      and dry steam generator conditions, which one of our  
22      assumptions is essentially a dry steam generator  
23      condition would lead to a low pressure on the secondary  
24      side.

25                    MEMBER CORRADINI:  And so that was my next

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1 question. So, can you just re-talk through? Because  
2 you need three things, high, dry and low. And I'm  
3 trying to understand the conditions on the secondary  
4 side that would lead you to low pressure.

5 DR. SALAY: What was the question? You  
6 wanted -- Well, the scenarios are, there's been a, the  
7 historical cause is an assumed leak, about an inch or  
8 half inch diameter equivalent.

9 And also, if a secondary valve sticks open  
10 somehow. Or, third option would be if the operator  
11 decides to depressurize so he can get some water in.  
12 But then somehow the supply of water fails.

13 MEMBER CORRADINI: Okay. All right.  
14 So, to frame it in another way, you picked the select  
15 set of conditions to give you the worst delta P, and  
16 holding at high pressure on the primary side? So  
17 there's a whole population --

18 DR. SALAY: A lot --

19 MEMBER CORRADINI: -- of other  
20 possibilities.

21 DR. SALAY: Oh, absolutely, yes. So  
22 there's a lot of things that happen. But if the -- But  
23 it's under these circumstances that you can get the  
24 bypass. Whereas, in the others --

25 MEMBER CORRADINI: Sure. So then let me

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1 ask the final question. What reference should I go to,  
2 to see an event tree that leads me to all the other  
3 pathways, so I understand this pathway relative to all  
4 the other pathways? Is there a reference you'd suggest  
5 I read?

6 DR. SALAY: I'll defer to the PRA guys.

7 MEMBER STETKAR: The answer is, no you  
8 can't. Because PRAs do not examine this phenomenon.

9 MEMBER CORRADINI: Okay.

10 MEMBER STETKAR: We'll get to that.

11 MEMBER CORRADINI: Thank you.

12 DR. LEE: Can I make a comment? When we  
13 published the NUREG-1570 back in March 1998, there's  
14 a whole section of discussion between CE and  
15 Westinghouse, and so forth. There are detailed  
16 discussion here.

17 Subsequent to that we published another  
18 report SCDAB Rev 5 of the steam generator. Is INL  
19 report, published in June 1998. That discussed a lot  
20 more about analysis.

21 But at that time just remember, when we do  
22 the CE like the old analysis, we did not change any of  
23 the mixing fractions. We were using the Westinghouse  
24 type. For those three parameters, in terms about the  
25 hot leg, countercurrent flow, the inlet plenum mixing,

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1 the ratio of the backflow, and so forth.

2 There are three parameters key to this same  
3 tube rupture. But the values we used at that time is  
4 a Westinghouse base. The one that Mike's doing is  
5 based on the CE one, which is informed by the CFD, okay.

6 So, if you want to look at all the variation  
7 about the CE plant versus Westinghouse, I would suggest  
8 that you go back to read the 1570. NUREG/CR tells you  
9 all sort of things different between CE and  
10 Westinghouse.

11 CHAIR REMPE: So, you're saying --

12 MEMBER CORRADINI: Thank you, Richard.

13 CHAIR REMPE: -- instead of --

14 DR. LEE: Read that one. And you can also  
15 read the SCDAB Rev 5 report. This has all the plan  
16 analysis, including CE, the end of your plan,  
17 Westinghouse, all in here.

18 CHAIR REMPE: But the INL report was using  
19 SCDAB, whereas this is a MELCOR analysis.

20 DR. LEE: But the thing is there's SCDAB  
21 Rev 5 and MELCOR are, MELCOR catch up with it later.  
22 So it's a similar type thing. Are you expecting  
23 something different between MELCOR and this?

24 DR. COYNE: If I could add a clarification  
25 to -- This is Kevin Coyne from the research staff. PRAS

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1 do look at consequential steam generator tube rupture.  
2 That's why we look at it for the local Level 3 PRA

3 MEMBER STETKAR: They don't -- We'll get  
4 into it later. They do not correctly evaluate the  
5 challenge frequency.

6 DR. COYNE: Okay. So one of the ground  
7 rules that NRR really wanted with this method is to be  
8 able to have a method that allowed them to make  
9 estimates so severe accident due to steam generator  
10 tube rupture, even if the PRA did not explicitly  
11 consider it.

12 So that was one of our going in mattering  
13 conditions, that this method had to be able to be  
14 appended to an existing PRA that took you through a  
15 Level 1 analysis to coordinate that frequency.

16 So one of the key first steps in the PRA  
17 analysis is to identify all the scenarios that lead to  
18 the high-dry-low conditions that Mike is going to get  
19 to in about four slides.

20 MEMBER STETKAR: If he ever gets there.

21 DR. COYNE: Mike is giving a typical  
22 example of how you would get to these high-dry-low  
23 conditions. The PRA will give you thousands, hundreds  
24 of data sets that gets you to this condition. So, this  
25 is just a typical one to illustrate the key points.

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1 But again, one of the key points wasn't to  
2 have a method that would fully integrate this into a  
3 PRA. It was to have a method that could be appended  
4 to an existing PRA analysis, to get some insights on  
5 severe accident tube rupture.

6 MEMBER STETKAR: And, Kevin, I think  
7 that's a very good, especially for the record, a very  
8 good and fair characterization of this effort. I just  
9 wanted to make sure that when we tread into the notion  
10 of the comprehensiveness of this, in the world of  
11 assessing risk from this particular condition, we're  
12 on a bit more, and in my opinion quite more shaky ground.

13 Because this has used a few stylized  
14 scenarios. And quite honestly, PRAs, I have yet to see  
15 a PRA that actually investigates the total frequency  
16 of these high-dry-low conditions. And we can get into  
17 that later.

18 But I don't want to interrupt too much,  
19 because it's important to understand the physics and  
20 the metallurgy, and all of that kind of stuff first.  
21 Because that's the real crux of this whole effort here.

22 DR. LEE: And one of the things I'd like  
23 to inform about, to address Joy. You brought up about  
24 the benchmarking between these codes. Since this  
25 study was done, I think back in about ten years ago we

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1 asked Karen Yurib to do some analysis, between the Zion  
2 plant, using SCDAB Rev 5, MELCOR, and then also MACCS,  
3 which EPRI did it.

4 And compared for this severe tube rupture,  
5 and see how they compare. So they all seem to be about  
6 in the same ball park. There was some efforts in  
7 benchmarking the three different codes to see how they  
8 performed under this accident scenario.

9 MEMBER SKILLMAN: Mike, let me ask this  
10 question, please. What is the assumption about the  
11 main steam isolation valves?

12 DR. SALAY: Not sure. And I assume  
13 they're closed.

14 (Off microphone comment)

15 MEMBER STETKAR: No. Why would they be  
16 closed? There's no reason for them to be closed. They  
17 would be fully open, unless I, John Stetkar, the  
18 operator, closed them.

19 MEMBER POWERS: Bingo.

20 MEMBER STETKAR: There's absolutely no  
21 reason for the MSIVs to be open in this particular  
22 scenario.

23 MEMBER POWERS: Closed.

24 MEMBER STETKAR: Or closed. I'm sorry.  
25 To be closed. They will be fully open.

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1                   MEMBER BALLINGER:       Doesn't it say  
2                   somewhere in there that there's a .5 square inch --

3                   MEMBER STETKAR:   That's -- See, they get  
4                   around it, because they assume that any of these  
5                   conditions depressurize the secondary side. That's  
6                   why it's important --

7                   MEMBER BALLINGER:   A .5 square inch --

8                   MEMBER STETKAR:   Right. Now, I don't  
9                   know, and I'm hoping we get to it. There is a notion  
10                  that that is large enough to get you to the  
11                  high-dry-low.

12                  MEMBER BALLINGER:   Yes.

13                  MEMBER STETKAR:   But after the tube fails  
14                  it's not enough to keep pressure low in the secondary  
15                  side. And I don't know what the implications of that  
16                  is. I don't know if you're going to address.

17                  DR. SALAY:   Yes, there is --

18                  MEMBER STETKAR:   When you get to it, that  
19                  covers it.

20                  DR. SALAY:   All right. And so, these are  
21                  some of the RCS structure temperatures from the  
22                  Westinghouse calc. Just to, it looks like you have the  
23                  dry out, then the temperature starts increasing. You  
24                  have, start getting the circulation of superheated  
25                  steam. And it heats up, the system heats up.

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1           The hot leg for Westinghouse is  
2 significantly hotter than either the average tube or  
3 the hottest tube. And when oxidation, heat oxidation  
4 occurs the temperature jumps pretty fast. And there  
5 are a few points of interest. Again --

6           MEMBER POWERS:       Have we wrestled  
7 successfully with the fact that we didn't see these  
8 kinds of temperatures in the hot leg of TMI?

9           DR. SALAY:   Yes. But don't know what  
10 temperatures we had, readings we had. So I haven't  
11 seen it compared to Three Mile Island.

12          MEMBER CORRADINI: But I guess, Dana,  
13 another way of asking Dana's question is, did any of  
14 the measured value at TMI peg out, so that we at least  
15 say that they were higher than X, or higher than Y? I  
16 know that's the case in the core. But I don't remember  
17 anything in the hot legs.

18          MEMBER POWERS: We kind of know what the  
19 temperatures were in the upper core structures at TMI.

20          DR. COYNE: Mike, correct me if I'm wrong,  
21 but TMI was a BW plant --

22          MEMBER POWERS: It is.

23          DR. COYNE: It doesn't, would not behave  
24 the same way as a Westinghouse or CE plant under these  
25 circumstances.

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1                   MEMBER POWERS: But we would expect that  
2                   if we saw high temperatures coming off the core that  
3                   we would see them in the hot leg, regardless of the  
4                   manufacturer of the plant, wouldn't we? And at TMI  
5                   we just didn't.

6                   Now, you're explanation of this as a  
7                   different type of plant, fair enough. I can't argue  
8                   with you there. But it would seem to be a calibration  
9                   that just comes to mind.

10                  DR. SALAY: That definitely makes sense to  
11                  compare against -- And I do mention that the B&W, that  
12                  we don't expect to see large recirc flows.

13                  DR. LEE: Remember that the B&W plant is  
14                  a candy cane design.

15                  DR. SALAY: All right.

16                  CHAIR REMPE: Before we leave that, and  
17                  again, I'm sorry. I have read the document. But I'm  
18                  just a little confused on the details. But I thought  
19                  when you went to the MELCOR analysis you added this  
20                  capability to do the hottest tube temperature and the  
21                  average tube temperature in the steam generator. And  
22                  that was not something that was in the SCDAP analysis  
23                  that was done years ago.

24                  DR. SALAY: That was in the SCDAP RELAP  
25                  last analysis that was done years ago. But it was not

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1 in the CE analysis that was done years ago.

2 CHAIR REMPE: Okay.

3 DR. SALAY: That's one of the things we had  
4 to add.

5 CHAIR REMPE: Okay. That's -- I guess my  
6 brain's not functioning right now. Okay.

7 DR. SALAY: So this is --

8 CHAIR REMPE: So that's why I was puzzled.  
9 I was going, I thought that was just the MELCOR. But  
10 okay. Got it.

11 DR. SALAY: And again, your RCS points of  
12 interest where things can fail. You have the lower  
13 head, the hot leg, surge line, the tubes, and the seal  
14 leakage, and whether your loop seal is coming in, has  
15 water in it or not. And I mentioned that.

16 CHAIR REMPE: So, before you leave that  
17 slide. Melting temperature for stainless steel and  
18 Inconel. That actually seems a bit high. It's an  
19 alloy, and some references might go down to 1650 to  
20 1725k, something like that, right.

21 And then I noticed you put like oxidation  
22 of zircaloy, which is in the core. But also you can  
23 have steam oxidation of stainless steel, for example.

24 Has anyone thought about what would happen  
25 in a steam environment for the stainless steel with the

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1 carbon steel from the hot leg, and thought about how  
2 that might affect thermal properties? Or if the  
3 properties, did you have properties for these other  
4 structures that, before you get to the steam generator  
5 tubes?

6 DR. SALAY: I'm sure someone's thought  
7 about it. But it was not part of the analysis. We're  
8 just doing a thermal-hydraulic and what's in --

9 CHAIR REMPE: Okay. So yes. And I know  
10 it has to have been thought of before. But if you start  
11 looking at when you're in a steam environment,  
12 references have like 540 to 600. So you'll start  
13 seeing stainless steel starting to have some changes.

14 MEMBER POWERS: There's an absolutely  
15 brilliant paper, exhaustive in its scholarship --

16 CHAIR REMPE: Must be by that Dr. Powers  
17 guy.

18 MEMBER POWERS: -- entitled, "Stainless  
19 Steel Oxidation, the Forgotten Source of Hydrogen",  
20 that explores that in massive and quantitative detail.

21 MEMBER BALLINGER: Did this exhaustive  
22 scholarly document consider the Connecticut Yankee  
23 fuel cladding steam oxidation studies that were done  
24 about a century ago?

25 MEMBER POWERS: Trust me. This

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1       exhaustive work was written so far after Connecticut  
2       Yankee had stainless steel cladding that we would  
3       probably overlook that --

4               MEMBER BALLINGER:   Probably --

5               MEMBER POWERS:   -- very active --

6               MEMBER BALLINGER:       -- should do a  
7       scholarly addenda.

8               MEMBER POWERS:   Probably would not, in  
9       looking at this either.

10              MEMBER BALLINGER:   Because the stainless  
11       steel swelled up like a dead fish.

12              MEMBER POWERS:   Well --

13              MEMBER BALLINGER:   -- and everything when  
14       it got real hot.

15              MEMBER POWERS:   When they get really hot  
16       stainless steel does foam.

17              MEMBER BALLINGER:   Oh, yes.

18              MEMBER POWERS:   And oxidizes in the steam.

19              MEMBER BALLINGER:   This was amazing, what  
20       they saw.

21              MEMBER POWERS:   And in fact, when they  
22       pulled the upper core internals off TMI, and turned to  
23       that, you can actually see how the stainless steel  
24       foamed during oxidation.  It's pretty well-known.  In  
25       fact, when you oxidize stainless steel at any time at

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1 high temperatures it foams.

2 The problem I think, Joy, is that by the  
3 time you get into these lines, and things like that,  
4 your hydrogen to steam ratio is such that you're really  
5 not getting any steam, it's pure oxidation.

6 CHAIR REMPE: You'd think that. But I  
7 just want to, I mean, I know --

8 (Simultaneous speaking)

9 MEMBER POWERS: But see, you're running  
10 steam on stainless steel. What they're actually  
11 bringing up here is a mixture of steam and hydrogen.  
12 And you can suppress stainless steel oxidation with  
13 just a little bit of hydrogen pretty dramatically.

14 CHAIR REMPE: Okay. Would you not even  
15 see any sort, so you don't think you're going to see  
16 any sort of changes in the --

17 MEMBER POWERS: Oh --

18 CHAIR REMPE: I mean, it --

19 MEMBER POWERS: The stainless steel very  
20 definitely oxidizes. But the oxide is fascinating.  
21 And just a little bit of hydrogen, you can, it's really  
22 quite dramatic with stainless steel.

23 CHAIR REMPE: What about thermal  
24 connectivity changes for the rest? I mean, things like  
25 --

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1                   MEMBER POWERS: Well, it depends on where  
2                   you're asking about thermal conductivity. Thermal  
3                   conductivity in the steel body itself isn't changed.  
4                   The surface layer changes.

5                   CHAIR REMPE: Yes. So, would it  
6                   insulate?

7                   MEMBER POWERS: It will insulate itself  
8                   somewhat.

9                   CHAIR REMPE: So, expert opinion, without  
10                  any calculations, dictates you don't think it's worth  
11                  looking at, anything at all?

12                  MEMBER POWERS: Not the first thing I  
13                  would look at.

14                  CHAIR REMPE: Okay.

15                  MEMBER POWERS: Not the last thing either.  
16                  But not the first thing I would look at.

17                  CHAIR REMPE: But we're spending a lot  
18                  looking about these steam generators too. So they're  
19                  Inconel way down the line.

20                  MEMBER POWERS: Yes, I think --

21                  CHAIR REMPE: And I'm just wondering when  
22                  you first come out of the hot leg --

23                  MEMBER POWERS: I think --

24                  CHAIR REMPE: I think we're forgetting  
25                  something --

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1                   MEMBER POWERS: I think we'll eventually  
2 get to it. But not at a very stringent pace. In the  
3 counter-current it's the mixing in the lower plenum  
4 that leads to crucial issues.

5                   CHAIR REMPE: Okay.

6                   DR. SALAY: All right. And again,  
7 there's a big difference in the thickness of the  
8 boundaries between severe accident conditions, and  
9 containment or marginal conditions, or site by site  
10 conditions.

11                   The hot leg, three inch. And the surge  
12 line is, has 1.5 inch thickness, rather than the steam  
13 generator tube which has the secondary side condition  
14 is just five hundredths of an inch. So there's a big  
15 difference in heat capacity, and how fast it responds.

16                   And again, you've heard this mentioned  
17 before, the scenario we're looking at is a  
18 high-dry-low. On the high primary pressure, dry  
19 secondary and low secondary pressure.

20                   MEMBER STETKAR: So, Mike, on your  
21 previous slide, instead of saying there's 1,000 pounds  
22 on the secondary side of the tube, do you mean there's  
23 zero pounds?

24                   DR. SALAY: Well, before. I mean, this is  
25 when it's higher. Yes, it can be very low, yes.

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1 MEMBER STETKAR: So, once you have the low  
2 pressure, the pressure we're looking at --

3 DR. SALAY: Yes. You have a --

4 MEMBER STETKAR: Okay.

5 DR. SALAY: Very low. And so you're  
6 assuming that there's, for the high, for the primary  
7 side that there's no significant leakage. And for the  
8 secondary side you are assuming that there is leakage,  
9 or some source of pressure loss.

10 So again, there are two flow patterns that  
11 can occur in severe accident flows. And the difference  
12 between the two is whether the loop seal has water in  
13 it or not. And if you don't have water in the loop seal,  
14 you have natural recirculation.

15 Whereas, if you have water in the loop seal  
16 you have to have, the only way the hot gasses from the  
17 core have to go through the hot leg as colder gas is  
18 returning from the steam generator, are coming back the  
19 other way. And so I'll go into these in a little more  
20 detail.

21 CHAIR REMPE: So, go back to that picture,  
22 please. What is the status of the expert opinion now  
23 on the potential for loop seal clearing in Westinghouse  
24 plants and in CE plants? Because I looked through like  
25 NUREG-6995, and this draft NUREG. And I wasn't sure

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1        what the current expert opinion is on this topic.

2                DR. SALAY:    From my understanding it's  
3        that generally it's not expected to clear.    But --

4                CHAIR REMPE:    For Westinghouse?    Let's  
5        start with Westinghouse, and then go to CE, okay.

6                DR. SALAY:    For Westinghouse.    And we,  
7        again, for CE we didn't look into it in that much detail.  
8        And didn't perform multiple analyses to look to try and  
9        feel out what would occur.

10               MEMBER POWERS:    Mike, it does clear.  
11        Doesn't it just reform?

12               MEMBER CORRADINI:    Why would it reform?

13               MEMBER POWERS:    Condensation.

14               DR. SALAY:    Well, but I thought it was a  
15        race on the leakage.    That's what I thought where Joy  
16        was going.    I'm curious about the leakage to the pump  
17        seals.    Because it's what you're losing versus what  
18        you're gaining.

19               DR. SALAY:    You are condensing some.    But  
20        I don't know if it's enough to --

21               MEMBER POWERS:    If you clear the loop seal  
22        you don't blow all the water out.    So it doesn't take  
23        very much condensation to reform.

24               MEMBER CORRADINI:    Well, but it is a race.  
25        So, but you're, just to answer Joy's question.    I was

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1 going to ask a similar one, is that, it wasn't looked  
2 at for CE. And from the Westinghouse standpoint  
3 there's nothing new there. So, for all intents and  
4 purposes your impression is it won't clear?

5 DR. SALAY: That was my understanding.  
6 I didn't focus on that issue. And I didn't re-read the  
7 NUREG-6995 looking at that. So, from my --

8 DR. LEE: The NUREG-1570, we have look  
9 into ANO-2 versus Surry. The ANL-2 have a very shallow  
10 loop seal. So if the loop seal clear, so you will  
11 establish the full natural circulation by this way.

12 If you have a pump seal which is very high  
13 you will also tend to clear the loop seal too. So it's  
14 very plant specific. So you cannot just lump all the  
15 same plant, and say they all behave that way. You  
16 really need to look at the configuration of the loop  
17 seal versus the rest of the piping. They are not all  
18 the same.

19 DR. SALAY: One of the big factor  
20 assumptions that affects whether you clear or not is  
21 how much leakage you get between the cold leg and the  
22 upper head, or the core region.

23 If, and from my understanding from  
24 different tests in the Westinghouse analyses, if you  
25 assume there was no leakage it would clear every time.

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1       Whereas, if you assume there was some leakage of gas  
2       through this region it would generally not.

3               CHAIR REMPE:   So, just for cleanup in the  
4       report, you might make sure that the statements are  
5       consistent throughout it about the Westinghouse plants  
6       on whatever the topic is.

7               And I think the report's pretty clear,  
8       saying there's just no analysis for the CE plants. And  
9       if that's what you want to go with, that's what it is.  
10       Now, did you say earlier you did do some analyses of  
11       it for the CE plants, as part of this effort, and we  
12       haven't seen it?

13              DR. SALAY:   I looked at it, and looked at  
14       how I would go about doing analyses, analysis.   But  
15       didn't actually go through the calculations.   It was  
16       decided to focus on other --

17              CHAIR REMPE:   Okay.   Thank you.

18              DR. SALAY:   Again, for the full loop  
19       natural circulation, water's cleared from the loop,  
20       core loop seal.   And from NUREG-6995 the loop seal  
21       clearing is affected by the depth of the pump loop seal  
22       and water temperature, reactor core pump seal leakage  
23       in rate and elevation, primary side depressurization  
24       rates, and downcomer bypass flow.   These Westinghouse  
25       studies indicated that loop seals are more likely to

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1 remain blocked with water.

2 MEMBER BANERJEE: Excuse me. When, the  
3 previous slide that you showed, the counter-current  
4 situation with the loop seal. Do we have capability  
5 in our "system" to handle a single phase  
6 counter-current flow like that?

7 DR. SALAY: You're saying in the hot leg?

8 MEMBER BANERJEE: In that hot leg, yes.

9 DR. SALAY: Yes. I will get to that.  
10 That's a little later. That's what this main project  
11 is about, the analyses. So --

12 MEMBER BANERJEE: Right. It's not  
13 obvious.

14 DR. SALAY: No, the codes can't do it. So  
15 you need to use CFD to calculate it, or some other  
16 method. And then implement two pathways, and have the  
17 --

18 MEMBER BANERJEE: I don't know if the  
19 codes can't do it, the comp codes can't do it.

20 DR. SALAY: Well the codes by themselves, they just  
21 don't handle the sheer --

22 MEMBER BANERJEE: Yes. That's for  
23 stratification with counter-current. So, okay. So  
24 you'll come to that later.

25 MEMBER SKILLMAN: And, Mike, before you

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1 change. Just as a matter of discipline you showed the  
2 pressurizer with a level. I'm assuming it's dead  
3 empty.

4 DR. SALAY: Actually, in some of the  
5 analyses it, for some reason the surge line didn't  
6 drain. And it actually stayed, yes. The reason the  
7 level's in there is just forgotten.

8 So it's assumed to be empty. But when we  
9 did run analyses in some of them it seemed like it  
10 drained but somehow filled back up. I don't know if  
11 it's from condensation.

12 MEMBER SKILLMAN: Really.

13 CHAIR REMPE: Calculations.

14 MEMBER CORRADINI: That doesn't make any  
15 sense.

16 MEMBER SKILLMAN: Yes. That doesn't --  
17 Because, you know, I would expect based on what happened  
18 at TMI, there's a transfer from the pressurizer to that  
19 loop seal. And that, and there's a condensing function  
20 continuing. And I would think that that is part of the  
21 riddle of what keeps that loop seal in place. But I  
22 think the pressurizer has to be empty.

23 DR. SALAY: That's one of the things it was  
24 calculating. So I didn't get a chance to explore why  
25 that was occurring either. And then the careful

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1 monitoring and benchmarking is important to get  
2 competence and to gain confidence in whether you're  
3 clearing or not.

4 Because from what I understand from the  
5 sensitivity studies in the previous analyses, if you  
6 have your nodalization different, it also can affect  
7 what exactly occurs.

8 So, full loop circulation reduces, you  
9 don't get a lot of mixing in full loop recirculation,  
10 so you get very hot gasses reaching the tubes. And this  
11 challenges the tubes very severely. And the  
12 expectation is that they will fail.

13 CHAIR REMPE: So, you said that it's  
14 important to do nodalization studies. And that was  
15 done and reported in the older NUREG for the SCDAP  
16 analyses.

17 DR. SALAY: Yes.

18 CHAIR REMPE: Was that done in your recent  
19 calculations for MELCOR?

20 DR. SALAY: No. We didn't focus -- No.  
21 We didn't look at it in detail.

22 CHAIR REMPE: Okay.

23 DR. SALAY: And you have full  
24 recirculation flows, system analyses tools, such as  
25 MELCOR, SCDAP, or use those to calculate the flows.

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1 For counter-current natural circulation the system  
2 behaves a little bit differently, since it can't go,  
3 flow through the whole system.

4 It has to go up through the, to the steam  
5 generator, up to the core, along the hot leg, up the  
6 steam generator, back through the steam generator to  
7 the inlet plenum, where it can mix. And then the colder  
8 gasses go down along the hot leg, and back to the core  
9 to heat up.

10 So there's a lot more mixing that occurs  
11 between the hot gasses and colder gasses, than with the  
12 full loop natural circulation. So the tubes are not  
13 as challenged. And as Sanjoy Banerjee mentioned,  
14 it's, or asked about the codes' capability to do this,  
15 they can't, they're not set up to handle this  
16 counter-current flow.

17 And so what is typically done is that, they  
18 also can't handle the, provide the two temperature  
19 distribution. And that affects where it fails, and  
20 whether a flaw is likely to be --

21 MEMBER BANERJEE: You can handle the, I  
22 would think you could handle the flows in the steam  
23 generator by sort of modeling in more detail the bundle,  
24 right?

25 DR. SALAY: Yes, you can get that.

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1                   MEMBER BANERJEE:   That behavior in the  
2                   core.

3                   DR. SALAY:   Yes.   But the --

4                   MEMBER BANERJEE:   But the counter-current  
5                   you can't at the moment?

6                   DR. SALAY:   Well, it's just 1D and  
7                   friction.   And so you put two 1D together, and then you  
8                   somehow couple it, either with a model, or with a model  
9                   that's either directly calibrated against experiments,  
10                  or a model that's calculated as a CFD.

11                  So you run the CFD calculations to give you  
12                  help, your rate of counter-current flow, and your rate  
13                  of mixing in the inlet plenum.   And you adjust some  
14                  parameters in the codes to match the CFD results.   And  
15                  the CFD results found scale with temperature.   And so  
16                  --

17                  MEMBER BANERJEE:   Because the reason I'm  
18                  asking is that I suppose the stratification is one of  
19                  the key phenomena that you have to capture, right, in  
20                  order to look at the failure of the hot leg.

21                  DR. SALAY:   Yes.

22                  MEMBER BANERJEE:   So you almost have to do  
23                  this entirely by CFD essentially, with the boundary  
24                  conditions being set by the code, right?

25                  DR. SALAY:   Yes.

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1                   MEMBER BANERJEE: I'm just looking at the  
2 methodology.

3                   DR. SALAY: Yes, no. Yes, this is how --  
4 Yes, with CFD you get the, you sort of get a set state  
5 sort of result. But you can't do the whole transient,  
6 because it's just too much work. And this can do the  
7 transient, but can't get the capture of that. So you'd  
8 run the CFD to get the counter-current --

9                   MEMBER BANERJEE: So will you in the  
10 future go through the methodology as to precisely how  
11 you're sort of coupling the, let's say the system codes,  
12 the 1D codes to the CFD, and iterating between the --

13                  DR. SALAY: I won't describe it in that  
14 much detail. But it's, ultimately you have I think  
15 three parameters. You have how much --

16                  MEMBER BANERJEE: If you're going to do  
17 this later you don't have to go through it now.

18                  DR. SALAY: I don't think I go through it  
19 in that much detail. So I want, so I just do a brief  
20 overview saying you use the CFD. But so, CFD provides  
21 you this counter-current amount.

22                  You have this Froude based relationship  
23 with a parameter that you can tune to match that. And  
24 then you, CFD also tells you how much mixing you get,  
25 and what. It also tells you how many tubes are in the

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1 hot plume that reach.

2 Because you're not, your plume comes in,  
3 it spreads out, and comes into the tube sheet. But it  
4 tells, the CFD tells you how many tubes are actually  
5 in the hot leg, and what the distribution of temperature  
6 entry does to those.

7 MEMBER BANERJEE: Yes. I think we've  
8 seen those before.

9 DR. SALAY: Yes. You've seen them but --

10 MEMBER BANERJEE: And they oscillate in  
11 the plume, and all sorts of things up --

12 DR. SALAY: Yes. So there's the three  
13 parameters. There's the flow in the amount of mixing.  
14 How much --

15 MEMBER BANERJEE: Yes.

16 DR. SALAY: Your mass flow in the hot leg.  
17 Your mixing fraction and your recirc ratio. The recirc  
18 ratio helps mass go through the steam generator tubes,  
19 mass flow rate through steam generator tubes relative,  
20 divided by the mass going through the hot leg.

21 MEMBER BANERJEE: I think I can see what  
22 you are doing. But in terms of, you're taking a slice,  
23 right, in time? Some point in time which is set on some  
24 boundary condition --

25 DR. SALAY: Yes. But it's --

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1                   MEMBER BANERJEE:    -- from the system  
2 codes, right? In other words you have -- You can't do  
3 the full calculation with the CFD. So you said  
4 something, you said that, backflow conditions, you know  
5 --

6                   DR. SALAY: Right. You set the CFD code,  
7 and you run the CFD code at different temperatures.  
8 And it's shown that these parameters, the mixing  
9 fraction and the mass flow, and the recirc ratio, they  
10 generally are constant at the different temperature  
11 scale.

12                   So you can have confidence that it's, you  
13 can use these parameters as inputs into the system code.  
14 And that as you, as the accident progresses that it,  
15 that was generally the behavior that you'd get from the  
16 CFD.

17                   MEMBER BANERJEE: I don't quite see that.  
18 Because as the accident progresses, you don't know the  
19 phenomena yet, backflow. But I imagine the amount of  
20 hot gas coming out of the core will increase, right?

21                   DR. SALAY: Yes.

22                   MEMBER BANERJEE: And it will go and, go  
23 through this complex path. And some of it will run back  
24 as you've shown. But it's exactly what's going to  
25 happen. But the proportions will change with time,

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1 right, when it goes back?

2 DR. SALAY: From my understanding what's  
3 been observed and what was done also determined in the  
4 earlier analyses was that it generally doesn't change  
5 the amount of tubes that are hot, the mixing ratio and  
6 mixing fraction, and these parameters.

7 They generally stay the same, which, and  
8 these parameters are sufficient to characterize that  
9 they change, they stay the same as you go up in  
10 temperature, and the accident progresses.

11 MEMBER BANERJEE: Interesting. Are you  
12 going to show some of those results here?

13 DR. SALAY: They've been shown before --  
14 (Simultaneous speaking)

15 MEMBER BANERJEE: But I don't remember  
16 them exactly. Was it sort of a fairly robust result?

17 DR. SALAY: In the CFD analyses they  
18 looked at one temperature. And then at high  
19 temperatures they looked at snapshots in time. And  
20 then the parameters were pretty similar.

21 MEMBER BANERJEE: Okay.

22 DR. SALAY: It's a --

23 CHAIR REMPE: I'd like to see a variation  
24 in the hot tube fraction, for example, by sending the  
25 -- Basically when you set that hot tube fraction into

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1 MELCOR SCDAP you're making some engineering judgment  
2 on what value to pick, based on how much there was  
3 oscillation in the CFD analysis, right?

4 DR. SALAY: Well, there was more  
5 fluctuation in Westinghouse than in CE, because in CE  
6 the -- Well, in Westinghouse the hot leg comes in at  
7 an angle to the tube sheet. Not the tube sheet, to the  
8 separator that divides the inlet plenum and the outlet  
9 plenum.

10 So there was a little more fluctuation.  
11 Whereas the CE it's perpendicular. And so there's less  
12 fluctuation. But yes. In the parameters in the hot  
13 tube fraction distribution did, the temperature  
14 distribution in entering the tubes did account for some  
15 fluctuation in --

16 MEMBER BANERJEE: How sensitive, excuse  
17 me, Joy, are the results to getting this wrong? What  
18 are the uncertainties here? Suppose things change by  
19 a factor of two, you got the proportions wrong, what  
20 would --

21 DR. SALAY: Well, it makes a difference  
22 between -- Yes, because, it makes a difference between  
23 which component fails first.

24 MEMBER BANERJEE: Yes. I think that's  
25 the issue, right.

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1 DR. SALAY: And because, actually,  
2 initially had we had the parameters -- We did some  
3 adjustments of that and actually did change it. I  
4 think it was less than a factor of two. And it  
5 completely made a difference between the tubes failing  
6 first and RCS components failing first. So, it is very  
7 sensitive to these flows.

8 MEMBER CORRADINI: So but, if I might ask  
9 Sanjoy's question differently? If you focus only on  
10 the mixing of the counter-current flow I can imagine  
11 this mixing co-efficient, or whatever you call it, you  
12 insert into the system codes is a large uncertainty.  
13 But I would expect the initial boundary conditions that  
14 get you the high, dry and low are larger uncertainties.

15 DR. SALAY: Yes. I'm sure there are lots  
16 of uncertainties in those conditions. But are you  
17 saying in the sequence itself?

18 MEMBER CORRADINI: Yes.

19 DR. SALAY: Yes. I mean, of course, but  
20 of course the part that I'm looking at is, what if the  
21 part that I'm starting off is, what if you're at start  
22 off and get these conditions? So, I'm in --

23 MEMBER CORRADINI: Yes. I understand,  
24 Mike. I'm completely with you. I just wanted to put  
25 it in context. I guess I actually wanted to go back

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1 to something that Dana asked. And I'm sure you didn't  
2 consider it, but I'm curious about that observation.  
3 Because I guess I'm not as an expert as Dana is in  
4 oxidation.

5 Is that, if I started having severe  
6 oxidation of the upper core internals, would that  
7 change the flow path and the flow resistance, that I  
8 actually could alter this flow path?

9 Dana made this point about steel oxidation  
10 observation. Would it affect the flow path or the flow  
11 circulation path that you're assuming in your  
12 calculation?

13 DR. SALAY: Yes. I don't know what, how  
14 much of a size change there would be if it oxidizes.

15 MEMBER CORRADINI: Okay. All right.

16 MEMBER POWERS: I surely don't know, Mike.  
17 But what I have seen, certainly from the TMI upper grid,  
18 locally you change the flow pathway. But there's an  
19 awful lot of room up in the upper plenum for it to reform  
20 this kind of picture that Mike's portrayed out here.

21 When you transfer to the boiler I think  
22 that you might have a more dramatic effect from swelling  
23 and foaming of the stainless steel oxides.

24 MEMBER CORRADINI: Okay.

25 MEMBER POWERS: But I assuredly don't

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1 know.

2 MEMBER CORRADINI: I'm just trying to  
3 understand. Because I think Sanjoy's question, which  
4 is starting down this path is, this is given that you  
5 kind of have to flip between a CFD calculation, and then  
6 tune the system code calculation. I can understand  
7 where this is a major uncertainty. That's why I was  
8 just trying to ask these questions.

9 MEMBER POWERS: Well, I don't know that  
10 that's the major uncertainty. But it's certainly a  
11 challenging part of the calculation. There's no  
12 question of that.

13 MEMBER CORRADINI: Well, given, you know  
14 -- Yes, okay.

15 MEMBER BANERJEE: But you have the  
16 sensitivities done some? I mean, you've done this sort  
17 of parametrically?

18 DR. SALAY: Well, we kind of look to, the  
19 parametrics were done in the previous analyses. We  
20 didn't do many sensitivities.

21 MEMBER BANERJEE: But it was done  
22 previously, yes? We wrote a letter on this, right.  
23 Bill Shack was the -- I'm trying to remember way back  
24 in history. I think Shack was the chairman, wasn't he,  
25 of the subcommittee at that time? Do you remember,

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1 Dana? I was there attending innocuously, but not the  
2 chair.

3 MEMBER POWERS: You're never innocuous.

4 MEMBER BANERJEE: But Shack I think was  
5 the chairman.

6 MEMBER POWERS: He truly is never  
7 innocuous.

8 CHAIR REMPE: CFD sensitivities right?

9 MEMBER BANERJEE: Yes.

10 CHAIR REMPE: There were some CFD CE  
11 sensitivities done previously? No, right?

12 DR. SALAY: I'm sure Chris did, looked at  
13 a few different things.

14 CHAIR REMPE: But it's not documented  
15 previously. It was only done for this effort, right?

16 DR. SALAY: Yes, I mean, it --

17 CHAIR REMPE: And we don't have those.

18 MEMBER CORRADINI: We have all the ACRS  
19 letters that were given to us.

20 MEMBER BANERJEE: Oh sure, yes, we have  
21 the ACRS letters. I just don't recall. But I guess  
22 this timing was the issue always, right, the  
23 uncertainty and the timing?

24 DR. SALAY: Yes.

25 MEMBER BANERJEE: Because in one case if

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1       you got massive failure of the steam generator tubes  
2       it led to a very different situation from some RCS  
3       component failing --

4               DR. SALAY:   Yes.

5               MEMBER BANERJEE:  -- within containment,  
6       which was the hot leg really.

7               DR. SALAY:   But if one tube fails, again,  
8       the system pressure is still high.

9               MEMBER    BANERJEE:       Yes.       That's  
10       different, yes.  It's one or two tubes.  It doesn't --

11              MEMBER CORRADINI:  But I think, Sanjoy, to  
12       answer your question, it was the October 22nd letter  
13       in 2009 --

14              MEMBER BANERJEE:  Right.

15              MEMBER CORRADINI:  -- where it was our  
16       final, our most recent set of suggestions for this  
17       program, going to a user need only basis.

18              MEMBER BANERJEE:   Okay.  I'll re-read  
19       that letter.

20              DR. SALAY:   And again, for Babcock &  
21       Wilcox plants, from the pervious studies it was, I'm  
22       not sure they were CFD, but they came to the conclusion  
23       that vigorous natural circulation flows wouldn't be  
24       expected in these plants, because of the way they're  
25       configured.  And so, they were not part of the severe

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1 accident induced failure studies.

2 MEMBER SKILLMAN: I think there's another  
3 detail. And that is that the B&W claims had that vent  
4 valve in the upper plenum to actually allow the hot leg  
5 and the cold leg to equalize, so you don't get a loop  
6 fill.

7 MEMBER CORRADINI: Say that again, Dick?  
8 I didn't appreciate that.

9 MEMBER SKILLMAN: The B&W plants have vent  
10 valves. There are four large 14 inch gravity operated  
11 valves that equalize between the downcomer and the  
12 inner plenum. That is a very key design feature of the  
13 B&W fleet, of all the plants that were built.

14 MEMBER CORRADINI: So that does what  
15 again? I'm sorry.

16 MEMBER SKILLMAN: It ensures that your  
17 downcomer is always available. If you go back to the  
18 --

19 MEMBER CORRADINI: Well, I'm looking at  
20 Slide 14 to understand what you're saying.

21 MEMBER SKILLMAN: Okay. If you see right  
22 in the, see all those holes, all those round things at  
23 the top of the upper internals?

24 MEMBER CORRADINI: Yes.

25 MEMBER SKILLMAN: Four of those are 14

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1       inch diameter check valves, gravity operated. And  
2       they assure that if there's delta P between the inner  
3       and outer portion of the steel on the plenum, that's  
4       the core support assembly, that those equalize.

5                   MEMBER CORRADINI:     So essentially if  
6       there is too much pressure on the hot side it pushes  
7       into the cold side.

8                   MEMBER SKILLMAN:    That's correct.

9                   MEMBER CORRADINI:    Okay. Yes.

10                  DR.        SALAY:               All        right.  
11       Thermal-hydraulic analyses for this project used both  
12       Westinghouse and Combustion Engineering TH analyses as  
13       input to the tube failure calculator, and the finite  
14       element modeling.

15                  The Westinghouse calculations as you're,  
16       have been, were performed for the steam generator  
17       action plan before. And it's documented in  
18       NUREG-6995. The TH analyses at the time did not  
19       receive the same level of attention.

20                  So that's why we were looking at it, and  
21       performing some additional TH analyses for CE,  
22       Combustion Engineering plants under this project. And  
23       we're using those CFD and system codes. CFD is used  
24       to provide multiple parameters for the system code.

25                  And it can also be used, the temperature

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1 distribution can be used to calculate the flaws. The  
2 CFD approach is validated using Westinghouse 1/7 scale  
3 tests. And here you see some diagrams of the tests.  
4 These tests are reduced scale, electrically heated core  
5 vessel and two steam generators.

6 It focused on temperature measurements and  
7 transport of heat. You can see in the different  
8 diagrams where temperature readings were taken. These  
9 tests demonstrated the counter-current flow path.  
10 They were focused on tube integrity, but knowing that  
11 the flow pattern provides lots of insights for that.

12 Scaling studies were, many scaling studies  
13 were performed to demonstrate that these were  
14 applicable to full scale plants. And information from  
15 these experiments have been used for system codes, and  
16 to study station blackout scenarios. The analyses,  
17 the CFD analyses for these were done around 2001.

18 And the CFD analyses started with the 1/7  
19 scale. We did the 1/7 scale for the first scale, then  
20 went to the Westinghouse, and then went to in this  
21 analysis CE plants. And several sensitivities were  
22 performed on heat transfer, surge line orientation,  
23 hydrogen content and potential tube leakage rates.

24 MEMBER POWERS: These particular tasks,  
25 of course, were revolutionary when they were done. And

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1 insightful, and just really spectacular result. And  
2 they are a true demonstration of the well-known adage  
3 that no good deed goes unpunished.

4 Because they raised a large number of  
5 questions that the tests never were intended to  
6 address. Does the equipment for doing these tests  
7 still exist, do you know?

8 DR. SALAY: I have no idea. They have it.  
9 But the Europeans were planning on performing some  
10 similar experiments with the hot, much more resolution  
11 in, with their temperature measurements using newer  
12 methods. I think some of that's been scaled back, and  
13 they're looking for smaller PHD --

14 MEMBER CORRADINI: Mike, there's just --

15 MEMBER POWERS: Yes. The tests were  
16 done. They revealed things that people had speculated  
17 about. And of course it was dramatic. A complete  
18 change of thinking when they occurred. And of course  
19 now you, then you knew more. And so you started asking  
20 more questions.

21 And the test got criticized for a lot of  
22 things that they never intended to address, because  
23 they didn't know about them at the time. And one  
24 wonders if such experimentation ought not be continued.

25 DR. LEE: Actually, Dana, remember a few

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1 years ago we went with you to PSI. And they proposed  
2 that they going to do some testing when you have six  
3 it varies. The inlet coming into the plenum, the inlet  
4 coming on stimulator, the hot leg coming in pipe. You  
5 can varies by the closer to the sheet.

6 MEMBER STETKAR: Yes, tube sheet.

7 DR. SALAY: Right.

8 DR. LEE: Or further away. But they found  
9 out that the cost of doing such testing becomes  
10 prohibitively expensive for PSI. So they had  
11 abandoned that experiment. I thought they will  
12 propose it. But they have abandoned it. So, I think  
13 we will want to bring it back up to the French. And  
14 maybe they can --

15 MEMBER STETKAR: I was going to say,  
16 AREVA's not, or EEF or AREVA's not doing anything in  
17 this area.

18 DR. LEE: I don't know. But the thing is  
19 that it disappeared from the radar screen. And now  
20 they're proposing something. And recently I think  
21 Chris Boyd and I look at it. And they said it's more  
22 like a force flow thing.

23 So it was really not a natural circulation.  
24 So I don't quite know what you can get out of it. So,  
25 I think the purpose is that we bring it back to the

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1 attention of someone and --

2 MEMBER POWERS: Well, the reason I bring  
3 it up is --

4 DR. LEE: -- can really do something about  
5 it.

6 MEMBER POWERS: -- the, you know, we're  
7 about to embark on discussion of the recric program.  
8 There's a hole. And I'm wondering if this isn't  
9 something that we should, maybe with Mike's help we  
10 could highlight --

11 DR. LEE: And Chris.

12 MEMBER POWERS: And absolutely with  
13 Chris. To highlight as a need found to understand,  
14 especially as we make bigger use of CFD. You need the  
15 ability to calibrate, and to validate that CFD  
16 capabilities in these fairly complex situations.

17 And at the same time get information on how  
18 this rather subtle points in these design, in fact,  
19 behave during accidents might be very worthwhile for  
20 us to consider.

21 MEMBER BANERJEE: Are there international  
22 programs directed this way?

23 DR. LEE: I think when the European Union  
24 call for proposals, the different organization can  
25 suggest what they can look into. And this is one of

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1 the areas they can look into.

2 Because this is a, you know, steam tube  
3 rupture is a low probability, but a high risk type of  
4 event. So the Europeans are always interested in  
5 reducing the source term into alignment, especially for  
6 the EDF or the plants of BWR.

7 MEMBER BANERJEE: But there is no program  
8 in place right --

9 DR. LEE: Right now we don't have seen one.  
10 But a few years ago, yes, I was thinking the need to  
11 propose such a program. And we think this will be very  
12 useful because that will allow for the better  
13 benchmarking for the CFD. And then we can use that one  
14 in terms --

15 MEMBER BANERJEE: Were they proposing it  
16 for what was a standup facility? Or was it completely  
17 different?

18 DR. LEE: I don't know what the name of it  
19 is. But it is the same place. So they would have a  
20 plant there. But in the bottom there's more space so  
21 they can adjust that inlet coming in, relatively  
22 speaking of, from test to test. So if they can look  
23 at making some location of it in different country. The  
24 angle coming in, and the distance from the tube plate.

25 MEMBER BANERJEE: I can see that they have

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1 facilities which could be used.

2 DR. LEE: But it become cost. Cost is a  
3 problem. Now, with Switzerland planning to phase out  
4 nuclear power, right. So, PSI is having problems  
5 getting resources to fund such a project, or to take  
6 on such project. So it is better to bring in the  
7 others. We should do that.

8 MEMBER BANERJEE: It's a good point.  
9 These were very nice experiments. I remember them.

10 MEMBER POWERS: They were very revealing.  
11 And they changed, had a qualitative impact on our  
12 thinking, which is just bad. I mean, it's bad because  
13 it proves how dumb you were before, and whatnot. But  
14 they also had the impact of, as we can see now, raising  
15 lots of questions that we never had before.

16 CHAIR REMPE: So maybe before this comes  
17 to the full committee it would be good to ask someone  
18 from Westinghouse if the facility still exists also?  
19 Or are you thinking just let's go to Europe, Dana?

20 MEMBER POWERS: Well, you know, I ask  
21 about the facility. My own view is, old facilities  
22 usually are well designed for old experiments.

23 And now that we have such marvelous  
24 computation capabilities we ought to be able to design  
25 a better experiment. Of course, when you design a

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1 better experiment it oftentimes becomes cost  
2 prohibitive. It might not see some sort of a  
3 balancing. I mean, I'm not the one to decide whether  
4 old, reuse old experiments, or --

5 CHAIR REMPE: But it would be nice to know  
6 if it even exists still, or if it's available.

7 MEMBER POWERS: I had spent, I will admit,  
8 a little while looking in the details of that  
9 experiment. And I think we could design a better  
10 experiment now. I meant one of us be able to design  
11 a better experiment.

12 DR. SALAY: All right. And this shows  
13 some of the results of scale-up from the 1/7 scale to  
14 full scale. And this is one scale, SF6 to full scale  
15 severe accident conditions for generator steam.

16 On the top right you see the temperature  
17 distribution. Chris, scale and the tubes. Okay.  
18 The temperature distribution for the two analyses.  
19 And this shows the scale from zero. Well, it doesn't  
20 go to one. But zero represents the cold side of the  
21 steam generator tubes.

22 And one represents the temperature entry  
23 in the hot leg. So it's normalized, as it's based on  
24 the temperatures coming in. I mean, that's how you can  
25 apply it to different temperatures. So, as the similar

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1 solutions were obtained for both analyses, when heat  
2 transfer rates are scaled the full scale showed a  
3 slightly lower temperature distribution entering the  
4 tubes.

5 Yes, the heat transfer rate under severe  
6 accident conditions are different, however. And the  
7 geometry isn't similar. And they were identified as  
8 an area that needed further looking into. The recirc  
9 ratio, the mass flow in the tubes, the mass flow of the  
10 hot leg is increased a little bit when they went from  
11 1/7 scale to full scale.

12 And the mixing fraction, the amount of the,  
13 I think the, I can't remember, the hot leg that gets  
14 mixed with gas returning from the steam generator tubes  
15 went up also a little bit. Oops, wrong way.

16 And now I'm moving to the CSGTR behavior.  
17 And it differs a little bit from Westinghouse plants.  
18 This is primarily because there's less opportunity for  
19 mixing for hot gas before it reaches the steam generator  
20 tube inlet.

21 There are a few different reasons.  
22 There's a shorter lower hot leg length to diameter  
23 ratio. So there's less opportunity for mixing there.  
24 And some CE plants have shallow inlet plena.

25 MEMBER BANERJEE: So, did you have to

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1 repeat this CFD calculations with these shallow plena?

2 DR. SALAY: Yes, yes. The CFD  
3 calculations were done specifically --

4 (Simultaneous speaking)

5 MEMBER BANERJEE: They're very geometry  
6 sensitive?

7 DR. SALAY: Yes, you have to do it  
8 specifically. And a third aspect probably that  
9 affects the mixing is that the hot leg comes in normal  
10 to the sheet, separating the two plena.

11 MEMBER BANERJEE: So we haven't seen  
12 these, even these calculations, right, the CFD ones?  
13 Have we?

14 DR. SALAY: I think in a few rounds I'm  
15 sure they were presented in --

16 DR. LEE: I thought three years ago I saw  
17 it.

18 MEMBER BANERJEE: Maybe in --

19 CHAIR REMPE: But not documented I think  
20 is the issue here.

21 MEMBER BANERJEE: I don't always attend  
22 these, so I must have missed it. I should have known  
23 to see it.

24 CHAIR REMPE: There's a report. It  
25 mentions that the replacement steam generators for the

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1 Westinghouse plants are becoming more like CE plants.  
2 And so, if you go through the next couple of slides could  
3 you kind of characterize?

4 I mean, you've talked about this separator  
5 plate that's characteristic of the Westinghouse  
6 plants. But what are the replacements looking like  
7 now?

8 DR. SALAY: I don't know.

9 CHAIR REMPE: Oh, okay.

10 (Simultaneous speaking)

11 MEMBER BANERJEE: -- geometry sensitive,  
12 right.

13 CHAIR REMPE: Yes, but --

14 (Simultaneous speaking)

15 CHAIR REMPE: So we're getting into what  
16 may be the --

17 DR. BOYD: This is Chris -- Is this on?  
18 This is Chris Boyd from research. I had that same  
19 question. And we were concerned because the only one  
20 we really had back ten years ago was Calvert Cliffs  
21 because they were just doing a change. And the inlet  
22 plenum was significantly different.

23 So I got the impression that we can do  
24 whatever we want, I guess, in designing inlet plena for  
25 the replacements. So we did ask for a survey of

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1 Westinghouse replacements. And we asked for maybe ten  
2 or 12. We ended up getting about four.

3 And in the Westinghouse space the ones that  
4 we saw were nearly identical, you know, if you held them  
5 at arm's length maybe a half inch difference. But  
6 there wasn't any significant variations like we saw  
7 with the CE plant.

8 So, with, so the impression that the  
9 Westinghouse's are different and flatter, and more like  
10 the CE is not anything that we found.

11 CHAIR REMPE: Okay.

12 DR. BOYD: That was a hypothetical  
13 concern. Because apparently replacement steam  
14 generator design can take some liberties on the  
15 original design.

16 CHAIR REMPE: Okay. So perhaps maybe a  
17 cleanup of the report. That ought to be --

18 DR. BOYD: Right.

19 CHAIR REMPE: -- an item. Thank you.

20 DR. SALAY: So, with these differences the  
21 tubes see hotter temperatures relative to the hot leg,  
22 than they do in Westinghouse plants. And because of  
23 this it's, under certain conditions the tube, even  
24 unflawed tubes using standard failure models could be  
25 predicted to rupture before hot legs.

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1                   And unlike before the flawed tube, a lot  
2                   of tubes, if you're looking at unflawed tubes would hit  
3                   the failure point at about the same time. And so, you  
4                   could get a big failure, where potentially you could  
5                   depressurize enough to not, to prevent subsequent RCS  
6                   failure.

7                   And here shows a CE inlet plenum. This was  
8                   actually a replacement for Calvert Cliffs, compared to  
9                   Westinghouse. If you look at the plume it has about,  
10                  it's about that wide there. And you only have 1.5  
11                  length to diameter ratios before it hits the tube sheet.

12                  Whereas, in the Westinghouse you have  
13                  about four and a half-length to diameter ratios, which  
14                  provides much more opportunity for mixing. So here,  
15                  some CFD results for both the Westinghouse steam  
16                  generator and CE steam generator. And you're looking  
17                  at the normalized temperature fields.

18                  Again, zero is the cold side of the steam  
19                  generator, and one, the hottest temperature is the  
20                  temperature that the hot leg sees. And you can see the  
21                  temperature entering the tube sheet, it's  
22                  substantially hotter for CE than for Westinghouse.

23                  And so here, this figure should, details  
24                  a bunch of things to look at and consider, the  
25                  pressurizer draining, your natural circulation bypass

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1 flow, your oxidation rate core blockage, pump seal  
2 leakage, your nodalization, your downcomer clearance.

3 That's also necessary for full loop  
4 natural circulation. Your lower head can't be full of  
5 water. Because otherwise it blocks the flow. Of  
6 course, loop seal clearing, that's been mentioned.  
7 How much mixing you get in the hot leg.

8 How much mixing you get in the inlet  
9 plenum. And tube heat transfer and secondary flows,  
10 and tube sheet nodalization. So for MELCOR and CE  
11 commercial unit calculation it's Sandia National Labs  
12 generated Combustion Engineering deck. That was based  
13 on previous RELAP and MELCOR decks.

14 Go a little bit over. The addition of the  
15 hottest tube. Estimate of the tube temperature  
16 profile. I don't actually talk about the secondary  
17 relief valve opening criteria. But there are a few  
18 different criteria.

19 MEMBER BANERJEE: The reason you moved  
20 from RELAP, away from RELAP was what?

21 DR. LEE: Because we stopped the  
22 development of SCDAP Rev 5 and INL.

23 MEMBER BANERJEE: Oh, so it was --

24 DR. LEE: -- we put out completely INL and  
25 the SCDAP Rev development.

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1 CHAIR REMPE: Well actually, the NUREG  
2 that has the SCDAP calculations was done by ISL, not  
3 INL. And so --

4 DR. LEE: But previously INL did a very  
5 sensitive --

6 CHAIR REMPE: Right.

7 DR. LEE: -- SCDAP Rev 5.

8 CHAIR REMPE: Yes, but --

9 DR. LEE: Looking at everything can come  
10 under the sun on heat transfer, everything. So is a  
11 very comprehensive study at that time.

12 MEMBER BANERJEE: So, the reason you  
13 pulled out was --

14 DR. LEE: Because Bechtel Company took  
15 over the running of INL. And there is conflict of  
16 interest problem. And the General Counsel have us pull  
17 out.

18 MEMBER BANERJEE: Because that's what I  
19 was wondering, why you would do this. Okay. Maybe  
20 these are political reasons --

21 DR. SALAY: And there is also, I have  
22 nothing.

23 CHAIR REMPE: Well, the report said it was  
24 because that you wanted to do the radiation releases  
25 too, is the official document statement is why you

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1 switched to MELCOR.

2 DR. SALAY: Yes. We're moving to MELCOR.  
3 And we did want to calculate fission particle releases.  
4 And if we can do it in the future that's, and the  
5 opportunity is there, the deck's there, and --

6 MEMBER BANERJEE: And MELCOR was adapted  
7 to do these sort of detailed thermal-hydraulic  
8 calculations in the RCS and secondary side? As you  
9 showed in the previous slide --

10 DR. SALAY: Yes.

11 MEMBER BANERJEE: -- that's a --

12 DR. SALAY: Yes. It uses the CFD analyses  
13 as input to -- So you have run a few cases to calibrate  
14 it so that you're matching the results.

15 MEMBER BANERJEE: But it can capture those  
16 complicated phenomena like loop seal blocking,  
17 clearing --

18 DR. SALAY: Yes. Same thing.

19 MEMBER BANERJEE: Yes. Okay.

20 DR. LEE: After we pull out from SCDAP Rev  
21 5 we stopped using it for analysis. It took us about  
22 ten years or so to bring in parity between SCDAP Rev  
23 5 and MELCOR incidents and analysis.

24 MEMBER BANERJEE: Okay. Thank you.

25 DR. LEE: A long time.

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1 MEMBER BANERJEE: Yes. It's not obvious  
2 that it --

3 DR. LEE: Yes.

4 CHAIR REMPE: Before you --

5 DR. LEE: It's a long history. Sorry.

6 CHAIR REMPE: It's okay. Everybody's --

7 I'd like to talk a little bit more about the hottest  
8 tube implementation that was done for MELCOR. When it  
9 was done for the SCDAP stuff I guess they relied on --

10 You have a prediction for the hottest tube.  
11 And I guess a long time ago they had a figure of 17 in  
12 NUREG-1922, where they tried to say, okay, this is the  
13 hottest tube. And we're going to apply it.

14 And it's not like this hot tube fraction  
15 that's coming from the CFD stuff. They apply it to a  
16 certain number of tubes and say, okay, so the one tube  
17 failing, there's ten percent, or whatever they want to  
18 say percent. And it's I think expert opinion.

19 DR. SALAY: Yes. It was expert opinion.  
20 A few different people said, well we could detect, and  
21 it could be 20 in --

22 CHAIR REMPE: Okay. What did you do for  
23 the MELCOR analysis.

24 DR. SALAY: Twenty.

25 CHAIR REMPE: Okay. And was that the

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1 same? I mean, that wasn't the same as what was done  
2 for the SCDAP analysis a long time ago.

3 DR. SALAY: In the SCDAP analysis it was  
4 done for Westinghouse. Westinghouse the tubes don't  
5 get hot enough to -- So that unflawed with the even  
6 approach --

7 CHAIR REMPE: Okay.

8 DR. SALAY: -- in failure temperature.

9 CHAIR REMPE: Okay. So this might be an  
10 important expert opinion. And I believe it was the NRC  
11 experts --

12 DR. SALAY: YES.

13 CHAIR REMPE: -- that came up with this 20  
14 percent. But it's not really documented that well, I  
15 thought, in the report. I mean, there's a couple of  
16 sentences, and that's about it.

17 DR. SALAY: Yes. I just heard people  
18 talking about it too. I haven't --

19 CHAIR REMPE: Okay.

20 DR. SALAY: Again, for the addition of the  
21 hottest tube you need to capture the tube temperature  
22 that's in, that's shown in the CFD calculations. So  
23 it's, you use this to get your peak temperature. And  
24 you have your average temperature.

25 And you can use that to scale your spatial

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1 distribution, so this provides sort of a time dependent  
2 anchor to the spatial distribution. And a few methods  
3 were tried, just used post processing method. But  
4 there were doubts that it was, I mean, just calculate  
5 based on the results.

6 And there were doubts that this adequately  
7 captured the behavior. So then tried to match the  
8 method to the one that was used for SCDAP RELAP. And  
9 it had some stability issues.

10 And then finally went with this method  
11 where you actually removed heat at the inlet, and then  
12 added the same amount of heat back after, when it came,  
13 where the flow comes into that outlet plenum. And so,  
14 you're not adding energy, but you're changing the  
15 temperature of the tube, so, to match the CFD. And so  
16 --

17 MEMBER CORRADINI: So this was an, that's  
18 the one you settled on is an arbitrary addition of a  
19 +Q in your cartoon?

20 DR. SALAY: Well, not -- This was a method  
21 that was used previously. And it's what matches with  
22 the CFD, yes. And so, you need some way to do the  
23 increase of temperature. And you can't really capture  
24 it other than --

25 MEMBER CORRADINI: I just want to make

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1       sure I understand. So you settled on the final, the  
2       heat addition method to --

3                     DR. SALAY: Yes.

4                     MEMBER CORRADINI: Okay. And then to get  
5       back to Joy's question, by judgment you added this over  
6       a group of how many tubes?

7                     DR. SALAY: Well, there's only one tube  
8       that you calculate. But you're assuming that it  
9       represents 20 when it fails. And --

10                    MEMBER CORRADINI: Okay. Okay.

11                    DR. SALAY: I think it doesn't really make  
12       that much difference once it's big enough to  
13       depressurize in the system.

14                    CHAIR REMPE: How many smaller -- Like if  
15       you went to ten would you have a big enough hole?

16                    DR. SALAY: I didn't --

17                    CHAIR REMPE: There's no sensitivities on  
18       it then?

19                    DR. SALAY: Yes. And then for  
20       approximation of the tube temperature field, so you  
21       then, from the previous addition of hottest tube you  
22       have these two temperatures. And you can apply the  
23       temperature distribution from CFD.

24                    There was an approximate, it was  
25       approximately by parabolic shape that goes all the way

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1 to the top of the tube sheet. And so you can come up  
2 with a time variant temperature distribution that you  
3 can then test against, test your flaws against to see  
4 if --

5 MEMBER BANERJEE: The situation if I  
6 remember was the plume waves around, right?

7 DR. SALAY: It waves around more in  
8 Westinghouse. But then, this is sort of meant to be  
9 bounding a little bit. So just tried a simple  
10 approximation that can be used to calculate.

11 MEMBER BANERJEE: But the --

12 DR. SALAY: What fraction.

13 MEMBER BANERJEE: -- material is exposed  
14 to --

15 DR. SALAY: It varies.

16 MEMBER BANERJEE: Yes. And fluctuating  
17 temperature field.

18 DR. SALAY: And when this was done the  
19 temperature distribution was accounted for the  
20 fluctuations and things within 19, NUREG-1922 I think.  
21 And so, I know there were discussions back then about  
22 what's appropriate to use the peak at one point, or  
23 should you average it to account, just vary, have it  
24 sort of a time average value at any one point. And I  
25 think they did the latter.

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1 But from what my understanding is that the  
2 CE analyses, it didn't fluctuate to the same extent.  
3 Because part of that fluctuation was that it was coming  
4 in at an angle.

5 MEMBER BANERJEE: Okay.

6 DR. SALAY: So, and here are some results.  
7 And this is for no auxiliary feedwater. The turbine  
8 driven auxiliary feedwater is assumed to fail. And  
9 again, the small secondary leak --

10 MEMBER CORRADINI: So, can I ask a  
11 question about the pressure plot, so I just understand  
12 it? So, I interpret that up to about 14,000 seconds  
13 it's the PORV operating, and then you poop out of the  
14 PORV. And then --

15 DR. SALAY: And then you're going to get  
16 --

17 MEMBER CORRADINI: -- the PORV starts  
18 operating.

19 DR. SALAY: Yes. That's correct.

20 MEMBER CORRADINI: Okay. So we're  
21 sitting there for essentially, 7,000, so essentially  
22 six hours, unless I missed -- From about 14,000 seconds  
23 to about 23,000 seconds. And I'm just basically  
24 cycling the SRV.

25 DR. SALAY: Yes.

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1                   MEMBER CORRADINI:     Okay.     And the  
2     temperatures out of the SRV would be essentially the  
3     temperatures coming out of the hot leg, yes?

4                   DR. SALAY:   Yes, they're hot.

5                   MEMBER CORRADINI:   Okay.   So what side  
6     group is worried about, or at lease evaluating the fact  
7     that I would essentially do the same thing here that  
8     I would do in a BWR, and essentially fail this thing  
9     open, just due to the operation of this valve at  
10    extremely high temperatures?   Because if I'm going to  
11    start worrying about uncertainties, that's the one I  
12    would look at.

13                  DR. LEE:   Mike, there are on data on SRV  
14    failure under severe accident conditions.

15                  MEMBER CORRADINI:   Okay.

16                  DR. LEE:   That I know of.

17                  MEMBER CORRADINI:   Okay.

18                  DR. LEE:   United States not at war.

19                  MEMBER CORRADINI:   Say it again, Richard,  
20    I'm sorry.

21                  DR. LEE:   There are no experiment data on  
22    SRV or PORV behavior under severe accident condition.

23                  MEMBER CORRADINI:   Okay.

24                  DR. LEE:   These are called assumption.  
25    How many times you cycle it, right.   Mike, am I correct?

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1 MEMBER STETKAR: Mike, in principle --

2 MEMBER CORRADINI: That is correct.

3 MEMBER STETKAR: -- it ought to be  
4 addressed in the PRA model for, you know, the Level 2  
5 PRA model, in principle.

6 MEMBER CORRADINI: Okay. The only reason  
7 I asked --

8 MEMBER STETKAR: Whether it is or not is  
9 a different topic. But in principle that's where that  
10 would come in.

11 MEMBER POWERS: Yes. The difficulty is  
12 that you don't have data --

13 MEMBER STETKAR: Right.

14 MEMBER POWERS: -- for severe accident  
15 conditions.

16 MEMBER STETKAR: Right.

17 MEMBER CORRADINI: So, that's fine. I  
18 figured that was the case. I just wanted to make, get  
19 it on the record. The second question is I guess maybe  
20 to Chris Boyd.

21 And I'm assuming CFD can't do this. But  
22 I'm very curious about, when the SRV opens does it  
23 change the flow pattern inside the counter-current  
24 flow?

25 MEMBER STETKAR: It does.

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1 MEMBER CORRADINI: I assume it does.

2 DR. BOYD: Hi, Mike. This is Chris Boyd.  
3 Yes, of course that would completely stop the  
4 counter-current flow. And we looked at that. And  
5 then, once it shuts it reestablishes fairly quickly.

6 All of the metal materials are sort of  
7 pre-heated, and hot gasses sort of seem to quickly  
8 re-establish that flow pattern. But there is a delay  
9 there, and a little snag, and everything, when you open  
10 the PORVs.

11 MEMBER CORRADINI: Okay. But it  
12 reestablishes quickly?

13 DR. BOYD: Relatively quickly, yes, it  
14 reestablishes.

15 MEMBER CORRADINI: Okay. Thank you.

16 DR. SALAY: All right. So again, on the  
17 top right you see the pressure plot. And it's the hot  
18 legs, the two second areas, and the containment's on  
19 there at the bottom. And the lower plot you see the  
20 secondary water level, and then in the steam  
21 generators.

22 So, when everything shuts down you lose  
23 power. The cooling from the steam generators continue  
24 to cool the system. And this brings the pressure down.  
25 But you're boiling off. And so, this keeps the

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1 secondary pressure pretty level.

2 At some point later you've lost enough  
3 inventory that you can't keep up with the heat  
4 production, and the pressure, and the primary pressure  
5 starts to increase up to the PRV set point. And I'll  
6 switch to the second part where -- So it stays there.

7 The PRV's cycling, and eventually going to  
8 cover the core. Start to heat up. As Mike Corradini  
9 mentioned, the batteries run out, and they switch to  
10 the SRV. Eventually you hit the point where the tubes  
11 fail.

12 And this depressurizes the primary to the  
13 safe, as the pressurizer. So the pressure's  
14 equilibrate. And it wasn't the high enough pressure  
15 to have the secondary SRVs go. And the temperature --

16 MEMBER STETKAR: First, that would be  
17 different if the secondary SRVs were open.

18 DR. SALAY: Yes.

19 MEMBER STETKAR: Okay.

20 DR. SALAY: Yes. I mean, I did some of  
21 those analyses too. And so then the temperature  
22 continues to rise. And the pressure's high enough to  
23 end up with a failure of the hot legs. And the system  
24 depressurizes.

25 And so, this is, the rest of the results

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1       were calculated, you know, for all this. It's being  
2       done primarily in the calculator. It was also done in  
3       MELCOR as a screening calc. And this shows some of the  
4       results.

5               The top one is, the top right figure is the  
6       creep rupture index for different components, the steam  
7       generator tubes, unflawed steam generator tubes, hot  
8       leg As, the surge line, and zero. This is an index that  
9       goes from zero to one, where one represents damage.

10              When this index reaches one the  
11       component's considered to have failed. So then it, the  
12       loop B hottest tubes fail first. And then followed  
13       sometime after by the loop B hot leg. On the lower  
14       right you see a similar block.

15              But for different steam generator tubes  
16       with different creep, not creep rupture, it sees  
17       different -- I can't remember what it's called.  
18       Different stress multipliers, which represent  
19       different flaws in tubes. And so --

20              MEMBER CORRADINI: So just, Mike, just so  
21       I understand, the lower right is the same calculation.  
22       But now you've manipulated the stress risers, because  
23       you have a different damaged, or pre-damaged, or  
24       pre-flawed tube?

25              DR. SALAY: Yes. It's the exact same

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1 calc. And it was actually, it was evaluated, it  
2 evaluated all these different stress risers --

3 MEMBER CORRADINI: Okay.

4 DR. SALAY: -- just to get a little map in  
5 case, to see what happens.

6 MEMBER CORRADINI: Okay. So same  
7 thermal-hydraulic conditions, but different  
8 structural boundaries, or structural initial  
9 conditions of the tubes?

10 DR. SALAY: Well, these -- Yes.  
11 Different assumed failure of tube. Different assumed  
12 tube conditions, or tube flaws.

13 MEMBER CORRADINI: Okay. Thank you.

14 DR. SALAY: And yes. You know, it was the  
15 exact same calculation. It calculated all these  
16 things at the same time.

17 MEMBER CORRADINI: Thank you. Thank you.

18 DR. SALAY: All right. And then some  
19 variations were run. Here you see in Slide 31 you see  
20 the same behavior on if you open, if the operator opens  
21 the valves, the secondary deforms when the accident  
22 first occurs. And so you're down to atmospheric in  
23 secondary pretty rapidly.

24 And this also, blowdown cools the, cools  
25 and lowers the primary pressure. But it comes back up.

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1 And it fails significantly earlier. But also, due to  
2 long term station blackout, where the turbine driven  
3 auxiliary feedwater operates, it's considered  
4 operating until the battery dies.

5 And then that's also shown in the bottom  
6 right. And along with the short term station blackout,  
7 which is also above. And if you look at it, it looks,  
8 they look pretty similar, but just time shifted.  
9 Although the lower the K power it seems that it's, heats  
10 up a little slower. But otherwise it's pretty similar  
11 behavior.

12 And some conclusions are that Combustion  
13 Engineering's steam generator tube rupture brings  
14 consequential steam generator tube rupture behavior  
15 differs a little bit from Westinghouse plants because  
16 of less mixing. Because this Combustion Engineering  
17 steam generator tubes are thoroughly stressed  
18 relative to hot legs, in comparison to Westinghouse  
19 plants.

20 And so a greater likelihood the tubes will  
21 fails relative, earlier, relative to Westinghouse  
22 plants. And despite I showed, the fact that I showed  
23 a calculation where the tubes failed first in most of  
24 the analyses, the RCS components failed first.

25 MEMBER CORRADINI: So, may I ask a

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1 question here, Mike?

2 DR. SALAY: Sure.

3 MEMBER CORRADINI: As you connect back up  
4 to the draft NUREG. And again, I'm jumping to an end  
5 state. But I just want to unwrap it. Right underneath  
6 the table in the summary for the draft NUREG, the  
7 statement is given that for the CE plants the  
8 conditional probability is .22 and .31, versus  
9 essentially a factor of ten lower for the Westinghouse  
10 plant.

11 Is that directly a function of the mixing  
12 that you were speaking of, and the difference in mixing?  
13 Are there other things that later we're going to learn  
14 about that contribute to that?

15 DR. SALAY: Well, the mixing is, really  
16 affects how hot a temperature your tubes see.

17 MEMBER CORRADINI: Right.

18 DR. SALAY: So if --

19 MEMBER CORRADINI: I understand.

20 DR. SALAY: So if you get a lot of mixing  
21 your tubes don't see that much, that high of a  
22 temperature.

23 MEMBER CORRADINI: Okay. But to say, I  
24 want to say it very dramatically. The factor of ten  
25 or 20 difference in the summarized probability is

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1 primarily a function of this mixing phenomena?

2 MEMBER STETKAR: Or is it because the hot  
3 leg fails earlier?

4 DR. SALAY: Well, it's sort of the same  
5 thing. Because it's, you're saying the same thing as  
6 one. Both heat up. But if you get a lot of mixing one  
7 heats up faster than the other. And so, yes. I'd say  
8 mixing is the --

9 MEMBER STETKAR: But if you had more  
10 Westinghouse scenarios, where you had a completely  
11 depressurized steam generator empty at time T zero,  
12 open secondary relief valve. Would those numerical  
13 factors change your conditional probabilities? They  
14 would. Because the hot leg wouldn't fail then.  
15 Right?

16 DR. SALAY: For Westinghouse.

17 MEMBER STETKAR: For Westinghouse.

18 DR. SALAY: That's --

19 MEMBER CORRADINI: So that, so I guess  
20 John has unwrapped it more than I have. I assumed  
21 mixing was the dominant difference between the two.

22 MEMBER STETKAR: Well, I think, as Mike  
23 said, I'm not a thermal-hydraulics guy. Mike  
24 Corradini, you know that. It's --

25 MEMBER CORRADINI: And you do that bloody

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1       electrical engineer on the Board.

2               MEMBER STETKAR:   Yes.   Well, no.

3               DR. SALAY:   Yes, but at Westinghouse you  
4       need appreciable flaws for it to, for the tube to fail  
5       before the RCS.

6               MEMBER CORRADINI:   But I guess what I'm  
7       asking, from a flaw standpoint, I can't imagine one  
8       steam generator's flaw distribution is different than  
9       another.   But maybe I'm missing that.   That's what I  
10      was trying to get at.

11              MEMBER STETKAR:   Yes.   And my question  
12      was, I mean, your statement on, wherever it is, a couple  
13      of slides back, where you did the case where the  
14      operator opened the secondary relief valves actively.

15              The conclusion was much faster, stronger  
16      depressurization, earlier tube rupture, which would  
17      mean the conditional probability of the tube rupture  
18      is much higher in those scenarios, right?   Because the  
19      hot leg doesn't get a chance to fail.   Is that correct?  
20      Or am I misinterpreting something.

21              DR. SALAY:   That's again with, that's with  
22      these, the scoping calculations, with, where I'm  
23      assuming that the 20 fails.   These were analyzed in  
24      more details with final analyses, and the flaw  
25      calculator.   So these were just screening calcs.   And

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1 I don't know if this specific scenario was --

2 MEMBER STETKAR: Let me try something.  
3 Let me see if I can ask it differently. Suppose the  
4 world worked as if every single scenario matched this  
5 condition, every single for a Westinghouse plant, such  
6 that the secondary side of the steam generator was  
7 completely open to the atmosphere, and it was dry.

8 Would the conditional probabilities that  
9 Mike Corradini referred to up front for Westinghouse  
10 plants, that factor of ten lower than a CE plant, would  
11 those conditional probabilities be the same if the  
12 Westinghouse world always worked this way?

13 DR. SALAY: If the Westinghouse --

14 MEMBER STETKAR: If every scenario always  
15 had, this is Westinghouse plant now, always had the  
16 secondary side of the steam generator completely  
17 depressurized and dry.

18 DR. SALAY: Yes.

19 MEMBER STETKAR: Would those, would that  
20 factor of ten lower conditional probability for the  
21 Westinghouse plants apply? Or if you want to think of  
22 it an absolute sense, would that ten to the minus two  
23 conditional probability apply? Or would it be higher?

24 DR. COYNE: I'm not sure that that's a fair  
25 question for you. Because it's going into what the

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1 calculator's doing, and the correlations you used for  
2 creep failure of tubes. I think a fairer question to  
3 you is --

4 DR. SALAY: And it's also Westinghouse.

5 DR. COYNE: Right. If the quick  
6 depressurization of the secondary side appreciably  
7 changes the ratio of, or the relative temperature  
8 distribution that the steam generator tubes are seeing.

9 In other words, does opening the secondary  
10 relief valve to rapidly depressurize the secondary  
11 appreciably change the mixing coefficients that you  
12 would have used for the system level code analysis?

13 DR. SALAY: What I think is that the  
14 Westinghouse -- Yes, and I didn't analyze Westinghouse.  
15 So I'm not quite sure how it is. But this is, in the  
16 Westinghouse you're getting one or two tubes, because  
17 you needed the flaws. You're not getting this  
18 depressurization from when the tubes fail. So if the  
19 tubes fail then, or if flawed they fail earlier. So  
20 --

21 MEMBER CORRADINI: Mike, I guess, I think  
22 I understand what John's asking. Let me try another  
23 way of asking it. And I don't know who clarified it.  
24 But I think the clarification made sense.

25 DR. SALAY: Yes.

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1                   MEMBER CORRADINI: If all the initial and  
2 boundary conditions were the same between the  
3 Westinghouse and the CE plant, when it's depressurized  
4 all that timing is the same, all the initial positions  
5 are the same.

6                   Is it the mix, is it the geometrical  
7 differences that cause a mixing difference, that  
8 evolved you to a difference in those probabilities? Or  
9 is there other things we need to hear about later that  
10 add to it? That's what I'm trying to get at.

11                  DR. SALAY: Well, to my understanding it's  
12 the mixing that affects the temperature difference  
13 between the two. Then you have the material properties  
14 for the failure. And it's those two in combination are  
15 what decides what fails first.

16                  MEMBER CORRADINI: Okay. Thank you.

17                  DR. COYNE: And we're going to get into  
18 more of this as we go through the day. But our  
19 presumption has been you're not going to see relative  
20 temperatures as high as CE in the Westinghouse plant  
21 with those kind of conditions you're describing.

22                  But the relative temperatures for  
23 Westinghouse tend to be, and I'll look to Chris Boyd  
24 or even Ali Azarm to bail me out here. More in the .5  
25 range, whereas you're seeing relative temperatures

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1 more in the .8 or .9 range for the CE, given the mixing  
2 coefficients.

3 DR. SALAY: Yes. Okay. If that's what  
4 you're asking, you have the relative temperatures are  
5 based on the flow pattern. Yes. So you have the  
6 secondary and, I mean, you're already assuming the low  
7 pressure on the primary.

8 So it, on the secondary. So your, the  
9 analyses already, this -- What was I going to say? Yes.  
10 What he just said. Yes. The temperatures, the  
11 normalized temperatures are still going to be  
12 substantially lower for Westinghouse.

13 MEMBER CORRADINI: But this is all driven  
14 again by geometry --

15 DR. SALAY: By the geometry, yes.

16 Yes. Well, yes, the, in the geometry and  
17 the length to diameter ratio of your hot leg.

18 MEMBER CORRADINI: Right. Okay. Thank  
19 you.

20 CHAIR REMPE: It's the geometry, and  
21 that's the hot tube fraction. But then you applied the  
22 hottest tube based on expert opinion. And I guess I  
23 kind of --

24 DR. SALAY: How many tubes failed, based  
25 on expert opinion? The hottest tube is based on the

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1 CFD result analyses.

2 CHAIR REMPE: Right. And so I'm just kind  
3 of -- There's two parts to it kind of though. The size  
4 also. Again, you said earlier, well you got enough  
5 that you depressurized. So it's not that critical that  
6 you used expert opinion to apply that hottest  
7 temperature to just the 20 tubes.

8 DR. SALAY: Yes. There's something --  
9 Could you repeat the question?

10 CHAIR REMPE: Okay. So the hot tube  
11 fraction is based on the CFD analysis.

12 DR. SALAY: Yes.

13 CHAIR REMPE: Whether you do .41 or .20,  
14 to 2.5 for the CE plant.

15 DR. SALAY: And the temperature of the  
16 hottest tube --

17 CHAIR REMPE: And that helps you get the  
18 temperature of the hottest tube.

19 DR. SALAY: Yes.

20 CHAIR REMPE: And that is all geometry  
21 based. But then, how big the hole is from the tubes  
22 failing --

23 DR. SALAY: That's completely, yes --

24 CHAIR REMPE: Expert opinion. And  
25 whereas in the Westinghouse analyses there was --

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1 DR. SALAY: Yes. That's -- Yes --

2 CHAIR REMPE: Was it based on something  
3 more than expert opinion back in that earlier NUREG?

4 DR. SALAY: Well, in the Westinghouse only  
5 the flawed tubes failed. So you only get one or two.  
6 So you don't --

7 CHAIR REMPE: So it didn't matter? It was  
8 the pristine, the expert opinion. Or the --

9 DR. SALAY: Yes. It's only if in the  
10 condition where unflawed tubes fail where you have this  
11 expert opinion going in --

12 CHAIR REMPE: Okay.

13 DR. SALAY: -- multiples. And so it's --  
14 Otherwise it's just a flaw. And I don't know.

15 CHAIR REMPE: I think I've got it.

16 DR. COYNE: Mike, to clarify, for the  
17 thermal-hydraulic ones that you were using to support  
18 the calculator calculation, you're suppressing the  
19 tube failures. You have just done other sensitivity  
20 studies where MELCOR can do this damage fraction, and  
21 you get a sense of when tubes fail.

22 But we actually calculate that fraction,  
23 for the purposes of the conditional probability using  
24 the calculator. With the thermal-hydraulic  
25 parameters as the input to the calculator. He can just

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1 do some side calculations in MELCOR that kind of give  
2 you a screen level impression of how the system's going  
3 to behave.

4 DR. SALAY: They're screening calcs, yes.

5 CHAIR REMPE: Did you ever do like  
6 comparisons with what the calculator predicted versus  
7 what the screening calcs predicted? And did they come  
8 out fairly easy, or consistent?

9 DR. AZARM: Ali Azarm, consultant to NRC.  
10 A couple of things I just want to clarify. Mike was  
11 focusing on the hottest tube. But when we actually  
12 look at the average hot tube and assign flaw to that,  
13 they also fail in the CE plant.

14 So it's not really driven just by this  
15 assumption of 20 hottest tubes. So I want to distract  
16 away from total focus on the hottest tube. And you will  
17 hear that there is some perhaps divergence of opinion  
18 regarding the weak area of it. So that's one of the  
19 things that I want to clarify.

20 Regarding your second question, that have  
21 we really checked this magnification factor, or the  
22 index versus actual calc on those. No. Actually it's  
23 not done. I looked at it one time when I knew they used  
24 this factor of two, damage factor of two.

25 MEMBER BALLINGER: That's this MP.

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1 DR. AZARM: MP factor, yes, that is  
2 correct, right. That's what he's talking when he talks  
3 about index. This is a qualitative way of saying,  
4 okay, if I am at MP of two and, you know, I can calculate  
5 one deterministic number.

6 Now, calculator is very much driven by what  
7 TH delta, as temperature and pressure. Because that's  
8 one of the very important input to the calculator.  
9 That is a specific scenario.

10 But also, calculator looks at many other  
11 uncertainty sources, fraction mechanic models,  
12 material properties as a function of temperature, et  
13 cetera. So yes, that's a big factor. But it's not 100  
14 percent.

15 CHAIR REMPE: Thank you.

16 DR. COYNE: And to add to what Dr. Azarm  
17 had said, the stress multiplier factor has been used  
18 in the past for these kind of screening studies. But  
19 it is very difficult to link the specific stress  
20 multiplier to any given plant.

21 You know the saying, you know, Springfield  
22 Unit 1 has the express multiplier of 1.75. It's very  
23 difficult to make that leap. But what we can do is we  
24 can have characteristic flaw distribution over  
25 operating experience for that actual steam generator

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1 to see what flaws exist.

2 So moving the question to what flaws exist  
3 in the tubes, as they're characterized by length and  
4 depth, and those kind of parameters that we'll talk  
5 about this afternoon, is an easier leap to get to a plant  
6 analysis, than using the stress multiplier, which was  
7 really was intended as sort of a screening level vehicle  
8 with the MELCOR analysis.

9 CHAIR REMPE: Okay. Thank you. Okay, so  
10 it's -- If you're done, Mike. And we were supposed to  
11 be done at 10:30 a.m. So we're really close to being  
12 on schedule. So let's take a 15 minute break and come  
13 back at ten of ten.

14 (Whereupon, the above-entitled matter  
15 went off the record at 10:35 a.m. and resumed at  
16 10:51 a.m.)

17 DR. IYENGAR: Morning again. We had an  
18 excellent discussion. And Mike Salay had presetted  
19 everything so I don't need to talk much. The topic  
20 you're going to hear now is a side topic, a little bit  
21 more focused and not an integral report of calculator.  
22 But it provides credence to the simplified model used  
23 in a calculator.

24 Inadvertently we had left out a couple of  
25 slides. And Christopher Brown has distributed two

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1 slides which actually will be the first two in my  
2 presentation. And there are some extra copies as well  
3 in the back of the slides. Just wanted to make sure  
4 that all of you have that.

5 The primary purpose of the analysis that  
6 we did was to verify whether the simplified model used  
7 in the calculator for RCS hot leg piping, whether that's  
8 adequate for the Westinghouse plant to arrive at the  
9 conclusion that there are hot leg fails before the steam  
10 generator tube.

11 It's very important because the  
12 calculator, as you will see later, uses a very simple  
13 access electric model of hot leg pipes and uses uniform  
14 temperature, there's no gradient across the space.  
15 And it's a very simple model and uses the model to  
16 determine the time to rupture.

17 So the natural question would be is is this  
18 good enough because you're arriving at a conclusion  
19 which is very important saying that the RCS pipe will  
20 fail before the steam generator tube, hence there will  
21 be an abortment of bypass.

22 So this is very important. So in order to  
23 validate that, there were a number of studies done prior  
24 to when I started working on this in 2010. AML had done  
25 some initial modeling studies of all the components in

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1 the RCS piping system and used the input from RELAP  
2 SCDAP for the worst case scenario for the  
3 thermohydraulic and pressure distributions, both  
4 spatially as well as temporally.

5 And they determine as you will see in the  
6 next slide, they determined a number of things they  
7 investigated, we have detail everything in Chapter 4  
8 of the draft NUREG. They looked at hot leg surge line  
9 and the primary manway to see, especially particularly  
10 near the welds in the manway to see if something, either  
11 that would melt or creep or default and show, cause some  
12 depressurization that way.

13 And looked at best estimates to determine,  
14 to detect, temperature detectors near the elbow region  
15 of the hot leg piping and see if that would fail and  
16 looked at multiple scenarios.

17 And it was determined through the study  
18 that hot leg in fact reaches, experiences the highest  
19 temperature and in fact is more potential for failure  
20 there compared to the other components. So as a result  
21 of that, we focused primarily on the RCS, I mean hot  
22 leg piping in the studies that I will be talking about  
23 in a few minutes.

24 Before that, the other purpose was to look  
25 at if hot leg piping fails, what would happen if you

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1 had a weld overlay near the nozzle region because as  
2 a mitigating effect against PWACCL primary water stress  
3 corrosion cracking, weld overlays are used.

4 And if you did use a weld overlay, that's  
5 going to make the region thicker, and would that  
6 influence relocation as was time for failure. That was  
7 also a consideration we had in our studies.

8 So mainly these are the two things, really  
9 simple, looked at detail finite element calculations  
10 of hot leg piping. Initially we started with what I  
11 call a system model, the entire hot leg and surge line  
12 region.

13 And we conducted a finite element analysis  
14 using three dimensional shell elements. And we  
15 assumed a material behavior to be elastic and also  
16 having two types of permanent deformation which is the  
17 plastic which would be a time independent permanent  
18 deformation of the material as well as creep would be  
19 a time dependent permanent deformation of the material  
20 because it's fairly important at high temperatures,  
21 these materials exhibit creep phenomena.

22 And I gave the creep law, we used a very  
23 simple creep law which had time and rate dependent, and  
24 the plasticity was rated. It's not needed, you know,  
25 this is just an assumption and it's a very reasonable

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1 assumption.

2           You could have more sophisticated  
3 constituted models for the high temperature. But  
4 sophistication will be of no use if you don't have a  
5 lot of experimental data to support the sophisticated  
6 constants of a model.

7           So in order to, see that's one problem. We  
8 don't have a lot of three dimensional experiments that  
9 could be used as data points to help the constant of  
10 the model. So with what we had, we had used this and  
11 I think this turned out to be pretty good.

12           And during the course of the study prior  
13 to 2009 that ANL conducted, they had used some data  
14 which was available from literature, and that was  
15 particularly not suitable for these temperatures  
16 because the data available in the literature didn't go  
17 up to even 1,000 degrees Centigrade.

18           So we subsequently did some additional  
19 testing which documented in the chapter, in the  
20 Appendix A that we have more expanded data. I think  
21 that's the first time we have data available in open  
22 literature internationally. So we had the benefit of  
23 that. We used that in our studies to inform the failure  
24 times.

25           MEMBER SKILLMAN: Raj, before you change,

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1       how did you account for the differences in the supports  
2       and restraints from the different designs?

3               DR. IYENGAR:       We focused mainly at  
4       Westinghouse plant. We had in our model we had used,  
5       it's detailed in Chapter 4, we had used, in the modeling  
6       they had used the gravitation effect, the weight of the  
7       whole system.

8               And we used the support system for the  
9       surge line, the failings and everything, and for the  
10      steam generator, mainly that region we use all the  
11      support.

12              They did support, you could do that, you  
13      know, you could take a point and a finite element known  
14      here and then connect it to a different point and have  
15      it as a rigid support or elastic support. We allowed  
16      for those things to allow the flexibility as well.

17              MEMBER SKILLMAN: Thank you.

18              DR. IYENGAR:    So those are all detailed  
19      here, all the number of supports. And we also did, we  
20      did couple of calculations of this surface area  
21      throughout the complex models.

22              And it turned out that this model is a very  
23      difficult one. It takes a lot of time to, and we had  
24      convergences issue especially when the temperatures go  
25      up really rapidly.

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1           And so in order to do the weld overlay  
2 studies, we thought because of the hot leg being the  
3 worst point for failure, we used a submodel as I'll be  
4 describing later, the hot leg alone.

5           And that actually provided us an  
6 opportunity to look at several scenarios to get some  
7 kind of sensitivity. Not a thorough sensitivity  
8 studies but to, you will see those results in a moment.

9           So as far as our analysis goes, this is a  
10 coupled thermal-mechanical path for analysis. What  
11 makes this more realistic than the simplified model  
12 used in the calculator is that we used the actual  
13 temperature and pressure distribution from RELAP SCDAP  
14 both spatially as well as time.

15           It's very important that spatially you see  
16 as you had seen that Mike Salay had presented that  
17 there's a variation in temperature in the upper portion  
18 of the hot leg versus the lower portion. We accounted  
19 for that.

20           And that turned out to be quite significant  
21 I think in these new calculations. We also looked at  
22 the heat transfer coefficient. We adjusted that  
23 spatially in the hot leg region. And based on the  
24 developing curve in 1922, and Mike Salay talked a little  
25 bit about that too.

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1           So we used all those input we got from that  
2 RELAP SCDAP for the Westinghouse model and fed it into  
3 the finite element model to get the temperature  
4 distribution for this and used the temperature  
5 distribution to run a mechanical simulation to  
6 determine the, ultimately the failure time.

7           So in the mechanic distribution, as I  
8 mentioned earlier, we took the gravity load where we  
9 assumed the body forces for the entire hot leg and surge  
10 line region and then used a point of mass forces for  
11 the steam generator itself and the manway.

12           And I did mention to you earlier that we  
13 used high temperature properties, especially for 316  
14 stainless steel. This is the first time that we used  
15 this, and we got that from some of the tests done at  
16 ANL.

17           And then we ran a thermal-mechanic  
18 simulation, and the thermal-mechanic simulation gives  
19 you the amount of creep, how it was through time, and  
20 it also tells you the plasticity which is instantaneous  
21 as well as we used those to determine the damage. And  
22 I will give you briefly how the damage is determined.

23           All these are documented. What you see  
24 are the stress strain curve for the plasticity  
25 assumption which is time independent. And then for the

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1 creep we used a simple amount in creep law as you see  
2 here. And  $Q$  with epsilon dot, a creep is a creep rate  
3 and  $A$  is a constant depending on the material. And  $Q$   
4 is the so called effective stress.

5 And  $T$  is the time. In this case, we didn't  
6 used a time hardening. You certainly could use a time  
7 hardening as well which will, you know, slightly change  
8 the material behavior, creep behavior. But for these  
9 materials, the time hardening is very small. So we  
10 have not used that, and the end was zero.

11 MEMBER BANERJEE: And so the time  
12 dependence was taken out of the creep?

13 DR. IYENGAR: No, no, no. There are two  
14 methods of time dependent. The time dependence is  
15 inherent here, inherent here, epsilon dot creep.

16 MEMBER BANERJEE: No, I mean the time  
17 dependence --

18 DR. IYENGAR: All this does is --

19 MEMBER BANERJEE: Hardens the material.

20 DR. IYENGAR: -- hardens the material.  
21 That's different, right? That's --

22 MEMBER BANERJEE: They've taken that out.

23 DR. IYENGAR: Yes. Normally for these  
24 materials, you know, the end was very close to zero for  
25 many materials. There are some materials which, you

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1 know, you don't use in reactor pressure vessels. But  
2 you could have just significant time hardening.

3 MEMBER BANERJEE: What's the time scales  
4 involved here? How long are the processes going on for  
5 the -- I haven't got a clear picture of is it a 1,000  
6 seconds?

7 DR. IYENGAR: Well, the failure time as  
8 you will see later on when I press in is 12,000 seconds  
9 or so. But really, that's not the time scale of real  
10 interest to us.

11 MEMBER BANERJEE: It's only when it's hot,  
12 right?

13 DR. IYENGAR: In terms of creep, it's less  
14 than an hour because until 9,000 seconds, it's fairly  
15 stable state and then shoots up.

16 MALE PARTICIPANT: And then it shoots up,  
17 yes.

18 DR. IYENGAR: And in fact, where it shoots  
19 up, the last 200, 300 seconds for the scenario reviews,  
20 that's where things are exciting. That's when all the  
21 action happens. And --

22 (Simultaneous speaking)

23 MEMBER BANERJEE: What is the temperature  
24 range there? Is it going up to, it goes very quickly  
25 up, right, once the core starts to --

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1 DR. IYENGAR: Right.

2 MEMBER BANERJEE: -- oxidize rapidly.

3 DR. IYENGAR: So after it goes to 9,000  
4 it's not that high. And then it starts going up. But  
5 then it ramps up further after about 10,000, 11,000  
6 seconds it ramps up quite fast. It goes from, I don't  
7 remember the exact numbers, I don't want to, it's  
8 probably from about 950 C to about 1,200 C. That's a  
9 very rapid rise.

10 And I don't want to spoil the final  
11 conclusion, but since you asked me this question I'll  
12 tell you anyway. It's because of that fact that  
13 Westinghouse, the RCS likely fails before the steam  
14 generator tube in our calculations because the last 300  
15 or 400 seconds, the temperature rises so high, so sharp  
16 in the hot leg region that it really doesn't matter.

17 You'll see, you can make 150 different  
18 assumptions, whether if you can say the heat transfer  
19 is either insulated completely, the hot leg piping, or  
20 we get it not insulated. It really doesn't matter  
21 because your failure times --

22 (Simultaneous speaking)

23 MEMBER BANERJEE: So I have to look at this  
24 quite physically. The way I would explain it to myself  
25 would be that the hot gas and steam coming out of the

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1 core doesn't have a chance to mix very much, you know,  
2 as it goes down the hot leg it's going to mix with the  
3 cool stream that's coming back. Right?

4 Now what happens then is that the hot leg  
5 then gets exposed to this really hot stuff before it  
6 mixes with the cold stuff that's coming back, if I think  
7 of it that way. And then if you impinge this hot  
8 material on the steam generator tubes, probably the  
9 steam generator tube will fail first, right?

10 But because it's mixed in, it doesn't have  
11 this really hot material hitting the steam generator  
12 tubes, at least implicitly that's how I would explain  
13 it to myself.

14 DR. IYENGAR: I think Mike probably is the  
15 best person to answer that question. It seems  
16 plausible.

17 MEMBER BANERJEE: All this other stuff is  
18 correct, but I mean physically, that's what's  
19 happening, isn't it? I mean, really. And as you get  
20 your, I think Chris Boyd was telling me as the hot leg  
21 becomes bigger, you know, the core stuff is not mixing  
22 that much. So if that impinges on the tube, then you're  
23 exposing it to a hotter temperature.

24 MEMBER POWERS: I think you get a  
25 combination of things. It's hot stuff and it's not

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1 wandering around among the tubes.

2 MEMBER BANERJEE: Also, yes.

3 MEMBER POWERS: So that you're putting a  
4 lot of hot stuff on, but it's always on the same tubes.

5 MEMBER BANERJEE: Yes, because if you have  
6 a shallower plenum, that would happen, right?

7 MEMBER POWERS: Yes.

8 MEMBER BANERJEE: You would get this,  
9 like, a jet heating this thing.

10 MEMBER POWERS: So it's the combination of  
11 the two that gets you in trouble really quickly.

12 MEMBER BANERJEE: Yes. So on the  
13 Westinghouse things you have, is this, are we in closed  
14 session, open session, I don't know.

15 CHAIR REMPE: Open.

16 MEMBER BANERJEE: Okay. Anyway, the  
17 plenum is much deeper. So you've got this --

18 MEMBER POWERS: Larger opportunity for  
19 the return flow to mix and --

20 MEMBER BANERJEE: Yes, mixing and all that  
21 sort of stuff.

22 MEMBER POWERS: And it tends to wander  
23 around among the tubes so that you get, you heat a tube  
24 up and then it'll move to a cooler tube and that tube  
25 has a chance to cool --

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1 MEMBER BANERJEE: Because it behaves like  
2 a plume?

3 MEMBER POWERS: That's right.

4 MEMBER BANERJEE: And you've got cross  
5 flow. So I think physically, you can see what's  
6 happening.

7 MEMBER POWERS: Yes.

8 MEMBER BANERJEE: I mean, all this CFD and  
9 all is great and --

10 (Simultaneous speaking)

11 MEMBER BANERJEE: -- we have to understand  
12 what's going on.

13 MEMBER POWERS: Yes, the physical  
14 understanding. But I mean, the two are tightly coupled  
15 with each other. I mean, you understand them when you  
16 calculate and then you understand more.

17 MEMBER BANERJEE: The shallower plenum  
18 will give you a problem --

19 (Simultaneous speaking)

20 MEMBER POWERS: And we seem to be, like,  
21 the EPR seems to have a pretty shallow plenum. We're  
22 seeing shallower plenums that maybe weren't plausible  
23 to what we want.

24 MEMBER BANERJEE: Right. Okay.

25 DR. IYENGAR: I did mention the heat flux

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1 and heat transfer coefficient adjustment, and this is  
2 the developing curve, it's like that. This is closer  
3 to the hot leg here. And as it goes away, it changes  
4 according to this curve, and we got this curve in the  
5 late 1922.

6 So all of these were used, and we applied  
7 it to the various elements across the model. So that's  
8 why this was a little bit, a very difficult exercise.  
9 It's just very strenuous to model those things.

10 What you see here is at around 12,000  
11 seconds, like I said, you know, things are fairly stable  
12 and nice for 9,000 seconds after that, the action  
13 starts. So when I say 12,000 seconds, it's the  
14 accumulation of more like 2,500 seconds or so.

15 You do see two things here. What I have,  
16 what I show you are the accumulated creep strain, the  
17 effective creep strain on the left hand side, top.  
18 What you immediately see that the top surface has more  
19 creep train than the bottom surface.

20 There's no surprise because we used the  
21 countercurrent circulation flow there. The top side  
22 is hotter and the bottom side is a little bit colder.  
23 Not that cold, but relatively speaking, colder.

24 And you also have the accumulated plastic  
25 strain. And I want to bring your attention to the

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1 location where these strains are higher. It's in the  
2 top portion of the hot leg but away from the nozzle,  
3 the RPD nozzle.

4 And that's fairly important. I think in  
5 terms of dimension, I'm not sure this is probably what  
6 --

7 MEMBER STETKAR: You have to stay by the  
8 microphone. You can use the mouse.

9 DR. IYENGAR: This one?

10 MEMBER BALLINGER: What's the difference  
11 between the accumulated creep strain and accumulated  
12 plastic strain?

13 DR. IYENGAR: The plastic strain is the  
14 instantaneous response of accumulation. That's the  
15 model we assume that the strain is a combination of the  
16 elastic strain and instantaneous time independent  
17 plastic strain.

18 MEMBER BALLINGER: Okay, so that's what  
19 that is?

20 DR. IYENGAR: That's what that is. And  
21 then you have the time dependent creep strain, that's  
22 what that is. So the total plastic strain, if you will,  
23 will be combination based.

24 MEMBER BALLINGER: Okay, okay.

25 DR. IYENGAR: It's just a simple modeling

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1        thing they use for high temperature materials, again  
2        mentioned earlier, is a way to combine these methods  
3        strain to strain, right? And it's probably what you're  
4        thinking.

5                    MEMBER BALLINGER: Well, I mean, this is  
6        probably primary creep versus secondary creep.

7                    DR. IYENGAR: No, no.

8                    MEMBER BALLINGER: No?

9                    DR. IYENGAR: No, I won't make that  
10       distinction here. Primary creep is also --

11                   MEMBER BALLINGER: Instantaneous,  
12       though. Relatively.

13                   DR. IYENGAR: Relatively instantaneous  
14       but still time dependent. It's just slow, right? If  
15       you bear with me, let me go back to my --

16                   MEMBER BALLINGER: It's just a fine point,  
17       it's not --

18                   DR. IYENGAR: Well, it's an important  
19       point. So here you have, I had prepared a couple of  
20       slides for the last briefing at the request of Dr.  
21       Powers on a quick overview of high temperature feed,  
22       so I might as well use this, take some mileage out of  
23       it.

24                   So when you expose the temperature of these  
25       materials to high temperature and some stress, I have

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1 to learn how to use this now.

2 MEMBER BALLINGER: I understand what it  
3 is.

4 DR. IYENGAR: So as soon as you apply the  
5 stress, there's an instantaneous, that's your plant  
6 time independent plastic strain and elastic strain  
7 combination. And then you have primary creep which is  
8 time dependent, and then you have a secondary creep  
9 which is what we using is fairly steady state.

10 And the tertiary creep is significant. We  
11 haven't modeled that. That's one of the things that  
12 I wanted to mention. The temperatures that they're  
13 gaining when the simulated accident, really speaking  
14 the material is in the tertiary creep region.

15 But we really don't have a model, we don't  
16 have data for that. If anything, that will push the  
17 failure times that we show to a lower number.

18 MEMBER BALLINGER: You can use stress  
19 rupture data in there, right?

20 DR. IYENGAR: Yes. So up there we're  
21 using stress rupture data for --

22 MEMBER BALLINGER: Yes.

23 MEMBER POWERS: Yes, when we get into  
24 tertiary creep, you're in a wild region where materials  
25 behave in a non-linear fashion.

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1 DR. IYENGAR: Yes.

2 MEMBER POWERS: And so --

3 MEMBER BALLINGER: You're also in a lot of  
4 trouble.

5 MEMBER POWERS: You're in a world of hurt.  
6 I mean, but it's not only a function of the material,  
7 it's also a function of the geometry. And so it gets  
8 very complicated, I mean, you get very complicated  
9 models because you shouldn't be using the material  
10 there.

11 DR. IYENGAR: Yes. So in one of the  
12 backup slides, we show this using Ashby's deformation  
13 map plot where you have, for the stainless steel you  
14 have the temperature and the shear stress.

15 And this shows the region where the steel  
16 would exhibit different kinds of behavior, whether it's  
17 plastic, whether it's creep. We actually had this  
18 remarkable vision of try and put --

19 (Simultaneous speaking)

20 DR. IYENGAR: -- one graph. Save a lot of  
21 money on it by the way.

22 MEMBER POWERS: Yes, but it confuses the  
23 hell out of everybody that looks at it.

24 (Simultaneous speaking)

25 DR. IYENGAR: But the point made here is

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1       these steels, 316 steel as in this blue oval indicate,  
2       those are the normal operating conditions. What we're  
3       dealing with is on the red side for this. Because these  
4       materials are not designed to operate at these raises,  
5       you don't have data. You have data, all your data isn't  
6       all there.

7                       So that's one of the complexities we have.  
8       And today I think there was another complexity that was  
9       brought in by Dr. Joy Rempe which we of course did not  
10      consider is the oxidation effect on these at these high  
11      temperatures.

12                     And I think that's also pretty  
13      significant, we don't have a clear understanding on how  
14      that will affect the creep failures because that's  
15      fairly important as well.

16                     Okay, I have to go back. Sorry, I thought  
17      I would just take your time. We show the creep. And  
18      then the way we calculate damage is we use the  
19      Larsen-Miller Parameter which is a parameter we  
20      determined from the initial creep experiments, fresh  
21      rupture experiments.

22                     And for the materials that we considered  
23      in the study, we have used the most recent data that  
24      was done, you know, from ANL. And it's documented in  
25      Appendix A. So we used that and get the Larson-Miller

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1 Parameter and determine a time to rupture given stress  
2 state and the temperature.

3 So you could see that at the failure time  
4 for this system is the hot leg region set on 12,302  
5 seconds.

6 MEMBER BALLINGER: See, I see a failure  
7 time of 12,302 seconds. Is it 11,000, 13,000, 5,000,  
8 15,000? Or is it 12,302?

9 DR. IYENGAR: Excellent question. The  
10 failure time here is what we did is we did an average  
11 to the thickness. So we use time stamps as we go along.  
12 We use time stamps of even less than, you know, one  
13 second time stamps in this region.

14 And what I found was when I say 12,302, you  
15 know, I like to say it could be 12,250.

16 MEMBER BALLINGER: You think it's that  
17 good?

18 DR. IYENGAR: These are all approximate.  
19 But you know, it's better approximations of the time  
20 stamps.

21 MEMBER BALLINGER: I mean, it's easily a  
22 factor of two or three in creep rate on these things.  
23 The Larsen-Miller Parameter can vary by 50 percent. So  
24 I'm just curious as to really what kind of voracity do  
25 you have on these?

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1 DR. IYENGAR: I mean, we have used a lot  
2 of experimental data, get the Larsen-Miller Parameter  
3 and there could be a variation on that as well. The  
4 time stamps that we used in the final element model was  
5 very refined and small.

6 So what I found was these average failure  
7 time, average to the thickness was the failure starts  
8 at the inner surface of the hot leg and it propagates.  
9 It propagates rather quickly within two seconds in the  
10 model.

11 So your question is well taken. But I  
12 mean, given the input that I have, given the  
13 Larsen-Miller Parameter that I assume, then the  
14 failures are very rapid. You could see that with  
15 different assumptions I made that the failure times are  
16 bounded within, you know, less than 100 seconds if I  
17 turn off some things.

18 So, I mean, it doesn't quite answer your  
19 question because you asked the question is more based  
20 on the uncertainty of the material data that I used.  
21 But if you give me the data, I can tell you comfortably  
22 that with various assumptions I made, I'm not getting  
23 a whole lot of difference in the failure time.

24 MEMBER BALLINGER: The bad news is the  
25 temperature is high, the good news is the temperature's

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1 high --

2 DR. IYENGAR: Yes.

3 MEMBER BALLINGER: -- because if the  
4 temperature's really high, it doesn't really matter.

5 DR. IYENGAR: Yes. That's what I'm  
6 coming to. So this is --

7 MEMBER POWERS: I think that's, I mean, I  
8 think that's the \$64 question is we know what happens  
9 when the temperature gets very high. The question is  
10 does it get very high.

11 MEMBER BALLINGER: Yes, that was another  
12 question.

13 MEMBER POWERS: You know, and the TMI  
14 accident, we didn't seem to get very hot. Now we have  
15 a speculation that in the Fukushima reactor accidents,  
16 we did get hot. And so it will be very interesting when  
17 we have a chance to look to see if in fact we got very  
18 hot.

19 MEMBER BALLINGER: That boundary between  
20 the fusional creep and that's where you get a lot of  
21 uncertainty, a lot of scatter in the data. Very high  
22 temperature, you fail --

23 MEMBER POWERS: Very high temperatures,  
24 everything goes to hell on you. Very low temperatures,  
25 everything's fine. This question of what happens with

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1 this hot plume of gas coming up from the core and whether  
2 it, how much of the heat loses in transit is one of the  
3 features of uncertainty in accidents that we're kind  
4 of stuck with right now.

5 And we do see different modeling, for  
6 instance, in MAP where we don't get such high  
7 temperatures up in the primary piping system. But it's  
8 not one that you can resolve by better analyses or  
9 filter analyses.

10 You really need to melt down more reactors.  
11 That's just all the answer is, we just got to melt down  
12 more reactors.

13 (Simultaneous speaking)

14 CHAIR REMPE: -- if I take the quote out  
15 of context.

16 MEMBER BALLINGER: Do it in Iran?

17 (Laughter)

18 DR. IYENGAR: So for further studies, we  
19 used a smaller hot leg region to model. This is the  
20 model region. And we use the same temperature and  
21 pressure distribution both time wise and spatially.

22 And using the one without weld overlay, you  
23 see on the left hand side, the time to failure calculate  
24 set a little bit higher than the system model,  
25 presumably because a lot of the gravity loads were not

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1 used here.

2 The failure time increases like I say.  
3 Then we used a weld overlay on the nodal region. The  
4 weld overlay was about nine inches wide. And that's  
5 based on some prescription of 1.5 square of R over T  
6 on minority.

7 And not surprisingly, it didn't change the  
8 main point when a failure occurs because I was a little  
9 bit far away from the nozzle line D in valve region.  
10 And it did increase the time slightly and the location  
11 doesn't change.

12 CHAIR REMPE: I mean, we've been a little  
13 bit tongue in cheek here, but the difference between  
14 12,428 and 12,500, we really need to get a handle on  
15 what the uncertainty is on these numbers, some kind of  
16 estimate because I don't look at that as any different  
17 at all. In fact I'm not even sure the two is  
18 significant.

19 And so it's just we just got to get a handle  
20 on an estimate of what the upper and lower bounds are  
21 on these numbers or something.

22 DR. IYENGAR: Point well taken.

23 MEMBER POWERS: I will suspect that your  
24 systems level modeling can adjust that by 1,000  
25 seconds.

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1                   MEMBER BALLINGER:   1,000 seconds sounds  
2                   okay.   But I don't know --

3                   MEMBER POWERS:   If you set up the systems  
4                   level modeling and I set up the systems level modeling,  
5                   and Joy set up the systems level modeling, we would  
6                   probably have greater than 1,000 seconds difference  
7                   from that calculated number.

8                   MEMBER BALLINGER:       In a calculated  
9                   number.

10                  MEMBER POWERS:       Well, they're all  
11                  calculated.

12                  MEMBER BALLINGER:   Yes, yes.

13                  MEMBER POWERS:   I mean, just how you model  
14                  the system, how you nodalize it, how many nodes you take  
15                  and things like that can have that kind of change, this  
16                  far away from a main actual in the core.

17                  DR. IYENGAR:   Very true.   But I mean, I  
18                  wanted to bring your attention back to the purpose of  
19                  this exercise was to see how the simplified model using  
20                  the calculator performs, that if there were more  
21                  sophisticated model.

22                  Yes, I do agree with uncertainties that you  
23                  have pointed out.   But that was not the major focus of  
24                  this exercise.   Was a little bit less, I mean, more  
25                  focused on comparing how good or how confident are we

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1 of using the simplified model.

2 And with this hot leg model, you know, I  
3 did many different things. I turned off creep  
4 completely, I turned off plasticity completely. Yes?

5 MEMBER STETKAR: Let me interject here.  
6 I wanted to wait until you got to this slide. You said  
7 the purpose of this is to provide some guidance for this  
8 simplified calculator. Okay, we have a calculator.

9 You're proposing that that calculator be  
10 used in probabilistic risk assessments that evaluate  
11 the likelihood that we have detrimental effects on  
12 public from large releases. I see your sub number one  
13 here. It says well, we have an uncertainty distribution  
14 in this little calculator that we use.

15 There's no uncertainty there. That is not  
16 an uncertainty distribution. If you're proposing to  
17 use that uncertainty distribution for this little  
18 calculator, I will submit do not use the calculator in  
19 probabilistic risk assessment. There's no  
20 uncertainty in those parameters.

21 MEMBER BALLINGER: That's where I was  
22 going, actually. That's where I was going.

23 MEMBER STETKAR: So therefore, your  
24 simple calculator is fundamentally flawed because it  
25 does not correctly account for the uncertainties.

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1       Uncertainties are everything in risk assessment.

2               If we don't look at uncertainties, the  
3       convolution of uncertainties and timing and understand  
4       that effect correctly, we're going to have the wrong  
5       answer. Period. It's the wrong answer.

6               So understanding the uncertainties and  
7       characterizing them appropriately is everything in  
8       risk assessment.

9               MEMBER STETKAR: The difference between  
10      the CE and the Westinghouse plant is a factor of ten,  
11      right? I'm at that order, a factor of ten and I just  
12      asked the question is the factor of ten actually --

13              MEMBER STETKAR: But my point, a lot of,  
14      where they're eventually going to get to is the  
15      conditional probability of a large early release  
16      depends on this relative timing. The relative, the  
17      uncertainty and the relative timing is everything.

18              If you are absolutely certain that one  
19      thing occurs 5.77362 minutes before the second one,  
20      you're wrong.

21              MEMBER BALLINGER: If you were to take a  
22      pipe, scalable stainless steel pipe and pressurize it  
23      and run it at that temperature and do basically a stress  
24      rupture test on the thing, there would be a factor of  
25      two because when you get into tertiary creep and those

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1 kinds of things, a little flaw here, a little flaw there  
2 starts a propagating defect. And so you really don't  
3 know. So I think there's a factor of two there to start  
4 with.

5 MEMBER STETKAR: I don't know. But my  
6 point is that this is being characterized as the  
7 uncertainty distribution in the little calculator  
8 that's supposed to be used to support probabilistic  
9 risk assessment, it is wrong.

10 MEMBER BALLINGER: The only way we survive  
11 in the metallurgy bit is to plot everything on long log  
12 paper.

13 MEMBER STETKAR: Kevin's desperate. He  
14 wants to say something.

15 DR. COYNE: Kevin Coyne, Office of  
16 Research. I am desperate to say something. So the  
17 Staff is certainly not willing to concede the point that  
18 the calculator is fundamentally flawed until at least  
19 the point that we get a chance to brief the Committee  
20 on what's in the calculator.

21 So I think you'll see there's more  
22 treatment of uncertainties than, you know, is indicated  
23 on Raj's graph here and Ali Azarm and I we will all go  
24 through some of that. And the comments may very well  
25 be valid, but we'll --

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1 (Simultaneous speaking)

2 DR. COYNE: -- prefer to wait until we've  
3 had a chance to brief you on it before we come to that  
4 conclusion.

5 MEMBER STETKAR: I'm just concerned when  
6 I hear people say, well the whole purpose of this was  
7 to support the calculator and then you see uncertainty  
8 distributions that have no uncertainty.

9 DR. COYNE: So to back up from the purpose,  
10 and I'll turn it over to Ali Azarm in a second, but the  
11 purpose of Raj's analysis was to provide with some  
12 confidence that the more simplified correlations we're  
13 using in the calculator to estimate the time of the hot  
14 leg failure and pressurized resurge line failure are  
15 not, either not conservative or wildly conservative.

16 So there was an early recognition when this  
17 work started that we're using sort of a one dimensional  
18 treatment of the temperature and the hot leg failure.

19 Raj used the abacus code to try to bring  
20 some three dimensionality into it, some more  
21 sophisticated modeling to give us some point estimates  
22 of when he is predicting hot leg failure given the same  
23 thermohydraulic conditions using more sophisticated  
24 tools for us to compare against what the calculator  
25 would give.

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1           So, you know, all these points about the  
2           uncertainty of the numbers or lack thereof in Raj's  
3           analysis is true. I think Raj's main point on the weld  
4           overlay versus non weld overlay is that yes, those are  
5           indeed almost the same number.

6           It wasn't trying to make a distinction in  
7           72 seconds. It was trying to show that there wasn't  
8           an appreciable effect with welder relays which was an  
9           initial concern of ours that this massive hunk of metal  
10          put over the hot leg nozzle would somehow delay the time  
11          to hot leg failure such that we had a more significant  
12          concern with the steam generator tube failures.

13          Turns out, the more detailed analysis is  
14          indicating that that isn't as an extreme effect as we  
15          thought. But again, this was a touchdown, a benchmark  
16          point to look at the results of the calculator to give  
17          us some confidence that the correlations we're using  
18          aren't non-conservative or wildly conservative. And  
19          so that's what this figure is trying to show.

20          MEMBER STETKAR: Your point is certainly  
21          well taken there, Kevin. However, all that does is  
22          delay the question that I have about how does the  
23          calculator treat the uncertainty because I didn't dig  
24          into the calculator.

25          How does it treat the uncertainties

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1 because this uncertainty, this 90 percent confidence  
2 interval that it's within 300 seconds, that we  
3 understand it that well strikes me as being wolfedly  
4 narrow.

5 So there must be something in the  
6 calculator then that does something to expand that  
7 uncertainty. So you know, and if we're going to talk  
8 about the calculator later, we can do that.

9 DR. AZARM: Ali Azarm again. Dr.  
10 Stetkar, I just want to little bit clarify. The  
11 calculator uses the EPRI model for Larson-Miller. And  
12 the EPRI model has coefficients, and in front of each  
13 coefficient you have the tolerance or the variance for  
14 example.

15 It says that the factor in front of this  
16 is 1.1 plus/minus 0.25 which is treated as the normal  
17 distribution. Now why the calculator uncertainty in  
18 this case was so small? Because when the calculator  
19 fail the hot leg, you were at the very high temperature.

20 And as Dr. Dana Powers was saying, when you  
21 are in that region, you are going to fail and your  
22 variance is very small. If you would have looked at  
23 lower probability stuff at the lower temperature, it's  
24 much larger spread.

25 Anyway, we will talk about it enough. And

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1 we hear your comments at that.

2 MEMBER BALLINGER: But as a practical  
3 matter, publishing something that goes out with an M  
4 number with a number 12,302 in it just doesn't make any  
5 sense. I mean, that's --

6 (Simultaneous speaking)

7 MEMBER POWERS: You could right the number  
8 down.

9 MEMBER BALLINGER: I know, but -- okay.

10 MEMBER POWERS: You know what the  
11 uncertainty is, I know what the uncertainty is. I  
12 mean, that's the number they get. What's wrong with  
13 that? You can see what he does in his percentiles.  
14 He's courting them out to numbers.

15 DR. IYENGAR: We did enough, I come from  
16 the combination mechanics background. And when you  
17 put these time increments, the code and gets a number.  
18 We just repeat what the code tells us.

19 We don't round off. So if it gives you  
20 12,302, I probably could make it 12,300 seconds. But  
21 that's not what the code had given me. So that's all.  
22 This is maybe being more honest to what the code  
23 predicts rather than trying to, you know, take --

24 (Simultaneous speaking)

25 MEMBER BALLINGER: We have code fixation.

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1 (Simultaneous speaking)

2 DR. IYENGAR: Well, I also want to tell you  
3 one point is that I've said many things that we do not  
4 understand and don't have data, and the regimes for this  
5 temperature.

6 And assumptions we made here are actually,  
7 as I told you, will provide failure times little bit  
8 higher than what it would be if you knew everything  
9 about how 316 fails at that temperature because you  
10 would have a tertiary creep, you would have some  
11 oxidation effects.

12 These are all the push the failure time to  
13 a lower time. So I think that also has to be put in  
14 perspective when you talk about these things. Any  
15 other question? Yes? Thank you.

16 DR. COYNE: You had a last slide.

17 DR. IYENGAR: Oh, I have a last slide?

18 CHAIR REMPE: You do have another slide,  
19 yes.

20 DR. IYENGAR: I thought it was, I think  
21 like I said, I think we have gone through all these  
22 conclusions. Weld overlay had a small, very small  
23 insurance on the location of failure time. And I think  
24 what I thought was the more complex analysis predicted  
25 times which are little bit lower than what the

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1 calculator had predicted. And we had quite a bit of  
2 discussion on that point. So if there are any other  
3 questions?

4 CHAIR REMPE: Okay. Because we're going  
5 to switch topics next, and it's getting close to the  
6 lunch hour, I would suggest we go ahead and take a break  
7 for lunch. And we're supposed to come back here at  
8 12:45. Okay? We're off the record then.

9 (Whereupon, the above-entitled matter  
10 went off the record at 11:38 a.m. and resumed at 12:45  
11 p.m.)

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

2 (12:45 p.m.)

3 CHAIR REMPE: Okay, so we're ready to  
4 resume this meeting and we're going to hear about the  
5 steam generator tube flaw distribution  
6 characterization effort.

7 DR. AZARM: That is correct.

8 CHAIR REMPE: For the record, please  
9 introduce yourself too.

10 DR. AZARM: This is Ali Azarm. I'm a  
11 consultant to research. I supported them early on when  
12 I was an employee of Information System Laboratory,  
13 ISL, and now currently I'm an independent consultant.

14 I am going to present three sets of slides  
15 today or three presentation. The first one is going  
16 to be on some work we did four or five years ago in  
17 updating flaw distribution.

18 Then that follows the overview of  
19 calculator, and I heard this morning there might be some  
20 interest and question regarding that software.

21 And finally I'm going to present a brief  
22 summary of probabilistic risk assessment simplified  
23 models that we develop for NRC.

24 In the first presentation, Mr. Mica  
25 Baquera --

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1 MR. BAQUERA: Mica Baquera.

2 DR. AZARM: -- yes, is the co-author from  
3 research so any hard questions I'm going to transfer  
4 to him.

5 As you know by now, there is a software  
6 called calculator or steam generator calculator and  
7 this software gets bunch of input and one of the input  
8 it needs is a sample of flaw, 1,500 flaws with a certain  
9 depth, certain length.

10 So we needed to develop statistics to  
11 generate the samples needed for the calculator. At  
12 first, initially, we looked at to see what is available  
13 rather than trying to undertake this task.

14 The previous work we found and, you know,  
15 was the work by Gorman, NUREG/CR-6521. This basically  
16 has the statistics provided, summary statistic  
17 provided for characterization of cracks for Inconel  
18 600, which was susceptible to stress corrosion  
19 cracking.

20 Now, given that we know almost every plant  
21 in U.S. changes steam generator and now they are using  
22 the thermally treated Inconel 600 and 690, which are  
23 not really as susceptible to crack but are more  
24 susceptible to wear and volumetric type of flaws, the  
25 use of Gorman report and the statistics cannot be

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1 justified.

2 So as result, NRC initiated the small task  
3 to update the flaw distributions. This work was  
4 contracted to ISL so that's why you have a report from  
5 ISL on that.

6 So the first thing we have to talk about,  
7 where the data is coming from. Licensee generally  
8 reports in the PDF format, hard copy. Information of  
9 the detected steam generator flaws at each in-service  
10 inspection are usually done during refueling outage.

11 The information includes the location,  
12 depth and length and the voltage associated with the  
13 detected flaws. These reports also include number of  
14 flaws that are plugged in each cycle.

15 But given availability of these reports,  
16 NRC reviewed a large set of these reports, NRC research,  
17 and with the understanding that they wanted to have a  
18 manageable set of them for the consultant to go through  
19 and extract the data and put in the database and try  
20 to evaluate it. And they wanted to select plants that  
21 has enough cycles and of different types such that we  
22 get a good scope of type of flaws that exist out there.

23 This data -- okay. So what was reported  
24 was given to ISL. It was Surry Unit 1 and 2, which is  
25 a 600 thermally treated tube materials.

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1                   It shows number of cycles to be 26 cycles.  
2           That needs a little bit explanation. It was actually  
3           12 ISI cycle in each unit and then each unit had one  
4           mid-cycle inspection, so each unit had 13 cycles so  
5           together was 26 cycles. So we have 26 PDF reports.  
6           That's what it means.

7                   It doesn't mean it means 26 refueling  
8           outage. It doesn't mean it's 26 equivalent full power  
9           years of operation. For example, in case of Surry, the  
10          total full power operation or EFP month was 268.5 or  
11          about 22 EFPY.

12                   But this slide basically show you that we  
13          had Surry as a representative of Inconel 600 for  
14          Westinghouse and then we have, which had lots of cycle  
15          in it so allows us to look at the change of number of  
16          flaw generated as a function of the age of the steam  
17          generator and the cycle flaws.

18                   And for the C-E plant, or Inconel 690 for  
19          both C-E and Westinghouse we had bunch of different  
20          plants but with less number of cycles.

21                   CHAIR REMPE: So these plants were made by  
22          different vendors, right? Like wasn't St. Lucie made  
23          by B&W and I don't know who made the other ones but  
24          they're not, how different are the designs under the  
25          690s that are C-E or are Westinghouse plants?

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1 DR. AZARM: We used to have a slide that  
2 actually was showing the model number and design of each  
3 of the steam generator, but to your question, I want  
4 either Mica or Ken Karwoski, if he's still here. They  
5 are much more knowledgeable than I am in this regard.

6 MEMBER BALLINGER: It's not clear that the  
7 steam generator supplier for the replacement was  
8 actually the original --

9 CHAIR REMPE: Definitely not --

10 (Simultaneous speaking)

11 MR. KARWOSKI: This is Ken Karwoski from  
12 the staff. You're correct. A lot of these, the NSSS  
13 vendor is different than the steam generator  
14 replacement manufacturer.

15 In the case of St. Lucie 1 and 2, those are  
16 C-E designed plants. St. Lucie 1 has an AREVA or, I'm  
17 sorry, B&W Canada steam generator. St. Lucie 2 has an  
18 AREVA steam generator.

19 CHAIR REMPE: I remember that one.

20 MR. KARWOSKI: In terms of similarities of  
21 the steam generators, most of the steam generators in  
22 the combustion engineering designed PWRs, they tend to  
23 be larger. They usually have, typically have two steam  
24 generators rather than three or four on the  
25 Westinghouse as well as two steam generators, so much

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1 larger than the --

2 CHAIR REMPE: Within a category like the  
3 C-E ones, how different are the designs? I remember  
4 the issues with St. Lucie Unit 2 versus Unit 1 that  
5 occurred and so what I'm trying to get to is just because  
6 it's a C-E one and it has a replacement one, that the  
7 plant, that the steam generator might be quite  
8 different.

9 MR. KARWOSKI: Yes, the steam generator,  
10 yes, can be quite different. There's a lot of  
11 similarities but they can be quite different.

12 In the case of St. Lucie 1 versus 2, the  
13 issue at St. Lucie 2 they've attributed to fabrication  
14 or manufacturing as you may recall. But, you know,  
15 there are similarities. Like in terms of the original  
16 St. Lucie 1 and 2 steam generators, I believe they were  
17 identical.

18 And so the replacements, they'll have some  
19 different features. You know, one might have a lattice  
20 grid tube support structure and the other might have  
21 a tube support plate so there can be some minor  
22 differences but, for the most part, they're fairly  
23 similar.

24 CHAIR REMPE: But then the inspection  
25 results might be quite different just because it was

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1 put in a different plant or it might have a bit different  
2 in design, perhaps the water chemistry or something  
3 like that. I'm not sure as we go further how good it  
4 is to be combining results from different plants.

5 MALE PARTICIPANT: I was going to -- I'm  
6 sorry.

7 MR. KARWOSKI: There can be differences in  
8 the performance between one vendor and the next and the  
9 performance of one type of steam generator at one unit  
10 versus another for the various reasons that you cited.

11 CHAIR REMPE: Thank you.

12 MR. BAQUERA: Yes. Just to your point,  
13 there's multiple different parameters that can vary on  
14 how a steam generator is going to perform, you know,  
15 licensee performance, how well they're monitoring  
16 things, how often they, you know, go in and inspect,  
17 you know.

18 So there's going to be a variety of  
19 different functions here so that's why we wanted to  
20 take, you know, some plants that were performing very  
21 well, some plants that had steam generators that  
22 weren't performing quite as well and use that kind of  
23 as a bounding sample for the calculator model.

24 CHAIR REMPE: Thank you.

25 DR. AZARM: Okay, when you look at these

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1 PDF files, depending on the design of the steam  
2 generator and the vendor, you know, the C-E plants  
3 versus Westinghouse, they use different naming for the  
4 types of flaws they find.

5 So and I give you an example of what we have  
6 seen and the question is that as you will see later in  
7 this calculator software we can only model two things,  
8 a volumetric or wear flaw or the crack.

9 So we have to group them, yes. Like if  
10 somebody wants to track the performance of each model  
11 of a steam generator separately, needs much more data  
12 and should not mix and match.

13 But for the purpose of the calculator  
14 software and consistent with the models and calculator  
15 software, we have to group them to two categories,  
16 cracked and wear, and this basically shows how that  
17 grouping was done.

18 What we tried to do rather than give you  
19 tables of data and, you know, confuse the issue, I tried  
20 to -- and, you know, some of the data is missing. You  
21 know, some reports may not have documentation of small,  
22 shallow type of flaws and some others do.

23 What I tried to do, I tried to graphically  
24 show you what is in this database. In this graph, I  
25 basically did empirical or cumulative distribution. I

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1 don't know if I have to explain it but basically what  
2 it is is that, you know, if I look at all the data I  
3 have, the recorded depth of the flaw, and look at the  
4 probability that I exceed that depth.

5 For example, the probability that I exceed  
6 a depth of 20 percent might be 0.1. So what I did, I  
7 tried to present what the data is in the database and  
8 aggregate over everything we see in the form of a graph.

9 And the point I wanted to make is couple  
10 of things. One is that usually they plug a tube that  
11 sees a flaw greater than 30 percent. I know the  
12 criteria is 40 but they are conservative. They  
13 sometimes plug at 35 percent. Sometimes might even  
14 plug area if they think the growth of the flaw is  
15 unstable.

16 So what you will see, somewhere around  
17 30/40 percent, kind of the shape of the graph, keep  
18 changing because those tubes that are plugged and those  
19 plugs that have flaws two sizes are, in a sense are  
20 removed. By plugging them, those flaws are not going  
21 to grow bigger and show up in other ones.

22 The other thing I wanted to emphasize here  
23 is that, yes, we did see some flaws that they were big,  
24 85 percent depth. So even though you have a plugging  
25 limit of 40 percent within the next cycle until you do

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1 your inspection, either the smaller flaw grow much  
2 bigger or a new flaw is going to be generated that is  
3 much deeper. So, yes, there are bigger flaws, deeper  
4 flaws, with much less probability.

5 CHAIR REMPE: So before you leave this  
6 plot -- and I'm going to have to acknowledge that some  
7 of my questions come from a consultant who's not able  
8 to join us today. Dr. Shack mentioned the fact that  
9 he really liked this plot, but it doesn't appear in your  
10 letter report or the draft NUREG.

11 And so I, but yet if we go to the letter  
12 report, and maybe this is a hard question to answer when  
13 it's not here, but there's a Figure 10 in the letter  
14 report. And could you, for the uneducated person, try  
15 and convey how you went from this information to Figure  
16 10 in your letter report?

17 DR. AZARM: Can I see the Figure 10? What  
18 is Figure 10 in letter report? I'm sorry. These  
19 things --

20 DR. COYNE: Ali, on the laptop there's a  
21 reference. There's a folder with references and you  
22 hopefully should be able to find the letter report on  
23 that reference list.

24 CHAIR REMPE: It's a probability versus  
25 flaw depth distribution and it probably is good to have

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1 access to the letter report because that comment about  
2 this is a great figure but I didn't see it in the letter  
3 report or the main NUREG or the draft NUREG is going  
4 to come up a lot today.

5 And if you wanted me to shut up, just ask  
6 me a technical question about my question and I'll have  
7 to say I don't know. See if we can go through it because  
8 I think some of his points are worth mentioning here.

9 DR. COYNE: The ISL flaw report?

10 CHAIR REMPE: Yes. It's a letter report  
11 in the flaw database. I can give you the ML number if  
12 that helps you.

13 DR. AZARM: No, I think I find it. It's  
14 --

15 CHAIR REMPE: Yes, I think you're getting  
16 there.

17 DR. AZARM: I am getting there.

18 OPERATOR: Please pardon the  
19 interruption. Your conference contains less than  
20 three participants at this time. If you would like to  
21 continue, press Star 1 now or the conference will be  
22 terminated.

23 DR. AZARM: Okay. I think what this  
24 figure is --

25 CHAIR REMPE: Is this related to that

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1 other figure you had up there?

2 DR. AZARM: I do believe so.

3 CHAIR REMPE: Yes.

4 DR. AZARM: Supposedly this is the --

5 MALE PARTICIPANT: It's one minus.

6 DR. AZARM: Yes, one minus.

7 CHAIR REMPE: Is it really one minus?

8 Because I actually took --

9 DR. AZARM: Yes, yes.

10 CHAIR REMPE: -- a couple of data points  
11 and I didn't see it was a direct one and I discussed  
12 it with Shack and of course, again, you've got this  
13 empirical gamma distribution --

14 DR. AZARM: Yes.

15 CHAIR REMPE: -- rather than the direct  
16 data --

17 DR. AZARM: Yes.

18 CHAIR REMPE: -- which he kind of wished  
19 that if you, he would really have preferred to see some  
20 direct data showing --

21 DR. AZARM: Yes, he --

22 CHAIR REMPE: -- how it compared too  
23 because he's got a distribution here.

24 DR. AZARM: Yes. Correct, and you will  
25 see. We will come back and discuss this because we have

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1 some note of cautious when we use the fitted gamma  
2 distribution. And this shows the gamma distribution  
3 trying to fit the actual raw data. The figure I was  
4 showing in the slide --

5 CHAIR REMPE: It's the raw --

6 DR. AZARM: -- is actual raw data.

7 CHAIR REMPE: And so his point is, boy, it  
8 would be good to show the raw data on there.

9 DR. AZARM: Yes.

10 CHAIR REMPE: And he really thought it was  
11 a great figure and he was glad to see you put it in the  
12 presentation.

13 DR. AZARM: Yes. I appreciate that.  
14 Thank you. Now, I have to go back where I was.

15 CHAIR REMPE: Sorry.

16 DR. AZARM: That's okay. Yes, I am. I'm  
17 there. Okay. Yes, whenever we fit the distribution,  
18 we kind of smear some stuff and, yes, it is always good  
19 to look at raw data and I wish, you know, to --

20 MEMBER POWERS: Is there a basis --

21 DR. AZARM: -- repeat that report.

22 MEMBER POWERS: Is there a basis for  
23 assuming a gamma distribution?

24 DR. AZARM: Frankly, no. Good question.  
25 The only reason gamma was used, because that's what

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1 Gorman used.

2 MEMBER POWERS: It kind of looks like a  
3 gamma.

4 DR. AZARM: Yes, yes. That's true.

5 MEMBER POWERS: I mean, that's the basis  
6 but, you know, you would think that if ever there was  
7 something that ought to have a heavy tail it would be  
8 flaws as a distribution.

9 Yes, I mean, the advantage of gamma is you  
10 got, it's the minimum number of parameters you can  
11 possibly take and it's a nice high-entropy  
12 distribution.

13 In fact, I think, isn't the gamma the one  
14 that maximizes entropy under constraint of the mean?  
15 I think it is.

16 DR. AZARM: I think it is if --

17 (Simultaneous speaking)

18 MEMBER POWERS: It's one of those that, I  
19 mean, it's a reasonably high distribution, entropy  
20 distribution.

21 MEMBER BALLINGER: But these are flaws of  
22 all types.

23 DR. AZARM: Correct.

24 MEMBER BALLINGER: So there's stuff built  
25 into here that wear is different than stress corrosion

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1       cracking, is different than loose parts and stuff like  
2       that. That's everything.

3               DR. AZARM:     That's everything thrown  
4       together. It just --

5               MEMBER BALLINGER:     So there's no  
6       distribution of loose parts flaws.

7               DR. AZARM:   Yes, but loose part is also  
8       cause a flaw that is categorized now under wear. So  
9       I can go into the database, very simply do the same graph  
10      for cracks and for wear but I cannot go to better  
11      resolution than that on this.

12              Now, the next slide also shows you raw  
13      data. This is for the length. Again, we are looking  
14      at wear or crack in a very ideal manner that has a depth,  
15      a length and, as you know, that is idealized but this  
16      is what is reported for the length distribution.

17              CHAIR REMPE:   Before you leave that one  
18      and, again, it didn't appear in the NUREG, draft NUREG  
19      or the ISL report, but there was a Table 4 in your ISL  
20      report.

21              And in that table there's only one flaw  
22      that's 4.4 centimeters and all the rest are less than  
23      2.1 centimeters, and so what's the real data in this  
24      empirical distribution and why did it get to be so long?

25              DR. AZARM:   Basically I think this is

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1 coming directly -- Let me just little bit explain this.

2 CHAIR REMPE: Please do, yes.

3 DR. AZARM: This directly is coming from  
4 the database. There's no manipulation, nothing done.  
5 The problem that you see with this distribution right  
6 at the tail at 1.5 inches or 3.8 centimeter, I can't  
7 draw it any more. Basically after 1.5 inch is actual  
8 data and, again, Ken, correct me if I am, you know.

9 MR. KARWOSKI: No. That's --

10 DR. AZARM: Then we have bunch of data.  
11 Thirty-nine percent of the data is exactly 1.5 inches,  
12 3.81 centimeter. It's like a sharp drop. That's  
13 because of all those flaws was by tube support plate  
14 and they might have just put that thickness of tube  
15 support plate and they didn't measure it exactly or the  
16 flaw.

17 Then there was one or two flaw, I do not  
18 exactly remember, that was in the tube sheet and those  
19 were bigger. So I didn't draw that end of the  
20 distribution. I will only do a gamma fit, they have  
21 smoothed it out.

22 But the real story of the data is that we  
23 have a sharp drop at 1.5 inches, which is all the flaws  
24 and tube support. Now, we don't really have actual  
25 length for them. And then we have couple of larger

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1       flaws that was at tube sheet.

2               CHAIR REMPE:   But, again, if this is the  
3       exceedance probability in this plot, it looks like that  
4       you have 40 percent or something greater than 3.75  
5       centimeters.

6               MEMBER POWERS:   Yes, well, that's what  
7       he's saying, is --

8               DR. AZARM:    That's correct.   That is  
9       correct.

10              MEMBER POWERS:   When they find a flaw in  
11      the tube sheet, they just call it --

12              MALE PARTICIPANT:   All messed up.

13              MEMBER POWERS:   -- the width of the tube  
14      sheet because they don't know any better.

15              MALE PARTICIPANT:   Yes.

16              CHAIR REMPE:    But in the database, you  
17      only had one that was greater than 4.4 centimeters in  
18      that Table 2, or Table 4.   I'm sorry.

19              MEMBER POWERS:    No, here it says 39  
20      percent --

21              (Simultaneous speaking)

22              CHAIR REMPE:    If I go to Table 4 in your  
23      report, which is Page 19 out of 33 of your report --

24              MEMBER BALLINGER:   19 or 16?

25              CHAIR REMPE:    Well, it depends if you look

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1 at the report number or the pages in the PDF.

2 DR. AZARM: It is Table 4, correct.

3 CHAIR REMPE: Yes. Okay, so I see one  
4 flaw that's bigger than 2.1 centimeters and that's that  
5 one 4.4 one, right?

6 DR. AZARM: Yes. That 4.4 one, I am  
7 pretty sure that is the one that was on the tube sheet.

8 CHAIR REMPE: So then there's one.

9 DR. AZARM: There is one very big one on  
10 tube sheet.

11 CHAIR REMPE: Right.

12 DR. AZARM: And there could have been lots  
13 of 3.81 after 2.1 centimeter that they didn't capture.

14 CHAIR REMPE: That they didn't capture and  
15 so that's why you've made it so many.

16 DR. AZARM: That is.

17 CHAIR REMPE: Okay.

18 DR. AZARM: But, you know, what I did  
19 there, I didn't use this table. I just inquire  
20 database to dump thing and draw it for me. So what you  
21 see in that graph is actually what is in database. Now,  
22 they may not have used the whole thing for the  
23 statistical analysis because they have bunch of false  
24 data that they might have truncated out.

25 CHAIR REMPE: Okay.

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1 DR. AZARM: Okay. Now, let's see.

2 (Off microphone discussion)

3 DR. AZARM: Okay, so if this is the data,  
4 what do you want to do with this data? What is this  
5 model that we want to create? First of all, we want  
6 to be able that if you are at a cycle which is EFPY 15  
7 --

8 MALE PARTICIPANT: Excuse me.

9 DR. AZARM: -- and you want to predict how  
10 many flaws am I going to generate or am I going to see  
11 in my next inspection? Well, that's one statistic we  
12 want to create, the flow generation rate.

13 And we try to create that statistics for  
14 600 thermally treated, 690 thermally treated and we had  
15 for 600 -- For 690 we didn't see any crack but for 600  
16 we did see some cracks so we tried to generate the flaw  
17 generation rate and I --

18 MEMBER BALLINGER: When you say 600  
19 thermally treated you saw, I know of only one case where  
20 there were cracks at 600 thermally treated and that was  
21 an error due to an error in processing the tubes.

22 That has nothing to do with stress  
23 corrosion cracking. They were stress corrosion cracks  
24 but they were not generated during operation. They  
25 were generated because the tubing itself was not

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1 processed properly.

2 DR. AZARM: Well, that's a more detailed  
3 question. I do believe the database has  
4 circumferential and axial is called single SCI, I think  
5 single crack indication. Now, was it a true crack, but  
6 that's --

7 MEMBER BALLINGER: Was it all Seabrook?

8 CHAIR REMPE: Seabrook wasn't in our  
9 database then.

10 DR. AZARM: Seabrook is not --

11 MEMBER BALLINGER: The reports though,  
12 the sort of references that go back and forth.

13 CHAIR REMPE: He had a table here earlier  
14 and what they did --

15 MEMBER BANERJEE: Yes, he had one. He had  
16 St., what is it, St. Lucie?

17 DR. AZARM: No, Surry.

18 (Simultaneous speaking)

19 DR. AZARM: Should have had it because,  
20 you know, again, this is in the database.

21 (Off microphone discussion)

22 DR. AZARM: Just I want to make a note. I  
23 just want to be sure. To our knowledge the 690, the  
24 oldest plant is North Anna that has 19 EFPY and has shown  
25 no crack. So we have no crack with 690, so we can't

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1 generate any flaw rate generation for it.

2 So one part of the model is that to be able  
3 for each steam generator at any age to predict how many  
4 flaws am I going to see in the next cycle?

5 The second part of the model is that what  
6 is the characteristic of this flaw? What is their  
7 length? What is their depth, et cetera?

8 Again, we can split the hair and create  
9 many categories, you know. Basically we have been able  
10 with the limited data we have to define the flaw length  
11 distribution for wears and cracks.

12 And as you said and I agree, there's very  
13 few cracks in the database. They could not distinguish  
14 that much between 600 thermally treated and 690  
15 thermally treated with the exception that there is no  
16 crack with 690 and you will see the result of that.

17 They were able to do something with the  
18 circumferential flaw length. Again, this is for  
19 cracks only, for 600 thermally treated, a small amount  
20 of data.

21 And they have done fits of the flaw depth  
22 distribution for both wear and crack and, again, they  
23 use one distribution for 600 thermally treated, 690  
24 thermally treated.

25 Again, under a larger database, all these

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1 things can be separated and we can do much better  
2 resolution. I'm just reporting of what has been done.

3 What is the model? The flaw generation  
4 rate increase as a function of the steam generator  
5 service life, and that function was shown to be linearly  
6 increasing. So it's simple regression model using  
7 Excel, so there's no fancy statistics here.

8 So that's the way that they calculate it  
9 and measure and then they fit it to a regression and  
10 then they calculate it equivalent to flaw generation  
11 rate.

12 For the flaw length and depth events they  
13 tried to use gamma distribution. Again, no fancy  
14 fitting. You know, we could have taken large number  
15 of distribution, do a goodness of fit, et cetera.

16 MEMBER POWERS: But the length and depth,  
17 they have to be correlated. Length and depth have to  
18 be correlated. It has to be a bivariate --

19 DR. AZARM: Correct. Correct. It has  
20 not been done. Correct. I do agree with that.  
21 That's known to be independent and they have been fit  
22 with the gamma distribution. The parameters were  
23 estimated, again, very simply by matching the first two  
24 moments.

25 Okay, I'm going to read actually from my

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1 notes. That way we don't confuse you guys. This data  
2 summarizes the results of the statistical analysis.  
3 For thermally treated Inconel 600, the rate of wear flaw  
4 generation per tube is a linearly increasing function  
5 of the service life measured by EFPY and shown by k,  
6 and I think that's the very first equation.

7 So it basically says that k is basically  
8 lambda as a function of EFPKY is linearly increasing  
9 with an intercept at the coefficient.

10 The result also show little or no  
11 dependence on the service life for crack generation.  
12 That might be the result of very small data they had.

13 Actually I have written, this was  
14 surprising. I'm reading my notes. It is generally  
15 postulated that once crack are generated due to SCC,  
16 their number increase fast over service life, but we  
17 don't see that.

18 Gamma distributions were generally fitted  
19 for the flaw depth and sizes. Again, the size of crack  
20 flaws are only applicable to thermally treated 600  
21 tubes. The distribution for the sizes of the wear are  
22 aggregated over both 600 and 690, so that's what this  
23 table is showing you and I think it's in the report also.

24 CHAIR REMPE: Well, it depends on what  
25 report you look at.

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1 MALE PARTICIPANT: Yes.

2 CHAIR REMPE: It agrees with what's in the  
3 draft NUREG, but if I go to your letter report, there  
4 is a figure, or a coefficient of a half that appears  
5 in the first term on the right of that very, the  
6 volumetric flow rate and, again, it depends where I look  
7 in the report and so I was just wondering is the half  
8 supposed to be there or not, first of all?

9 DR. AZARM: Okay, I will give you an  
10 explanation based on my memory collection. When you  
11 have linearly increasing hazard rate, it's not that  
12 easy to estimate it from the data.

13 So what you define, you define the function  
14 of a cumulative probability distribution which I  
15 forgot, is log of PF minus one, something.

16 And that function is exactly like a hazard  
17 rate except there's a coefficient of one half in front  
18 of the coefficient. So that is not hazard rate.  
19 That's what was fitted and then hazard rate removes that  
20 one half from it.

21 CHAIR REMPE: Oh, okay.

22 DR. AZARM: So there is a mistake. If  
23 that's, you know, the factor of one half is coming  
24 because of the function they create to fit.

25 CHAIR REMPE: Okay. Could I also ask you

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1 to bring up that letter report again and --

2 DR. AZARM: Of course.

3 CHAIR REMPE: -- look at Figure 4? It's  
4 at Page 10 of 33 in the letter report. It's at the  
5 bottom. It's also Page 7 of the actual, but it's Figure  
6 4.

7 And this goes -- that, right there. And  
8 that's why I was asking the questions earlier about is  
9 it really appropriate to combine the data for these  
10 different plants into one distribution? As we heard  
11 earlier, there's a lot of parameters that affect how  
12 these steam generators run.

13 And again, our expert said that he was  
14 wondering if it wouldn't have been smarter to have come  
15 up with curves for each plant and then have an average  
16 one rather than combining the data for the various  
17 plants.

18 And I believe then he referenced Figure 8  
19 of this report and pointed out that when you get to the  
20 volumetric/wear flaws, if you go to Figure 8, you can  
21 see there's a, it's really hard to justify that that's  
22 a good curve fit to represent the data. Oh, you passed  
23 it.

24 MALE PARTICIPANT: No. There it is.

25 CHAIR REMPE: Yes. And again, I guess I'd

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1 like to hear your thoughts on it, an expert at this.

2 DR. AZARM: I will tell you what is my  
3 viewpoint looking at these. So when you look at this,  
4 and I think this is that side k that you see there.

5 CHAIR REMPE: Yes.

6 DR. AZARM: That empirical is log of one  
7 minus PF, et cetera. That is like a linear but has a  
8 one-half coefficient in it. Let me see if I can  
9 explain.

10 First thing first, let's assume that I'm  
11 at 15 cycle and I am trying to predict number of flaws  
12 by the next cycle, so I have a time period I predict  
13 and I have a lambda and this lambda is changing over  
14 time.

15 So even if lambda was constant and I ask  
16 you how many flaws do you expect to see by the next  
17 cycle, you basically say is a Poisson distribution and  
18 it could be 10, it could be 20, it could be 25 and is  
19 a distribution. It's not one number. So even for a  
20 constant failure rate, if I get data from ten different  
21 plants, I should see a big spread.

22 Just the consequence of assuming a Poisson  
23 or a generic Poisson when we have a linear increasing  
24 hazard rate, are the numbers that we are going to  
25 observe. But there is a probabilistic variation

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1 already in the Poisson that is going to create the  
2 spread.

3 On top of that, you are correct, there's  
4 a plant-to-plant variation, so that means the lambda  
5 itself -- if lambda was constant, even if I precisely  
6 predicted lambda I would still see a spread in actual  
7 data, but if lambda itself is changing because of  
8 plant-to-plant variation, you have an added spread.

9 Now, to do that, creating two levels of  
10 uncertainties or variation in your models, that is a  
11 good thing to do, is a sophisticated statistic. Again,  
12 I am tempted to say wasn't in the scope of this type  
13 of a study.

14 I think I can do those type of study. I  
15 need more data, because as you saw in Figure 4, if I  
16 separate the data, I don't have enough data to predict  
17 anything.

18 So the question was that given what we  
19 have, what is the best we can do and the simplest thing  
20 we can do, understanding that what we predict is we  
21 predict that you will have 100 flaws, it could be 150  
22 to 200 or it could be 50. It's going to be variation  
23 in it. But that said, that's my opinion of explaining  
24 that.

25 MEMBER BLEY: Well, I'm staring at this

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1 thinking if I draw that line and call that a model I'm  
2 making things up. About the only thing this seems good  
3 for is what you were hinting at and that is if you draw  
4 some kind of an upper bound up there you'll be able to  
5 say I'm probably less than this with some confidence.  
6 That's not a bad thing to be able to do. But the hint  
7 that the line is meaningful, just doesn't seem  
8 reasonable to me.

9 MEMBER BALLINGER: Most of this data, this  
10 is all wear data and it is very steam generator  
11 specific, plant to plant, within a plant, steam  
12 generator specific. So that probably dominates  
13 everything, I mean, aka, can you spell San Onofre? I  
14 mean --

15 DR. AZARM: I hear you and, again --

16 MEMBER BALLINGER: Let me ask a really  
17 dumb question. If you considered that these steam  
18 generator tubes were flawless, in other words you  
19 didn't have to worry about this, and you got hot enough,  
20 if you just treated them as unflawed and just did stress  
21 rupture because you get the very high temperatures,  
22 does it make any difference?

23 DR. AZARM: Okay. We are talking about at  
24 least assumptions in the calculator software itself.  
25 But I will answer you at least and you will hear

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1       elaboration of that.

2               If we have a tube that is flawed, even it's  
3       a very shallow flaw, you either feel it because of you  
4       are pressurizing it or you feel it due to creep rupture.  
5       The size of length of the flaw is going to be used to  
6       calculate the leak area. That's what our model is, you  
7       know, so just think about it.

8               If you don't have the flaw and you are  
9       talking about steam tube, of course you can calculate,  
10      oh, under pressure induce I can tell you exact thing.  
11      You get a big rupture. It's this and that. But for  
12      the creep rupture, I can't tell you because if you have  
13      a microscopic flaw that is going to go first.

14              MEMBER BALLINGER: Yes, that's what I  
15      mean.

16              (Simultaneous speaking)

17              MEMBER BALLINGER: If you get rid of all  
18      these flaws and just run a stress rupture test, there's  
19      going to be small imperfections in the tube.

20              DR. AZARM: Correct.

21              MEMBER BALLINGER: And when you get up to  
22      those temperatures, that's where things start.

23              DR. AZARM: Correct.

24              MEMBER BALLINGER: And does it make any  
25      difference on the time at which you get, on predicted

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1 time of failure? Have these or not?

2 DR. AZARM: You will see hopefully --  
3 there's one message I want to get across, that for  
4 Westinghouse plants, okay, it becomes more messy than  
5 that.

6 For Westinghouse we looked at, as a PRA  
7 part, both the pressure-induced and the creep rupture,  
8 so we looked at accidents like ATWS or main steam line  
9 break. That has nothing to do with the very high  
10 temperature in creep rupture. And then we looked at  
11 the severe accident that has to do with the high  
12 temperature and creep rupture.

13 MEMBER BALLINGER: I would combine  
14 pressure induced and creep rupture.

15 MALE PARTICIPANT: Just assume there's no  
16 flaws at all.

17 DR. AZARM: No. For Westinghouse plant  
18 you needed to have -- if you have even 50 percent flaw,  
19 you cannot fail it under pressure.

20 MEMBER BALLINGER: So it's creep rupture  
21 then?

22 DR. AZARM: Creep rupture but then the  
23 question of hot leg come, but let's get to PRA.

24 MEMBER BALLINGER: When does  
25 pressure-induced become creep -- anyway, okay.

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1 DR. AZARM: I can tell you that somebody  
2 told us start as a temperature of 600 as a threshold  
3 but that's, I think, the PRA report and calculator  
4 report question.

5 MEMBER BALLINGER: Okay, so below that  
6 temperature it's a classic failure?

7 DR. AZARM: Correct.

8 MEMBER BALLINGER: It's not time  
9 dependent then?

10 DR. AZARM: No. No.

11 MEMBER BALLINGER: Oh, okay.

12 DR. AZARM: And the calculator model has  
13 both of them and it switch. Once it goes above 600,  
14 we used to have 800 but we were told 600, we switch  
15 between the two models. Very good questions.

16 Again, this is a very small scope effort  
17 just to generate some meaningful flaw distributions to  
18 do the PRA. And perhaps more work is needed and more,  
19 I don't want to call it sophisticated statistics but  
20 at least consideration that even if we fit a line, the  
21 intercept might have a upper bound and lower bound and  
22 gives us a range.

23 MALE PARTICIPANT: We're lucky that John  
24 Stetkar is not here.

25 CHAIR REMPE: I think it would behoove the

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1 major draft to acknowledge some of the limitations,  
2 more of the study and to present a few of the plots that  
3 are in this presentation or in the draft or the letter  
4 report.

5 MEMBER BLEY: That seems pretty  
6 reasonable, yes.

7 MEMBER CORRADINI: Yes, this is Mike.  
8 I've been listening to all this wonderful material  
9 stuff, but I think Joy's last comment is very important,  
10 that the draft, before it goes out, needs to properly  
11 characterize this. Otherwise, it will cause  
12 confusion.

13 DR. AZARM: Yes.

14 MEMBER BALLINGER: Because you're  
15 calculating LERF at some point.

16 DR. AZARM: Yes.

17 MEMBER BALLINGER: Right.

18 DR. AZARM: Okay, these are just  
19 illustration type of graph. They took four steam  
20 generator, each steam generator with 3,300 tube and  
21 they look at the consequence of this linear hazard rate  
22 or linear failure rate.

23 Like if I am in the 20th cycle and I have  
24 600 or 690, how many flaws am I going to generate in  
25 that? So it shows you that at least based on the data

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1 we have, looks like 690 performs better.

2 MEMBER BALLINGER: Just if you step back  
3 and look at this, the enhancement factor on just  
4 failures due to flaws, stress corrosion cracking,  
5 whatever we call it, for 690 over 600 is supposed to  
6 be at least a factor of 20. I mean, one of these reports  
7 say. That's one of the criteria for using 690. I  
8 think it's 20, something like --

9 DR. AZARM: For crack.

10 MEMBER BALLINGER: Yes, for cracking.

11 DR. AZARM: That's correct.

12 MEMBER BALLINGER: But this shows only a  
13 factor of 800.

14 DR. AZARM: Yes, this is mainly dominated  
15 --

16 MEMBER BALLINGER: What's that?

17 DR. AZARM: This is mainly dominated by  
18 the number of wears.

19 MEMBER BALLINGER: By wear?

20 DR. AZARM: Yes.

21 MEMBER BALLINGER: Yes.

22 DR. AZARM: By volumetric flaws. I don't  
23 think crack is a big contributor to this.

24 MEMBER BALLINGER: This then is actually  
25 pretty informative, 690 is more subject to wear than

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1 600 is, more susceptible to wear.

2 DR. AZARM: Yes. Yes. Okay, the most  
3 important flaw parameter that specifies failure  
4 resistance of a tube is the flaw depth. This graph  
5 shows the fitted and empirical cumulative  
6 distribution. Now, the lower tail --

7 MEMBER BLEY: And this fits the one you  
8 said is just two parameter fit?

9 DR. AZARM: Two parameter fit. Now, the  
10 lower tail, this area, of empirical distribution is  
11 affected by the error associated with measuring small  
12 flaws.

13 The reason I'm making that point is that  
14 with small flaws and shallow flaws what we notice in  
15 the small database we have, we had one plant who  
16 reported lots of flaws but they were very shallow, five  
17 percent, three percent depth, two percent depth, where  
18 the other did not.

19 And knowing that the small flaws has a  
20 bigger error in them, there is a possibility that, one,  
21 we are not accurate in lower tail, even in empirical  
22 distribution.

23 The high end tail which I'm talking about  
24 here, the high end of the tail is also affected by the  
25 tubes removed due to plugging practice since these

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1       flaws will not be available for further growth to larger  
2       flaw in the next cycle. So we also expect that the end  
3       tail on the other side to behave a little bit different.

4               If I had to do this again, I would have  
5       actually divide, would have divided the data to three  
6       regions. Region less than 15 percent depth, region  
7       between 15 to 35 percent depth and region of 35 percent  
8       depth and above.

9               And there are other reasons for it. For  
10       example, in the high end region our probability of  
11       detection is very high.

12               MEMBER BALLINGER: Above 30 percent they  
13       would have plugged it, right?

14               DR. AZARM: Yes, but new ones can be  
15       generated. That's why we get big ones. So I would  
16       have done three regions. I would have generated three  
17       flaw generation rate and I would have generated three  
18       gamma distribution. That way I would assure that each  
19       region is properly fitted.

20               MEMBER BLEY: As it is, you kind of fiddled  
21       this to above 95th.

22               DR. AZARM: Yes. As it is, now we have --  
23       what happened is that when we wanted to do the  
24       Westinghouse and Westinghouse was totally dominated by  
25       high tail end of the distribution, we were getting

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1 underestimate because of just what I said.

2 So what we did, and you see that in PRA  
3 report and is very confusing, we tried to shift the  
4 gamma distribution to get a better fit at the high end  
5 and that's what is shown in the next graph.

6 The blue one is actually empirical one,  
7 the jagged line, the red one is the gamma distribution  
8 and the green one is the shifted one that does, because,  
9 you know, in that area, a small error is going to make  
10 a big difference. There's a big difference between  
11 0.01 and 0.001. So I think you see that in the PRA  
12 document, that we shift that. I just wanted to tell  
13 you why we did that.

14 So, again, if we would have known this  
15 stuff at the beginning, that, you know, we are going  
16 to be very exact at certain part of distribution and  
17 certain part of the data is going to be needed, perhaps  
18 we would have done different types of approach for this  
19 part.

20 Now, the title of this slide is wrong.  
21 This is not 10 steam generators. What I tried to do,  
22 I tried to say if I take 500 reactor year and try to  
23 see how many flaws I'm going to see in 500 reactor year  
24 and apply my distribution to it, what is all the  
25 different size I see?

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1           So I'm going to read from my note and then  
2 we can -- This graph shows the distribution of flaw  
3 length for the 10,000 detected flaw. Assuming 32 new  
4 flaw per reactor unit at each refueling inspection,  
5 10,000 flaw would translate to about 312 refueling  
6 cycle or about 500 reactor years. So the title is not  
7 correct. It's not ten steam generator. It's 500  
8 reactor years= worth of data.

9           This graph is based on shifted  
10 distribution using PRA study. It shows that we expect  
11 4 flaws to be greater than 70 percent depth with 3 of  
12 them between 70 to 80 percent and one flaw between 80  
13 to 90 percent. Why is that important? Because it also  
14 shows 2,730 flaw out of 10,000 or 27 percent have depth  
15 between 15 to 25 percent.

16           But the important thing is that if we  
17 assume that the regular steam generator tube rupture  
18 during normal operation can happen if I have a flaw  
19 deeper than 90 percent. If I have a very deep flaw,  
20 that even the 1,000 psi difference can cause my steam  
21 generator tube rupture. This data basically tells you  
22 you will have probability that's 1 over 500 or two to  
23 the minus three for the new replaced steam generator  
24 data.

25           So it kind of is saying that I'm

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1 calibrating this, even what we have seen, with the steam  
2 generator tube rupture during normal operation and it  
3 doesn't look as bad.

4 This is the same thing for the length  
5 distribution, and if you don't mind, I won't go through  
6 it but it's the same information.

7 In conclusion, in summary this study  
8 generated some statistics that can be used for  
9 generating the flaw samples for running the C-SGTR  
10 calculator.

11 It is the first study of its kind for  
12 providing insight to and estimate the performance of  
13 replaced steam generators with Inconel 600 and 690. It  
14 is a starting point and provides insightful  
15 observations.

16 So I think this is the first type of work  
17 in this area and I think it gives us at least we can  
18 generate flaw samples to run our calculator and, yes,  
19 we can do much better but it does the job for right now.

20 CHAIR REMPE: Thank you.

21 DR. AZARM: Thank you.

22 MEMBER POWERS: Just interject a note that  
23 because of some previous discussion we had on the  
24 selection of the gamma distribution for doing this, I  
25 think it's a good selection in the face of having

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1 mechanisms generating flaws because none of those  
2 mechanisms do you understand very well so for any one  
3 of them you might at best know the mean size of the flaw  
4 from that.

5 Then if you maximize entropy for knowing  
6 just the main flaw, you come up with the gamma  
7 distribution but you come up with an exponential  
8 distribution. If you sum the effects of all those  
9 mechanisms, you end up with the gamma distribution for  
10 the sum.

11 So I fully support the idea of using a gamma  
12 distribution for this because it's, I mean, it's very  
13 consistent, has an internal consistency even in the  
14 face of multiple mechanisms creating flaws, so just  
15 kick that in for whatever it's worth.

16 MEMBER BALLINGER: I keep coming back to  
17 not quite understanding. These deep flaws and stuff,  
18 they would have, those tubes would have been plugged.

19 DR. AZARM: Basically --

20 MEMBER BALLINGER: Where am I wrong there?  
21 Thirty percent volumetric or more, 40 percent, they  
22 would have plugged the tube. And so any, and by the  
23 way, the rules are any circumferential defect  
24 automatically gets plugged so doesn't that shut off the  
25 distribution at some point or are you just assuming that

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1 the tubes are -- I don't know.

2 DR. AZARM: Oh, the tube. Let me at least  
3 explain my best understanding and Ken or Mica can help  
4 you. I am at end of this cycle. I am going to go look  
5 at all my tubes with flaws. And, yes, you are right,  
6 if I see anything 40 percent I'm going to plug it.

7 MEMBER BALLINGER: Right.

8 DR. AZARM: Correct? So if I have done my  
9 job properly, which we assume we did, when I start my  
10 new cycle, there shouldn't be any tube with 40 percent  
11 flaw. Now I am trying to predict next cycle or I want  
12 to go to the next cycle and I'm going to do my  
13 inspection.

14 During this cycle, I can have a loose part  
15 creating a wear flaw, deep wear flaw and I'm going to  
16 see a 50 percent flaw. It does not create --

17 MEMBER BALLINGER: So it's wear, it's a,  
18 because you're not going to get -- okay.

19 DR. AZARM: Okay? So also there could  
20 have been a flaw here 29 percent which I didn't plug  
21 and, yes, my growth estimate of that flaw says 70  
22 percent chance this is never going to grow beyond 31  
23 percent but there is still 20 percent, 30 percent chance  
24 that it does.

25 MEMBER BALLINGER: For cracks or wear

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1 maybe, but in the oddball event of a loose part or  
2 something you can't --

3 DR. AZARM: Yes, yes.

4 MEMBER BALLINGER: -- say anything.

5 DR. AZARM: So it is a combination. Even  
6 though you are plugging them, when you look at next  
7 cycle you will see some new flaws as deep and there could  
8 be some old flaws that was not as deep now became deep.

9 Now, we have the capability from the  
10 reports to differentiate between those two even though  
11 right now we haven't done it, but we have the location  
12 of each of the tube and the flaw, how many inches it  
13 is above or below the TSP so we can say this big flaw  
14 you saw is as a result of the growth of a flaw that you  
15 didn't plug or this is a new flaw event.

16 MEMBER BALLINGER: I mean, I can  
17 understand the sort of random event, like a loose part  
18 or something, but the way these steam generators are  
19 operated, there's a statistical distribution of,  
20 statistical number of tubes depending on the ongoing  
21 issues of the steam generator that defines the  
22 inspection interval.

23 And if all of a sudden they see a larger  
24 increase or it goes outside, they change the  
25 distribution, increase the number of tubes that are

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1 inspected through a mid-cycle outage. So there's an  
2 operational part here that would tend to me to think  
3 to reduce the number of actual flaws that may get you.

4 DR. AZARM: We fully agree. That's why --

5 MEMBER BALLINGER: Okay. That's not  
6 reflected in these probabilities.

7 DR. AZARM: That's why I was worried about  
8 my gamma tail. That's what I was saying. Because of  
9 these big flaws are removed, I know it's going to affect  
10 my gamma tail. It actually has affected the shape of  
11 the flaw solution because you remove them.

12 Shall I go to the next presentation?

13 CHAIR REMPE: I think so. Are we ready  
14 for the next one, guys?

15 MALE PARTICIPANT: Yes.

16 CHAIR REMPE: Okay, please do.

17 DR. AZARM: Now we are in the calculator.  
18 To estimate the consequential steam generator tube  
19 rupture probability for a specific accident scenario  
20 and for a set of flaw in the steam generator tubes, the  
21 staff had its own software written in Java language.

22 This software use the fracture mechanic  
23 models developed by NRC and industry for steam  
24 generator tube failures, hot leg and surge line. That  
25 guy is happy to leave.

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1 (Laughter)

2 MALE PARTICIPANT: I thought you guys were  
3 -- I'm glad you had lunch because I thought you guys  
4 were going to eat with us.

5 (Laughter)

6 DR. AZARM: In this short presentation, we  
7 are trying to give you an overview and please feel free,  
8 ask questions because I don't think, you know, the  
9 presentation is written at a very high level but I'm  
10 ready to discuss any detailed question you ask.

11 The main objective of writing this  
12 calculator was to support the C-SGTR PRA. NRC did have  
13 some spreadsheet before this project to do some of the  
14 calculations similar to this, but it was frankly very  
15 difficult to trace what was done and to modify it and  
16 update it. That's why the decision was made to write  
17 a documented software in language that everybody can  
18 modify and use.

19 This calculator is therefore  
20 probabilistic in nature. It captures the failure time  
21 and leak size of a steam generator tube with different  
22 type and sizes of flaw for both thermally treated  
23 Inconel 600 and 690.

24 The software also has built-in creep  
25 rupture models for hot leg and surge line failure for

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1 generic, Westinghouse and C-E plant.

2 This slide basically shows an overview  
3 structure of the software. We either can put a  
4 preexisting set of flaw, like somebody just does  
5 inspection and gets 150 flaws and knows the sizes.  
6 They can create an input or we can simulate or give him  
7 sample from the flaw statistics. We need the thermal  
8 hydraulic response of an accident that we want to  
9 analyze, and you heard Mike talking about that.

10 And what we expect from calculator is to  
11 estimate the probability distribution of the leakage  
12 area of steam generator tube rupture and the  
13 probability of RCS failure as a function of accident  
14 time.

15 The calculator performs these  
16 calculations for two types of accident, a class of  
17 severe accident, post-core damage with dry steam  
18 generator and high primary and low secondary pressures  
19 when the dominant failure mechanism is creep rupture.

20 It also evaluates C-SGTR for a class of  
21 so-called DBA accidents, prior to core damage, with  
22 significantly higher than normal pressure across the  
23 steam generator tubes. In this case the dominant  
24 failure mechanism is the plastic failure or pressure  
25 induced.

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1           The information generated by the  
2 calculator then is used in PRA models to estimate the  
3 core damage probability and LERF.

4           The calculator is also equipped with a  
5 library of material properties for fracture mechanic  
6 analysis and library of all uncertainty parameters that  
7 we have used. And as I go through, I will mention to  
8 you what are the different types of uncertainty  
9 parameters we have.

10           The next one, it just shows you that this  
11 calculator exists. When you run it, this is the first  
12 page of calculator. It asks for plant name. It knows  
13 for each plant name the number of tubes, the size of  
14 the tubes, the material of the tubes and ask you for  
15 the accident TH values and it also asks you for critical  
16 area that you consider as a C-SGTR.

17           Next slide simply shows the four major  
18 fracture mechanic models of the calculator. These are  
19 pressure-induced failure and leak area model for flawed  
20 steam generator tubes, creep rupture failure and leak  
21 area model for steam generator tubes and finally creep  
22 rupture model for hot leg and surge line.

23           So this is basically the four models we  
24 have in calculator. And as we said, most of the models,  
25 the first two models is all based on past NRC work. The

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1 last two for hot leg and surge line coming from EPRI  
2 report.

3 Okay, this I think repeats what I just  
4 said. It basically says all the fracture mechanic  
5 models for flawed tube is NRC work. All the creep  
6 rupture of hot leg and surge line is EPRI model.

7 Material properties, we need them as a  
8 function of temperature. NRC did have 600 but did not  
9 have 690 thermally treated. We basically got those  
10 information from several sources of open literature  
11 because for each of the material, you know, if you look  
12 at ultimate strain, we not only want that as a function  
13 of temperature but also look at different sources who  
14 come up. What are the uncertainties associated with  
15 this?

16 So if you are at 700 degree temperature and  
17 look at XKSI is the mean and what is the error around  
18 it. So all these material properties also have  
19 uncertainties defined too.

20 CHAIR REMPE: How high a temperature did  
21 you find for the 690? How high a testing temperature  
22 did they go to? I assume it was lower than what you  
23 could find for the 600 because I think INL used to have  
24 it, at least 1,100 C, from the TMI days.

25 DR. AZARM: I don't know the answer to your

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1 question but we have that documented very detailed and  
2 we looked at, like, three different sources and we  
3 looked at actually one source on precious metal in the  
4 wear in addition.

5 CHAIR REMPE: Well, let me ask it in a way  
6 that won't require specific temperatures. Did you  
7 have data that encompassed the failure range where you  
8 were predicting --

9 DR. AZARM: Yes.

10 CHAIR REMPE: -- or were you extrapolating  
11 with the data?

12 DR. AZARM: No, we had the data,  
13 sufficient data that, you know, predicted the creep  
14 rupture failures we wanted. We did not ask for  
15 analysis. That's for pressure induced.

16 For Larson-Miller creep rupture  
17 parameters, again Inconel 600 we have a beautiful  
18 equations, et cetera, but for 690 we had to go and rely  
19 on open literature.

20 Again, we have documented what we have  
21 found and, again, we have accounted for the  
22 uncertainties to the best we saw.

23 Hot leg and surge line, these are coming  
24 from EPRI. Again, they are Larson-Miller type of  
25 equations. And as I was trying to say this morning,

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1 we can verify it. We haven't verified it. That's why  
2 we asked Dr. Iyengar to do independent calculations.

3 But the equation gives you the  
4 coefficients of the empirical model, Larson-Miller,  
5 has uncertainties or tolerances associated with that.

6 And we have taken those tolerances and  
7 assumed is a variance of a normal distribution and we  
8 have made samples from them and -- We have heard a lot  
9 about the sequence input, but what the calculation  
10 needs is the fraction of hot tubes and their average  
11 temperature, the fraction of cold tubes.

12 This software does not just look at hot  
13 tube. Also looks at cold tube because sometimes a  
14 difference between cold tube and hot tube is, like, 100  
15 degree, 150 degree, and if you have a larger flowing  
16 cold tube, it can go first. So the calculator tries  
17 to look at both of them.

18 We also need to have the fraction of the  
19 hottest tube and you guys discussed this question of  
20 20 versus 100 and it's your judgment but we basically  
21 get this input from the thermal hydraulic guys.

22 We want the primary and secondary pressure  
23 because we have to calculate the stresses on the hot  
24 leg and surge line and the tubes, and we also need to  
25 have the hot leg temperature and surge line temperature

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1 to be provided to us.

2 MEMBER BLEY: How did you decide how big  
3 those groups ought to be, the number of hot tubes and  
4 the number of cold tubes? There must be an iterative  
5 process because number of feed ruptures --

6 DR. AZARM: I will ask Mike to help, you  
7 know, with me but basically think about, at least from  
8 my viewpoint, when these things goes through a steam  
9 generator, exactly think about fire.

10 You have a plume and there's a variation  
11 of temperature and the hottest tube to me is, they call  
12 it group hottest and then they have average hot and  
13 average cold.

14 Now, they have done some CFD calculations.  
15 So far they have some idea that, you know, if I think  
16 about this as a plume on the top 25 percent is called  
17 hottest. I don't know.

18 (Simultaneous speaking)

19 MEMBER BLEY: Let me ask it a slightly  
20 different way. What I'm interested in is you must have  
21 really been thinking of the PRA as you do this, how many  
22 tubes do I need for this to be really significant, and  
23 done something like that and maybe iterated on it or  
24 did you just arbitrarily take some raucous group that's  
25 within 100 degrees of each other or something?

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1 DR. SALAY: I don't know how he -- This is  
2 Mike Salay. Well, ultimately it came, the temperature  
3 distribution came from CFD and they had a hot region  
4 and --

5 MEMBER BLEY: I'm not quite saying right  
6 what I'm after.

7 (Simultaneous speaking)

8 CHAIR REMPE: Can I interrupt?

9 MEMBER BLEY: If you took the very hottest  
10 tube -- in a second. If you took the very hottest tube  
11 and used that, that would be one piece of information  
12 but you'd only get one tube, the troublesome one or  
13 being vulnerable.

14 If you took, you know, some arbitrary  
15 Number 11, the average temperature would now be lower  
16 so it wouldn't be as severe but you'd have more tubes.  
17 How did you decide how to do that selection? I don't  
18 --

19 CHAIR REMPE: I think this morning you  
20 were missing. We discussed this a bit.

21 MEMBER BLEY: Oh, you went through that?

22 CHAIR REMPE: And so let me summarize what  
23 we had --

24 MEMBER BLEY: Sorry, I --

25 CHAIR REMPE: -- for the Westinghouse

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1 ones. That's why I --

2 MEMBER BLEY: Okay.

3 CHAIR REMPE: -- keep wanting to interrupt  
4 you. But for the Westinghouse ones, there was this  
5 document or this plot that was in the older NUREG.

6 But for the C-E ones, and there's a couple  
7 of sentences in the draft NUREG that they had some  
8 experts from NRC decide to use 20 and then there was  
9 some additional discussion that as long as it's big  
10 enough it doesn't matter.

11 Am I summarizing what I took away from this  
12 morning? So this is a good education for me if I missed  
13 something.

14 DR. SALAY: And I was talking for the,  
15 referring to our calcs and when we did the failures and  
16 I can't remember exactly how Ali, I mean, split it up  
17 in hottest and, or did you get that from us or --

18 DR. AZARM: I got that from your report,  
19 yes.

20 DR. SALAY: Oh, from --

21 DR. AZARM: What we basically did, I think  
22 we went to your report.

23 DR. SALAY: Again, my memory is not --

24 MEMBER BLEY: I'll go to the transcript.

25 CHAIR REMPE: Well, again, it's good to

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1 discuss it further because maybe I'm not understanding  
2 but I'll have to write a letter at some point perhaps  
3 and it's good for me to understand it. It was expert  
4 opinion. It wasn't a formal NRC interaction. It was  
5 --

6 DR. SALAY: And then Ali used this -- if  
7 you use that 20, then that was just, well, how many tubes  
8 are going to be the hottest and said about that many  
9 and that it's -- we were going to, it would have been  
10 nice to look into it further but we didn't, so.

11 DR. AZARM: And I just want to add  
12 something. Perhaps me and Dennis think a little bit  
13 similar from PRA words. I am just wondering if your  
14 question relates why we are deciding what is the  
15 critical size of the break, is it one tube, two tube,  
16 ten tubes? Is that what --

17 MEMBER BLEY: Well, it's related to that  
18 but, see, that's what -- I'll say, as I tried to before,  
19 if you took the one hottest tube, then you would be more  
20 vulnerable I suspect but you'd have less chance of  
21 having the flaw in there.

22 DR. AZARM: Correct.

23 MEMBER BLEY: If you took a slightly  
24 bigger group, you would have a lower average  
25 temperature, you wouldn't be as vulnerable, you'd have

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1 more chance of a flaw.

2 This is eventually going to get to when we  
3 talk about the PRA how did you treat the uncertainty  
4 having to do with this part of the problem?

5 DR. AZARM: Yes, we will talk about that.  
6 Just very briefly I'm going to tell you and we will talk  
7 about it.

8 Basically I think we have, just think about  
9 it. We have 100 hots and we have 2,000 average hot and  
10 1,000 average cold and we have 150 flaws. Random we  
11 throw them on these tubes, correct, and then see how  
12 it fails.

13 MEMBER BLEY: Given the kind of model we  
14 talked about a few minutes ago, yes.

15 DR. AZARM: So that is what is done in PRA.

16 MEMBER BLEY: But there is some  
17 uncertainty there that maybe things in different  
18 temperature regimes would over that, since last  
19 refueling might be more likely to have a problem or not.

20 So what I'm eventually going to wonder  
21 about is given all of these things that you could have  
22 done if you had all the money in the world, do we have  
23 a conservative result? Have we addressed the  
24 uncertainty in all of these various things or not? And  
25 I don't expect the answer here but eventually I want

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1 to --

2 DR. AZARM: Okay, we will discuss that to  
3 the best we can.

4 CHAIR REMPE: Because we didn't bring it  
5 up this morning and I hope Mike's still back there or  
6 someone can, when you picked the number of hot tubes  
7 to be 20, I think there was some discussion about this  
8 was big enough to get a large enough size.

9 But I don't recall the report ever  
10 mentioning any interaction about MELCOR, because you  
11 picked 20, you have a lower peak temperature. Did that  
12 type of, was that something that MELCOR was considered  
13 but --

14 DR. SALAY: No, it didn't. We just, I  
15 mean, there was actually, you simulated, it was just  
16 one tube for, in the MELCOR analyses you have one tube  
17 that's hot and one tube that's average temperature but  
18 it represents multiple tubes and the hot tubes taken  
19 to represent 20 and just --

20 CHAIR REMPE: So there was no interaction.  
21 If you picked 30, you wouldn't have had a lower hot  
22 temperature?

23 DR. SALAY: No.

24 CHAIR REMPE: Yes.

25 DR. SALAY: But ultimately you are

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1 characterizing the CFD, the distribution of hot tubes  
2 going in, so you know how many tubes, I mean, show the  
3 distribution for Westinghouse. It was never evaluated  
4 for C-E.

5 But, I mean, so the hottest and the medium  
6 give you sort of an anchor that you can put the whole  
7 distribution on and so you can actually, I mean, the  
8 information is there if you take the time to extract  
9 it.

10 MEMBER BLEY: And is that kind of what was  
11 done? You took the hottest one and used that as the  
12 temperature for the hot group when we get later views  
13 in it somewhere else?

14 DR. SALAY: No, we gave them the hot  
15 temperature and the medium temperature profiles and  
16 then I can't remember exactly how --

17 DR. AZARM: Average cold, average hot tube  
18 and the hottest tube.

19 DR. SALAY: And hottest tube. And then  
20 how many tubes were in the plume? I remember that  
21 information we gave and now it's in the whole thing and  
22 I guess you're using the 20 that we used for the hottest  
23 or --

24 DR. AZARM: I cannot swear.

25 DR. SALAY: Yes, I can't remember.

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1 DR. AZARM: You know, the number that goes  
2 around my head is 100. Don't ask me why, but I think  
3 because we needed a number of tubes exposed to hottest  
4 for us to throw our flaws at it randomly.

5 I don't know. My memory says 100 but I am  
6 aware of the 20 number that you are discussing also,  
7 that that was what failed, but we will get to that --

8 MEMBER BLEY: Okay.

9 DR. AZARM: -- in the PRA report. Okay,  
10 what is the calculator output? Put simply, when we run  
11 this calculator with this input, it has to tell you as  
12 a function of time accidents, what is your leak area  
13 and it has to give you that in a probabilistic manner.

14 We can't tell you the leak area at ten  
15 minutes is two centimeters squared. It has to tell you  
16 what -- it tells you at least what is the 5 percentile,  
17 25 percentile, 50, 75 and 95 percentile. So it gives  
18 you a distribution of leak rate as a function of time.

19 Also it gives you the probability  
20 distribution for the time that we expect the hot leg  
21 or surge line fails or, in a sense, at each given time  
22 says I think there's only 5 percent probability that  
23 hot leg fails and sometimes later it tells you it's 25  
24 percent probability.

25 So it indicates out to the best it can

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1 including all the uncertainties, probabilities for the  
2 failures and leak area of a steam generator tube  
3 rupture.

4 So as was discussed this morning,  
5 uncertainties are very important in these calculators  
6 and, unfortunately, that's the one we had very hard to  
7 find and determine.

8 These are criteria basically showing you  
9 the leak area as a function of accident time and, you  
10 know, they are showing you the mean, the 5 percent, 25  
11 percent, et cetera, so you get some appreciation of  
12 where that this calculates, the calculator calculates  
13 as uncertainties.

14 So if the critical area is 6 centimeters  
15 squared, then you will know that there's 5 percent  
16 chance that you get that by 14200 seconds. So that's  
17 the type of output the calculator generates.

18 MEMBER BALLINGER: So a leak area going  
19 down with time?

20 DR. AZARM: No, it shouldn't. It's a  
21 manifestation of the curve fit. It should go up all  
22 the time. Because once, you know, you opened up a crack  
23 or you failed the tube to certain size, it's not going  
24 to shrink back.

25 MEMBER BALLINGER: Okay. That's the way

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1 I would look at it.

2 DR. AZARM: Yes, yes. No, now it, you  
3 know, they have done Excel fit and looks like it's going  
4 down but, no, it basically, what basically showing, one  
5 big flaw might have failed early on and grow and then  
6 waits for a little while and now the tube with the big  
7 flaw fails. So it's just, it's like a stair or steps.  
8 Goes up as more tubes fail and then it goes, so. Now,  
9 we --

10 MEMBER BALLINGER: I'm just struck by the  
11 axis. All of this really happens over a 100-second  
12 interval.

13 DR. AZARM: Yes. Yes, yes, you are right.

14 MEMBER BALLINGER: Go from the, plus or --

15 DR. AZARM: When I show you the TH result,  
16 really nothing interesting is happening until you start  
17 having Zirco oxidation, exothermic reaction, rapid  
18 heat-up and by the time that happens, in couple of  
19 hundred seconds, in less than ten --

20 MALE PARTICIPANT: Temperature goes up  
21 pretty fast.

22 MEMBER BALLINGER: Well, I understand the  
23 temperature goes up.

24 DR. AZARM: And that's when everything  
25 fails.

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1                   MEMBER BALLINGER: But I guess we come  
2 back to the thing we talked about this morning. When  
3 does that point occur? I mean, how is it, you know,  
4 everything happens over a 100-second span over 14,000  
5 or 14,000 and change seconds.

6                   DR. AZARM: Yes. When I looked at this,  
7 everything is happening within ten minutes, let's put  
8 it that way. Now, within, you know, 600 seconds and  
9 actually the very rapid rise over, is going to happen  
10 within couple of hundred seconds. That's why when we  
11 talked about the why is the hot leg uncertainty so small  
12 I was saying because there's a very rapid rise of  
13 temperature.

14                   If I would run the same model at 700 degrees  
15 centigrade constant, you will see a very big  
16 uncertainty. But when the temperature is so  
17 dynamically increasing, it doesn't allow a big  
18 uncertainty. It just squish everything together.  
19 These are illustration. We are going to see some  
20 actual results later on.

21                   MEMBER BALLINGER: So I'll stop.

22                   DR. AZARM: The other slide basically  
23 shows that we sometimes use graphs that talks about RCS  
24 survival and survival of a steam generator tube rupture  
25 which is one minus three probability. There's a reason

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1 for that. Because all these things goes through a  
2 post-processing before enters PRA.

3 Now, I want to very fast talk about  
4 different sources of uncertainty. I am not claiming  
5 that we did a great job with them. We had to do many  
6 shortcuts, but at least this identify what are the major  
7 sources of uncertainties that the calculator tries to  
8 handle.

9 The first one is the modeling  
10 uncertainties. All fracture mechanic models has to  
11 have uncertainty. Even though some of the NRC reports  
12 gave us an equation, empirical equation with no  
13 uncertainty, we tried to go back to the actual test data  
14 and add an error term in the lump form of uncertainty.

15 MEMBER BLEY: Did you do that analytically  
16 or was that a judgement call?

17 DR. AZARM: No, we basically calculated  
18 the variance versus predicted and fitted to a normal.  
19 The problem was that, and this is very important, the  
20 problem is that everybody adds error term as plus  
21 epsilon.

22 In many of these models, the error term is  
23 predicted minus observed is one plus epsilon multiplied  
24 by predicted, is multiplicative which usually they  
25 don't do.

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1                   So we saw some of the multiplicative ones  
2                   so we put them in a lump but either we use as a summation  
3                   or multiplicative. The data sometimes was varied, so  
4                   it's crude but we tried to do that approach.

5                   Measurement uncertainties is a second type  
6                   of uncertainty we dealt with. We used it in material  
7                   properties, so when you look at the report and you see  
8                   long modules, you will see that it's just not giving  
9                   you the curve as a function of temperature. It gives  
10                  you lower bound and upper bound.

11                 MEMBER POWERS:     When you include  
12                  measurement uncertainties, do you attempt to handle  
13                  failure to detect?

14                 DR. AZARM:   Failure to detect flaws?

15                 MEMBER POWERS:   Yes. I look at a piece of  
16                  metal and I say there's seven flaws but there are really  
17                  eight because I just don't see one.

18                 DR. AZARM:   It is a very good question. I  
19                  will tell you of what was our position and our thought  
20                  process and the gentleman left. This is a question --

21                 MEMBER POWERS:   Yes, I know. He got away.

22                 DR. AZARM:   I will tell you. All the  
23                  statistic you do is undetected stuff. If somebody says  
24                  I can do a statistic on the stuff, that was not detected.  
25                  So all the statistics that you saw in the flaw is stuff

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1 that is detected. Hot leg accounts for the probability  
2 of detection.

3 Usually you do it in a controlled  
4 environment and saying, okay, for this type of flaw,  
5 this type of flaw the probability of detection is only  
6 50 percent. With this bigger flaw that is crack, the  
7 probability of detection is almost 99 percent. You  
8 create a curve. And then external to your statistics,  
9 you put them together. So the probability of detection  
10 and the statistics of flaw has to be joined at the end.

11 Now, we understood that that's going to be  
12 our approach but we have never accounted for curve in  
13 our report because we didn't have the right S curve to  
14 use for this flaw stuff, but that was our thought  
15 process.

16 Numerical errors in estimation. Again,  
17 we did not treat that formally as you know. For  
18 example, if I want to estimate a 95 percentile of the  
19 distribution, how many samples do I get? If I have 50  
20 different variables, how many samples do I get? If I  
21 do numerical integration, which we do quite often in  
22 Larson-Miller calculations, how good is our  
23 integration routine? How smart is our time spent? It  
24 was not done formally.

25 We did some MCAD calculations and compare

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1 rate, et cetera, and we just have the decision to use  
2 the calculator stuff. So that's the third type of  
3 uncertainty.

4 The fourth type of uncertainty is that we  
5 discussed this morning. First off, you know, one is  
6 that different plant have different flaw distributions  
7 and there's plant-to-plant variability. So I have to  
8 run all these many cases and then combine them outside  
9 the code in order to get an appreciation of uncertainty.

10 Also when we say short-term or long-term  
11 station blackout, there is no defined scenario called  
12 short-term station blackout or long-term station  
13 blackout. If you look at it, sometimes they do fast  
14 cooling. Sometimes they do, you know, slow cooling.  
15 The status of RCP seal leakage is different. So all  
16 of these things we group sometimes and we analyze and  
17 we try to use a bounding analysis for it.

18 But those can be, you know, depending on  
19 what is your approach, this last type of uncertainty  
20 has to be accounted for. Again, we didn't do the last  
21 type of uncertainty formally. We tried to the extent  
22 possible this bounding analysis.

23 MEMBER SKILLMAN: Back on your  
24 measurement uncertainties, that's back a slide, how do  
25 you account for the differences in the discovery by the

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1 rotating pancake coils and the bobbins from plant to  
2 plant with different gains and different blocking types  
3 and different manufacturers of those bobbins?

4 DR. AZARM: We didn't. You know, the  
5 measurement, uncertainty of flaw size that here we  
6 have, we have a placeholder. I think we are using three  
7 percent right now.

8 But we fully understand that it varies  
9 based on the steam generator tube design, based on  
10 different eddy current testing and rotating coil. We  
11 know it's different but we are not going to that level  
12 of resolution right now. We have a default value and  
13 we are putting three percent for it.

14 MEMBER SKILLMAN: A three percent  
15 uncertainty?

16 DR. AZARM: Yes. So if you are telling me  
17 something is ten percent deep, it's a 9.7 to 10.3 right  
18 now.

19 MEMBER SKILLMAN: Why is the three percent  
20 a good uncertainty?

21 DR. AZARM: We didn't have any input from  
22 anybody at that time so we put just a placeholder and  
23 that's the number that is, right now is default. But  
24 yes, I truly understand and I don't have, I understand  
25 the reason you are asking that question but I do not

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1 have the knowledge to give you the answer.

2 MEMBER SKILLMAN: Okay, thank you.

3 DR. AZARM: You're welcome. Another  
4 important thing. I think a lot of talk was given this  
5 morning about uncertainties but you have to not look  
6 at uncertainty magnitude but also look at the impact  
7 of uncertainty.

8 And I just put a graph here to show my  
9 point. This is basically a Larson-Miller parameter.  
10 As you know, you know, if I am over 600 or 700 degrees  
11 C, I shouldn't use the previous model and I have to use  
12 Larson-Miller to make sure that I'm not unnecessarily  
13 conservative.

14 And when we fit this in a log scale, it  
15 looked very good and actually when you look at, you  
16 know, at the uncertainty is showing up like a little  
17 bit 0.44 next to the intercept parameter and that's the  
18 fit. That's the fit of the regression.

19 But remember, this is now creep rupture so  
20 you are going to take ten, raise to that power and then  
21 you want to integrate, make it equal to one.

22 So that very little uncertainty that looks  
23 like a great fit, if you go with a constant temperature,  
24 it can create a factor of ten difference in the time  
25 of failure.

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1                   And you guys were real appreciative of that  
2                   in discussing it this morning and we fully understand  
3                   that. Again, some of these uncertainties was the  
4                   squish because of the behavior of TH. How am I doing  
5                   on time?

6                   CHAIR REMPE: You're a little bit over but  
7                   I know you only have a couple more slides so let's let  
8                   you finish and then we'll take our break then.

9                   DR. AZARM: Okay. I think this slide  
10                  shows an actual analysis of one loop. Just for your  
11                  information, in Westinghouse plant, they did not  
12                  differentiate it when they did the TH analysis which  
13                  when looked at pressurize and look without pressurize  
14                  it.

15                 In C plan the TH or the temperature of the  
16                 hot leg tube, et cetera, depends if you are in the loop  
17                 with the pressurizer or you are not in the loop with  
18                 the pressurizer.

19                 This slide shows an actual analysis of one  
20                 loop, loop without pressurizer of a C plan. In this  
21                 analysis the criteria for C-SGTR leak area for the plant  
22                 is set at six centimeters square or for one loop it's  
23                 set at three centimeters squared.

24                 The result clearly shows that there is a  
25                 competition or race between the RCS failure and the

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1 C-SGTR with leak area greater than three centimeters  
2 squared. Therefore, containment bypass probability  
3 will be relatively high, it's expected to be around 0.5.  
4 It basically talks about when we look at --

5 CHAIR REMPE: You should use the mouse and  
6 point with the screen because the transcriber can't get  
7 your comments.

8 DR. AZARM: When we look at the  
9 probability that RCS survive, let's take a number,  
10 46,500. The probability that RCS survive is 0.55 so  
11 the probability of RCS failing is 0.45.

12 And you will see that the probability of  
13 C-SGTR to just exceed the three centimeter squared,  
14 that criteria, is around the same thing. So at that  
15 point I have a probability -- No. I have to actually  
16 do conversion and integrate over time. I'm just making  
17 it very simple. So there is a probability about 0.25  
18 just at that point.

19 So when you have a C-SGTR probability that  
20 is high, usually you see these two curves are very close  
21 to each other across of each other. And, you know, when  
22 they are separated, then the probabilities become low.  
23 Actual numbers that goes to PRA, they come from  
24 point-by-point integration of incremental probability  
25 so there's another routine in addition to calculator

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1       that does that post-processing calculations.

2               This is more confusing graph.       It  
3       basically now is trying to superimpose the 5 percent,  
4       25 percent, 50 percent leak area distribution over the  
5       RCS and try to tell you that at any point that you can  
6       calculate the probability of RCS failure you can  
7       actually calculate the distribution of leak area.

8               So that way you can, if you change your leak  
9       area criteria, you can calculate with the post-process  
10      the new number.   So those are the type of stuff we can  
11      do with the calculator.

12              Okay, my last slide.       We have a  
13      calculator.   We do some verification and validation on  
14      it.   We basically, many of the empirical distribution,  
15      they also have both testing as well as results  
16      published.   We try to compare them with them.   Many of  
17      them we also did it on MCAD on this input platform and  
18      compared the result.

19              And we asked Dr. Majumdar of Argonne  
20      National Laboratory to review it and commented and we  
21      tried to resolve his comment.

22              Be fair to him, when he reviewed the  
23      calculator, was in draft format and didn't have all the  
24      whistles and bells on it that it has today.   So he  
25      reviewed a version, earlier version of calculator.

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1           You heard about the use of ABAQUS this  
2 morning for at least trying to see if this hot leg  
3 failure is meaningful, is reasonable and that was  
4 talked by Dr. Iyengar. And that's basically the  
5 activity that was done for V&V. I think that's --

6           CHAIR REMPE: So predicted 50 percentile  
7 so you were right with the deterministic --

8           DR. AZARM: No, we weren't.

9           MALE PARTICIPANT: I think that was your  
10 papers right on the microphone.

11          DR. AZARM: Oh, sorry. I think, believe  
12 when he did his analysis, 50 percent was saying that  
13 the hot leg is going to fail at time T0 and he was  
14 basically coming up that hot leg was going to fail at  
15 least couple of minutes later. Am I correct or the  
16 reverse?

17          CHAIR REMPE: Okay. So MELCOR predicted  
18 a couple minutes later than the calculator or what are  
19 you -- I'm looking at the last bullet here, the 50  
20 percentile, so the predictions.

21          DR. AZARM: Yes, that is related to what  
22 Dr. Iyengar did.

23          CHAIR REMPE: So it was the ABAQUS in this.

24          DR. AZARM: ABAQUS. ABAQUS basically  
25 tried to use the same MELCOR. They did their own heat

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1 transfer. They did their own distress calculation  
2 accounting for the delta T, et cetera, and they tried  
3 to deterministically, because they cannot calculate  
4 any uncertainty, calculate a time of hot leg failure.

5 And they find out at least their number is,  
6 like, couple of hundred second low of 50 percentile.  
7 So he was basically saying for Westinghouse the C-SGTR  
8 probability is, what we are calculating is bounding  
9 because he's predicting that the hot leg is going to  
10 fail area. That was the last bullet.

11 CHAIR REMPE: Okay. I didn't understand  
12 both bullets were connected. Okay, let's take a break,  
13 right, and come back at 2:45. Thank you.

14 (Whereupon, the above-entitled matter  
15 went off the record at 2:28 p.m. and resumed at 2:47  
16 p.m.)

17 CHAIR REMPE: We're going to go back on the  
18 record, folks. And just before you start at about 3:30  
19 Corradini has got to go catch a plane, and so I may  
20 interrupt during your presentation just to ask him if  
21 he has any final comments if that's okay, and I  
22 apologize, but we're juggling with a lot of different  
23 people and their schedules.

24 MEMBER POWERS: Do you know that your  
25 conference is still on?

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1                   MEMBER BALLINGER: Yes, I was curious, I  
2 thought it hung up.

3                   MEMBER POWERS: Yes, I think it hung up.

4                   CHAIR REMPE: It did, and he, we're aware  
5 of it and he's trying to reconnect and that's why I was  
6 trying to see if he wanted to do it now.

7                   MEMBER POWERS: How unfortunate.

8                   CHAIR REMPE: It's a good thing he can't  
9 talk to you right now, Dana. Please start.

10                  DR. AZARM: I think Kevin wants to say a  
11 summary?

12                  DR. COYNE: Yes, just a quick -- Kevin  
13 Coyne, Research. Just a quick clarification, well I  
14 guess it's not even a clarification, but just to  
15 re-summarize this key point on how the calculator  
16 handles tubes and hot/cold/hottest.

17                  DR. AZARM: All right.

18                  DR. COYNE: So we get thermal-hydraulic  
19 input from Mike Salay.

20                  DR. AZARM: He's been most wonderful.

21                  DR. COYNE: He has three categories,  
22 average cold, average hot, and hottest. The way they  
23 broke that up was informed by the detailed work they  
24 did for the Westinghouse Plant earlier and then  
25 judgment from how the CE CFD work went, but they did

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1 not redo that work for CE, they just believe that's not,  
2 and I'll say it kind in the negative, not an  
3 unreasonable assumption to make for CE based on their  
4 experience with Westinghouse.

5 But that breakdown between average cold,  
6 average hot, and hottest wasn't redone for CE. It's  
7 informed from our work with Westinghouse. The  
8 calculator doesn't actually, you know, count tubes,  
9 what it does is when you generated flaw distribution  
10 from the data that we talked about earlier it will  
11 allocate those flaws into one of those bins based on  
12 a user set input into the calculator.

13 So the user could choose to put all the  
14 flaws in the hottest, all the flaws in the average hot,  
15 all the flaws in the cold, or some distribution of doing  
16 that.

17 For the work that Ali is going to talk about  
18 in the next section how that allocation went was 1  
19 percent in the hottest, 9 percent in the average hot,  
20 and 90 percent in the cold, again, informed by some of  
21 the earlier work done for the Westinghouse and some of  
22 the CFD work that was done.

23 That's a user input that could be changed  
24 to do sensitivity studies if need be.

25 MALE PARTICIPANT: Thank you.

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1 DR. COYNE: And I don't know if we said  
2 outside the significance of the six square centimeters  
3 is an equivalent to diameter, so which seem to be a  
4 reasonable presumption for when you have C-SGTR bypass.

5 CHAIR REMPE: Thank you.

6 DR. AZARM: All right. So now I'm going  
7 to try to explain what we have done as a part of  
8 simplified probabilistic risk analysis for estimating  
9 LERF due to C-SGTR.

10 And I'm going to discuss both for severe  
11 accidents and the so-called DBA accidents. However,  
12 the main focus of this study was on the severe  
13 accidents.

14 MEMBER BLEY: Excuse me. Let me ask a  
15 simple question, I don't remember. What part of this  
16 work was borrowed from previous PRAs and what part is  
17 new for this work?

18 DR. AZARM: What --

19 MEMBER BLEY: Could you use the existing,  
20 previous PRA and how much of it, or what parts have you  
21 changed?

22 DR. AZARM: Oh, okay. We will get to  
23 that.

24 MEMBER BLEY: Oh, okay, if it's coming  
25 that's fine.

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1 DR. AZARM: We basically for the  
2 identifying sequences of accidents we used IPEEE for  
3 Zion and Calvert Cliffs.

4 MEMBER BLEY: Okay.

5 DR. AZARM: So we went through them and we  
6 identify sequences that you are interested and then we  
7 try to work in the LERF into it.

8 MEMBER BLEY: Okay.

9 DR. AZARM: So that was for the severe  
10 accident part. For the other one, the DBA one we used  
11 the stylized analysis, and I talked about it.

12 MEMBER STETKAR: You didn't look at how  
13 the existing PRAs that you looked at might not have  
14 identified all of the conditions that could lead to  
15 this, did you?

16 DR. AZARM: No.

17 MEMBER STETKAR: Let me get to the point  
18 that I'm going to make.

19 DR. AZARM: Okay.

20 MEMBER STETKAR: I have a 2-train plant,  
21 two steam generators. Something happens that causes  
22 a plant to trip and my atmospheric relief valves open  
23 on both of those steam generators, as they would,  
24 there's no reason to believe that one would open versus  
25 two.

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1 DR. AZARM: Okay.

2 MEMBER STETKAR: And one of them sticks  
3 open. What do the operators do? Here's a question for  
4 you, what do the operators do? You know the answer to  
5 this right away, right?

6 The operators are instructed to  
7 immediately isolate all feedwater flow to a faulted  
8 steam generator. They will do this, I have a faulted  
9 steam generator.

10 So they will immediately isolate all  
11 feedwater flow to that steam generator leaving that  
12 steam generator open to the atmosphere with no water  
13 in it, leaving one steam generator left to cool the  
14 core, and there's a whole bunch of ways I can get the  
15 core to melt after that.

16 Now how does the PRA that you used look at  
17 those scenarios? The answer, it doesn't. It looks at  
18 it perhaps from the perspective of a spuriously open  
19 safety relief valve on the secondary side as an  
20 initiating event, which is one of your so-called design  
21 basis initiating events.

22 But it doesn't look at a risk assessment  
23 that says how confused are the operators going to be  
24 now if they're starting to get into trouble where they  
25 followed the procedures, they've had an event, a safety

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1 injection that occurs because it had an overcooling  
2 transient, and they have a whole lot of other stuff  
3 going on.

4 You presumed that the operators behave as  
5 if this is an initiating event that starts by the valve  
6 opening by itself or that somehow you can model this  
7 as a station blackout with failure of the  
8 turbine-driven aux feedwater pump, which it certainly  
9 isn't.

10 The question is is in terms of drawing  
11 conclusions about the risk implication of these induced  
12 tube rupture events, consequential tube rupture  
13 events, with large early release fraction, fraction  
14 contribution to large early release frequency, I  
15 maintain that the risk assessments that you've used are  
16 incomplete.

17 Now how important they are I don't know  
18 because I have never done a PRA. I've been advising  
19 people to put these overcooling transients into the  
20 model because they can cause problems that increase the  
21 core damage frequency and perhaps increase the large  
22 early release frequency because of consequential tube  
23 rupture over the last four or five years, but I haven't  
24 seen anybody who's actually done it.

25 Now I haven't done it in any of the studies

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1       that I've ever done.

2                   DR. AZARM:   It's a very good question.

3                   MEMBER STETKAR:   So I don't know and  
4       that's the whole point I'm getting to in terms of trying  
5       to draw conclusions about how important might this be  
6       based on the snapshot of particular scenarios that  
7       you've taken from preexisting PRAs.

8                   DR. AZARM:   Okay.   Let me see if I -- Okay.

9                   MEMBER STETKAR:   And that's --

10                  DR. AZARM:   -- can shed some light to them.

11                  MEMBER STETKAR:   -- because that doesn't,  
12       none of what I said changes anything to do about some  
13       of the stuff that I missed, either the  
14       thermal-hydraulics or the materials properties.

15                  It does change some of the timing I think  
16       in terms of the relatively likelihoods of hot leg  
17       rupture versus larger releases.

18                  DR. AZARM:   Okay.   Let me see if I can shed  
19       some light, and I'm sure we have not covered all the  
20       bases.

21                  We actually did look at a spurious  
22       actuation of a steam generator relief valve as an  
23       initiator. We did understand that a steam generator  
24       is considered faulted.

25                  MEMBER STETKAR:   Okay.

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1 DR. AZARM: And we did understand that the  
2 plan is going to behave that it got a main steam break  
3 and the operator is going to go and try to close the  
4 high pressure injection because there is no reason to  
5 inject SI because of the overcooling.

6 Anyway, we were, and then we said what if  
7 I get a tube rupture because of this large delta P I  
8 have caused on the steam generator to fault.

9 MEMBER STETKAR: Yes.

10 DR. AZARM: Now I have something that acts  
11 like a main steam line break, at the same time has a  
12 steam generator tube rupture in it, and the operator  
13 is already confused because early on he had to stop  
14 injection, now he has to turn it on.

15 We did that but not on the severe accident  
16 --

17 MEMBER STETKAR: Not on the severe. See  
18 that's my concern, yes.

19 DR. AZARM: On the design basis accident.

20 MEMBER STETKAR: Yes. I'm transitioning  
21 from, I don't like this severe accident design basis,  
22 I'm just trying to paint a scenario for you.

23 DR. AZARM: Yes. Even though the DBA,  
24 so-called DBA accident was not our focus we did try to  
25 look at a series of them.

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1                   MEMBER STETKAR: I saw that, but most of  
2 what you focused your results and conclusions are on  
3 that severe accident which focuses, in my  
4 understanding, if not exclusively, primarily on the  
5 station blackout with two different findings of the  
6 turbine-drive aux feedwater pump failure.

7                   DR. AZARM: Okay. I will try to -- And you  
8 are right.

9                   MEMBER STETKAR: And then adding SAMG  
10 space though, but in SAMG space and SAMG timing operator  
11 actions to perhaps depressurize to get a low pressure  
12 feed into the steam generator or something like that.

13                   But, again, it's a timing issue. It's not  
14 the same scenario context that I painted originally.

15                   DR. AZARM: Yes. No, I fully agree that  
16 when NRC came to us the main focus was that core damage,  
17 onset of core damage has already occurred --

18                   MEMBER STETKAR: Yes.

19                   DR. AZARM: -- and you have finished Level  
20 1 and you just want to see the conditions of the --

21                   (Simultaneous speaking)

22                   MEMBER STETKAR: But see the thing that I  
23 took issue with in the NUREG, the draft NUREG, there  
24 are certain statements that says well, if you have a  
25 Level 1 PRA and a Level 2 PRA it's easy to identify these

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1 intermediate states.

2 And my point is that not from any PRA I've  
3 ever seen yet, because none of them that I've seen  
4 challenged this. They all look at do I have enough  
5 steam release yes or no, and if I have enough steam  
6 release few of them ask do I have too much and what  
7 happens if I have too much, in terms of it, well I call  
8 it plain vanilla transient response.

9 DR. COYNE: And just so I understand,  
10 because I think we've talked about this with similar  
11 scenarios on another project.

12 MEMBER STETKAR: We have, on another  
13 project that's true.

14 DR. COYNE: So the case that we would have  
15 is a core damage event with a faulted but isolated steam  
16 generator.

17 MEMBER STETKAR: Faulted but isolated  
18 steam generator, right.

19 DR. COYNE: And one or more steam  
20 generators with presumably aux feed availability so the  
21 aux feed system is available however there might be  
22 other reasons if you get into a core damage scenario  
23 such as RCPC.

24 MEMBER STETKAR: Aux feed could later go  
25 away to the remaining steam generators. I mean I don't

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1 know how we get to core damage on this.

2 DR. COYNE: Right.

3 MEMBER STETKAR: I'm not trying to --

4 DR. COYNE: So I think a short answer would  
5 be the way they count or identify the scenario is if  
6 you lose aux feedwater that would be counted as  
7 something that would lead to a dry steam generator  
8 condition.

9 I think the more difficult one to count are  
10 the cases where you don't lose aux feedwater. Say you  
11 have this case where you may have one dry steam  
12 generator --

13 MEMBER STETKAR: That certainly would be  
14 more difficult.

15 DR. COYNE: Right. And that is just --  
16 I'd agree that would be difficult to find in the PRA  
17 where you actually have done a thermal-hydraulic  
18 analysis to see how that --

19 MEMBER STETKAR: What I don't know, and I  
20 don't know whether it was covered when I was out so  
21 excuse me if it was.

22 What I don't know is, I know that you've  
23 assumed that a steam generator without feed is  
24 depressurized, is that statement throughout, but it  
25 says that the assumed whatever it was sized break was

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1 enough to depressurize you to get a delta P across the  
2 tubes but not enough to I think depressurize the primary  
3 side, or something like that.

4 In other words, I don't know what, the  
5 thing I'm trying to understand is if I go to core damage,  
6 however I got there, with a stuck open dry, a dry steam  
7 generator with an open atmospheric relief valve, or  
8 safety valve, atmospheric relief valve, is the timing  
9 of hot leg rupture under that case different from the  
10 conditions that were used for your station blackout  
11 core damage progression because of the presumed  
12 pressure in the secondary side of the plant, given the  
13 assumed whatever it is, half square centimeter or  
14 whatever it was, break is not nice, but leakage?

15 DR. AZARM: Mike had a set of runs which  
16 we didn't like very much, but what he did, he assumed  
17 for the secondary side SRVs stuck open at the beginning  
18 of transients.

19 MEMBER STETKAR: Okay.

20 DR. AZARM: And then he did that run, the  
21 situation got worse.

22 MEMBER STETKAR: I've read those words,  
23 yes.

24 DR. AZARM: And when recalculated the  
25 conditions of C-SGTR probability, instead of the normal

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1 0.22 we got 0.99. So --

2 MEMBER STETKAR: Well, and it would go to  
3 a large early, a larger release also because the whole  
4 core is a fail. It's a --

5 DR. AZARM: Right, yes. Yes, there is a  
6 run done like that and, you know, I heard this morning  
7 or this afternoon they quoted CES.22, but that's for  
8 various stylized --

9 MEMBER STETKAR: Yes, that's --

10 DR. AZARM: When we did this specific  
11 scenario with SRV open we get 0.99 for CE plant. Now  
12 we didn't have a Cleveland run --

13 MEMBER STETKAR: For Westinghouse.

14 DR. AZARM: -- as we did for Westinghouse.

15 MEMBER STETKAR: Couldn't we presume it  
16 would be higher than the 10 to the minus 2 --

17 DR. AZARM: Going to be higher, yes.

18 MEMBER STETKAR: You don't know how much  
19 higher, yes. Okay. This, by the way, the reason I  
20 said 2-train plant, it's a much bigger issue on a  
21 2-train plant.

22 Your conditional core damage probability  
23 given, especially when you start throwing in possible  
24 operator responses is a lot higher. But a 4-loop plant  
25 like, you know, the design plant, some more forgiving.

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1 DR. AZARM: Yes.

2 MEMBER STETKAR: You know, you're not  
3 going to get all of the valves stuck open on all the  
4 steam generators for example.

5 DR. AZARM: Anyway, this slide is very  
6 simple. It basically says there was an NRC/NRR user  
7 request. In response to that they have put together  
8 a draft NUREG together and it involves several  
9 different offices of NRC Research to pull this together  
10 and integrate it.

11 What was the objective of this simplified  
12 PRA analysis? Just basically they wanted a  
13 quantitative assessment, simplify for the use of NRR,  
14 that can address the C-SGTR during a severe accident  
15 after the onset of core damage and during a DBA event  
16 before the onset of core damage.

17 We wanted to have some simpler way to  
18 calculate the change in LERF and core damage  
19 probability due to containment bypass and they want it  
20 to be piloted on Westinghouse and CE, and later on a  
21 guide to be written that has not yet been written.

22 And there are a couple of terms that needs  
23 to be defined, C-SGTR I put in blue means a leakage that  
24 are greater than the threshold value of some leak area  
25 before a large vent path in RCS is established.

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1                   This vent path could be either due to the  
2                   component failure at hot leg or surge line or could be  
3                   intentional depressurization. Of course, LERF is a  
4                   C-SGTR that happened within the first ten hours.

5                   MEMBER STETKAR: But LERF, and Kevin help  
6                   me out, LERF in this study is defined as something  
7                   before you have confidence that 95 percent of the  
8                   population can be evacuated, right? Is that the  
9                   definition that you're using?

10                  DR. AZARM: That's the definition.

11                  MEMBER STETKAR: Okay.

12                  DR. AZARM: We are very much driven by  
13                  evacuation.

14                  MEMBER STETKAR: Yes.

15                  DR. AZARM: Okay. This basically gives  
16                  you an example, again, my notes doesn't read, of the  
17                  differences between what the distinction between the  
18                  C-SGTR after and before core damage.

19                  Occurrence of C-SGTR after core damage is  
20                  usually due to creep rupture high temperature. It can  
21                  contribute to LERF if RCS remains intact. Of course,  
22                  it cannot contribute to core damage because we assume  
23                  core damage has already occurred.

24                  On the contrary the C-SGTR before core  
25                  damage could occur due to pressure-induced, there is

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1 no reason for us to believe very high temperatures can  
2 be experienced.

3 It can lead to core damage and LERF so it  
4 can have delta increase in core damage on LERF exactly  
5 like some of the scenarios that Dr. Stetkar has  
6 mentioned.

7 An example of C-SGTR after the onset of  
8 core damage could be a fast or a short station blackout.  
9 This results in secondary side boil off establishment  
10 of counter current flow, hot leg, and onset of core  
11 damage, additional heat up and occurrence of C-SGTR  
12 when RCS is intact.

13 This is what you heard a lot this morning,  
14 so there's nothing really new in this slide. This is  
15 a pictorial that shows the timeline of various events  
16 and classification of them, or classification of  
17 releases into LERF.

18 It also highlights in some cases the C-SGTR  
19 may occur prior to hot leg failure, but is not of  
20 sufficient size to depressurize the primary so a hot  
21 leg could fail shortly after, and I think that's Case  
22 3.

23 The selection of critical C-SGTR area  
24 should ensure that sufficient depressurization would  
25 fall opposed to a failure. So you started, I think a

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1 couple of things, one, the point about evacuation was  
2 mentioned earlier, and, two, a consideration that why  
3 we are choosing six centimeters squared.

4 What is example of C-SGTR before core  
5 damage? I tried to give one example, blow down of one  
6 steam generator, rapid and complete blow down, delta  
7 pressure across tube increases almost by a factor of  
8 two, affected steam generator is dried out, operator  
9 fails to isolate the affected steam generator, primary  
10 remains high pressure and high pressure system  
11 continues to inject.

12 One or more tubes may rupture if they have  
13 deep flaws. Again, the condition as you will see, the  
14 calculator tells us don't worry about the small flaws,  
15 you need to have a really deep flaw for this to happen.

16 Operator might have turned off or stopped  
17 HPI. Now in the accident sequence not that he has a  
18 small LOCA to a steam generator tube rupture, he has  
19 to reestablish HPI and if he doesn't do that, for  
20 example, as an example if operator fails to do that then  
21 now you have a LOCA going outside to an open SRV, core  
22 uncovers, you get a fast core damage, and you are going  
23 to contribute to both CDF and LERF.

24 So, yes, this type of scenario you can find  
25 in the PRA and we kind of tried to bound it when we did

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1 the DBA or before core damage scenario.

2 CHAIR REMPE: Okay. So I think this is  
3 the time, if you don't mind before you go to the next  
4 slide, Mike, if you're out there and --

5 MEMBER CORRADINI: I'm out here. What's  
6 up?

7 CHAIR REMPE: Do you want to give like --  
8 Because I know you're going to be leaving soon to catch  
9 your plane, did you want to break in and provide some  
10 comments that we normally go around and get from people  
11 who attend?

12 MEMBER CORRADINI: Well I don't want to  
13 interrupt. I can stay on for a while longer and maybe  
14 there's a more natural breakpoint in about 20 minutes.

15 CHAIR REMPE: Why don't you just do it now?

16 (Simultaneous speaking)

17 MEMBER CORRADINI: Why don't we all just  
18 let John go after him again?

19 CHAIR REMPE: Do you have any insights?  
20 Actually, I would assume with respect to the  
21 thermal-hydraulics and the materials we discussed  
22 earlier today that you wanted to convey --

23 MEMBER CORRADINI: Well I think, I guess  
24 my general comment is I know the Staff has done a lot  
25 of work over many years trying to advance this.

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1 I think what at least the current NUREG  
2 and, the draft NUREG, excuse me, as it sits is that it  
3 still needs some additional -- I'm sorry, I'm getting  
4 a lot of background noise, is that me?

5 (Simultaneous speaking)

6 MEMBER CORRADINI: Is that me, I  
7 apologize, I'm on a handset.

8 CHAIR REMPE: I don't see anybody moving  
9 any papers here.

10 MEMBER CORRADINI: Okay, all right. But  
11 I guess my only point was the draft NUREG still needs  
12 to be further improved in terms of clarity and that's  
13 probably my overall comment.

14 There was a number of questions we had  
15 relative to the thermal-hydraulics and I think as we  
16 asked the questions Staff did a very good job of trying  
17 to explain where things were coming from, it just was  
18 hard to pull that out from the NUREG itself.

19 The second general comment, in terms of  
20 understanding, if this is going to be the last report  
21 in terms of the generic C-SGTR work and the next  
22 application would be the Level 3 PRA for Vogtle, it  
23 seems to me that there's got to be a story to be told  
24 at the beginning of this to see how it can be utilized  
25 and that's kind of missing. So I'll stop there.

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1 I think it's appropriate to make those  
2 changes prior to issuing it for draft for outside  
3 comments, but I don't want to push the issue, I just  
4 think staff would probably want to have a cleaner  
5 version before they go out to have additional comments  
6 from industry and stakeholders. That's it.

7 CHAIR REMPE: Okay, thank you. And,  
8 again, I apologize for interrupting, but I appreciate  
9 your tolerating it.

10 DR. AZARM: No problem.

11 CHAIR REMPE: Go ahead.

12 DR. AZARM: Okay. Now what is the steps  
13 in this simplified PRA analysis are now just focusing  
14 on the severe accident part. Later on I'm going to come  
15 back and do this with the so-called DBA part.

16 We have kind of a 7-step process. First  
17 we select accident sequences then we try to determine  
18 the TH characteristics of those sequences, or at least  
19 bound them, consider a single flaw and get some idea  
20 of that what are the size of flaw that can fail in the  
21 steam generator tube, where should be our focus, and  
22 you will see why we are doing that, because if you try  
23 to run the calculator with many samples of flaws it's  
24 going to take a long, long time so you better have some  
25 idea that where is the region that that is done in a

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1 contributor.

2           Depending on what you get from the  
3 screening analysis of flaw you generate samples of flaw  
4 that probabilistically can support your analysis, you  
5 perform case runs and post processing and then you  
6 estimate your containment bypass probability and then  
7 you look at your timing and calculate your LERF.

8           Now I'm going to go through each of these  
9 steps in an overview fashion. Okay, focusing on C-SGTR  
10 for severe accident, and the first is that we need to  
11 identify the core damage sequences that are identified  
12 with high primary pressure, dry secondary side.

13           As you saw, at least for the severe  
14 accident, they are considering most of term to be low  
15 secondary pressure. If Level 2 PRA are available, and  
16 we had a case that they were available in one of our  
17 pilots, we can basically look at those two questions  
18 because these are part of PDF identification for Level  
19 2 analyses and get the frequency of the sequences of  
20 interest.

21           If Level 2 PRA is not available then we have  
22 to go through Level 1 PRA, examine the dominant  
23 sequences for both internal and external event and try  
24 to identify that core damage sequence is that the  
25 primary was high pressure and a steam generator was dry,

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1 more so if the core damage after feed and bleed comes  
2 though that category, most of the station blackout  
3 scenarios come under category.

4 You have to make sure to look at external  
5 event as internal event and also you have to think,  
6 because remember if you talk about SBO these are  
7 multi-unit issue, so if you have multiple unit on one  
8 side and you have seismic event, most probably both are  
9 going to experience SBO, most probably, or the good  
10 probability both are going to go through the cycle  
11 scenarios and both are going to get a steam generator  
12 tube rupture, so somehow you have to keep track of  
13 multi-unit effect.

14 I'm not going to go through detail, I'm  
15 basically showing you we went through the two prior,  
16 the Zion and Calvert Cliffs and we looked at internal  
17 events, seismic, fire, flood, and I think in the case  
18 of Calvert Cliffs they had high wind, tracked a group  
19 of the sequences we found under short term SBO and long  
20 term SBO.

21 It doesn't mean they were exactly short  
22 term, it's more long term, but to group them on those  
23 two categories, and basically what we got, we typically  
24 got 2 times ten to the minus 6, this is from IPEEE's  
25 and their updates.

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1                   For short term SBO and about 2 times 10 to  
2                   the minus 5 for long term SBO, and it's consistent for  
3                   both of them. Now it was a little bit surprising to  
4                   us because kind of Calvert Cliffs was addressing some  
5                   of the common initiator issues in multi-unit core  
6                   damage and when you look at that they had fires, seismic  
7                   that dominated short-term SBO and long-term SBO  
8                   affecting both units.

9                   So, again, we captured that, I am showing  
10                  that, but really at the end we looked at one unit or  
11                  more, so we didn't look at the 2-unit risk. So that  
12                  led to step one in PRA to find a frequency and a class  
13                  of sequences that you want to start doing your  
14                  calculation with and that comes from existing PRAS, at  
15                  least for the severe accident side. For the DBA side,  
16                  no, it's a different story.

17                 Now the next thing is that the TH  
18                 characteristics for these sequences and, you know, we  
19                 can say we want many other sequences, but what was  
20                 available basically is a base-case for short-term SBO  
21                 and for Westinghouse or Zion based on a RELAP/SCDAP.

22                 I tried to basically, SBO with early  
23                 failure of TDAFW. The base case assumes 21 gpm RCP  
24                 leakage. Also, the base-case assumes 0.5 square inch  
25                 hole in the secondary side, which is sufficient to

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1 depressurize you before any, a steam generator tube  
2 rupture occurs and no recovery of AC power.

3 Long-term SBO is the same thing. If the  
4 turbine-driven AFW fails after battery failure, they  
5 have assumed that battery depletion is at four hours  
6 and we know that sometimes they can drag it to six hours  
7 or eight hours by load shedding and other stuff.

8 And as SCDAP ruled out there was a bunch  
9 of sensitivity analyses that was performed, they did  
10 sensitivity analysis based on RCP seal leakage rate.  
11 They went all the way to 450 gpm per pump.

12 That was important because in one case that  
13 they put 450 gpm RCP leakage it cleared the seal. So  
14 according to the SCDAP/RELAP analyses the seal clearing  
15 should happen somewhere between 350 gpm leakage of RCP  
16 450.

17 It doesn't happen in any other condition.  
18 They put a little bit larger hole in the secondary side,  
19 including open, the steam generator SRV and ARV, they  
20 take on that some of the threshold of leakage area and  
21 they did rapid early depressurization to show that the  
22 hot leg did not fail.

23 You have seen this result this morning.  
24 Again, this graph shows information we used for the PRA  
25 and calculator software.

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1                   We used hot leg temperatures, shown in red.  
2                   Average hot tube temperature, shown in green.   Primary  
3                   P, secondary P, and actually we should have also the  
4                   hottest fuel, but I don't think I'm showing it here.

5                   CHAIR REMPE:   The blue line, the hottest  
6                   tube, it's on there.

7                   MALE PARTICIPANT:   The blue.

8                   DR. AZARM:   Oh, it's the blue, okay.   All  
9                   right, I am showing that.   The important thing you  
10                  know, and we talk about that several times, after 1500  
11                  minutes, or whatever, 1600 minutes, 160 minutes, what  
12                  am I talking about?

13                  Really   nothing   is   happening.       It's  
14                  basically your steam generator going dry 2-1/2 hours,  
15                  2 hours the steam generator goes dry, et cetera.   And  
16                  then you'll start using water until you get to core  
17                  uncovery and once the onset of core damage happens you  
18                  will see in a few minutes you will start getting  
19                  zircaloy oxidation and everything shoots up.

20                  So if you look at here, somewhere between  
21                  180 to 214 minutes everything should be over.   So,  
22                  again, this is, and usually nothing happens frankly  
23                  after you are going to the temperatures above 800  
24                  degrees C.

25                  So actually the situation is worse than

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1       that.  It's a much shorter time, usually within ten  
2       minutes everything is over.  The other thing that you  
3       have to notice, just notice in this region the  
4       difference between the temperature of hot leg and the  
5       temperature of the hottest fuel or average hot tube.

6               There is a big, about 400 degrees C  
7       difference between them.  So it says hot leg is really,  
8       really hot.

9               CHAIR REMPE:  That gets more cleanup  
10      there, that's why --

11              (Simultaneous speaking)

12              CHAIR REMPE:  Actually, that brings up  
13      another question, and maybe Mike needs to answer it,  
14      but I guess there is a MELCOR stainless steel oxidation  
15      model, and is it turned on so you'd even see it?

16              I'm guessing it doesn't consider any  
17      blocking because of hydrogen in the system, but has this  
18      been considered at all?

19              DR. SALAY:  To my knowledge it wasn't  
20      considered, the stainless steel oxidation.  I don't  
21      think the model is activated, but I'm not sure.  I'd  
22      have to check for that.

23              CHAIR REMPE:  Okay.  Again, this might be  
24      another example of something that should be clarified  
25      what the document did or didn't do and maybe it can be

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1 ruled out because you can say yes, there's hydrogen in  
2 the hot leg that didn't go to the top of the vessel or  
3 whatever, but it would be nice to know if that's been  
4 looked at.

5 DR. SALAY: Right.

6 CHAIR REMPE: Thanks.

7 DR. AZARM: So that was the SCDAP/RELAP  
8 and this is the MELCOR one. No, I'm sorry. I'm sorry,  
9 this is just I draw it different. This is the long term  
10 station blackout. It's still a SCDAP/RELAP.

11 Here we will see the activities or the  
12 interesting part happens after 800 minutes, which is  
13 like 12 hours because you had turbine-driven AFW  
14 running for four hours and another two hours for the  
15 steam generator to dry out.

16 And most of the time we have done quite a  
17 bit cool down by that time, so that's why it delayed  
18 so much. But you will see, notice the same behavior  
19 if you look at your hottest fuel and average hot tube  
20 compared to hot leg, 800 degrees it starts shooting up  
21 and goes up very fast.

22 Next I am going to talk about MELCOR and  
23 Calvert Cliffs and just see the difference. They  
24 basically run a two base-case of short-term SBO and long  
25 term SBO.

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1                   They had I believe two sensitivity  
2 analyses, one was what I said earlier, they assume all  
3 this always is stuck open at times zero, that was one  
4 sensitivity analysis that basically gives us almost  
5 probability of one of C-SGTR.

6                   And they did some analysis with the RCS  
7 component, fail or not fail, a suppression trip  
8 rupture, et cetera.

9                   MEMBER STETKAR: Are you going to address,  
10 I don't know when or if, something I brought up this  
11 morning about uncertainties in these various  
12 temperatures and times, and I don't -- Are you going  
13 to address that?

14                  DR. AZARM: We did address as a part of  
15 calculator the uncertainties almost for everything  
16 except the TH analysis.

17                  MEMBER BALLINGER: But what you said was  
18 you identified the uncertainties. You didn't say "I  
19 addressed them."

20                  MEMBER STETKAR: If you go back to -- Let  
21 me see if I can ask it in the context of the picture,  
22 if you go back to three or four slides. Yes, that's  
23 good.

24                  This leads me to believe that the hot leg  
25 always heats up faster and more dramatically than the

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1 hottest steam generator tube, therefore, reinforcing  
2 the notion that the hot leg is going to fail first, but  
3 maybe not by much in time.

4 So the question is, what uncertainties are  
5 there in that timing such that if I have two  
6 distributions in time and I look at the inner section  
7 of those distributions where the intersection measures  
8 the likelihood that the tube heats up faster than the  
9 hot leg, have you looked at that?

10 DR. AZARM: Let me see if I can --

11 MEMBER STETKAR: If I could put it into  
12 words that way.

13 DR. AZARM: -- give you that picture.  
14 This is showing the survival probability. It's kind  
15 of like the two PDF but it's showing it in terms of  
16 cumulative.

17 When you look at Westinghouse there might  
18 be something to section in the tails that you would  
19 integrate over the time and then, you know, there are  
20 some other stuff.

21 So it's very low. It's not -- Even with  
22 the uncertainties we have included that does not  
23 include the TH uncertainty. With the uncertainties we  
24 have included we don't see that in Westinghouse.

25 Look at comparatively for even good case

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1 of CE Plant, you will see that overlap, and that's what  
2 in post processing you use for calculating the C-SGTR,  
3 but we'll get to that.

4 DR. SALAY: Yes. I also want to mention,  
5 although I wasn't involved in the steam generator  
6 action plan they looked at -- This is Mike Salay, the  
7 NRC -- that they tried to look at many different things  
8 in TH that may affect what fails first.

9 And from my understanding based on the flow  
10 patterns that you get the timing of when you start to  
11 heat up may vary a lot, but they seem to get a pretty  
12 consistent failure of the hot leg first unless you had  
13 two, because it's the same temperature as when you start  
14 rising the temperature they both rise at about the same  
15 time and it really depends on how the flows go around  
16 inside.

17 MEMBER STETKAR: Okay.

18 DR. AZARM: I think you'll see that in this  
19 picture, this is, just keep what you saw in Westinghouse  
20 in mind and now look at the CE results for MELCOR.

21 I tried to kind of keep the same colors,  
22 but look at your hot leg and look at your hottest tube.

23 MEMBER STETKAR: Yes.

24 DR. AZARM: They're basically tracking  
25 each other.

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1                   MEMBER STETKAR: No, and I'm not arguing  
2                   Westinghouse versus Calvert versus CE. I'm asking  
3                   about within the context, for example, it's clear for  
4                   the CE that any uncertainty would certainly affect the  
5                   conclusions.

6                   What I'm asking about is what's the extent  
7                   of the uncertainty in the Westinghouse where one  
8                   example you showed seemed to indicate that there might  
9                   not be, that you'd have to have very large uncertainties  
10                  to get much of an intersection.

11                  On the other hand, if I go back to that  
12                  slide, you know, Page 106, on my handout here, four or  
13                  five before that, it doesn't to me look -- The one before  
14                  that, even this one is the same.

15                  I'm looking at hundreds of minutes here and  
16                  on that scale, you know, I'm within ten minutes or less,  
17                  you know, on those slopes. They seem pretty close to  
18                  me.

19                  CHAIR REMPE: And this was done with  
20                  SCDAP, which has certain melt progression models, and  
21                  if, again, so you have certain assumptions on how the  
22                  core heats up in blocks or whatever, but if you went  
23                  to the CE Plant that was done with MELCOR, which has  
24                  assumptions, now they've been benchmarked sort of  
25                  against each other but I don't know.

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1           Are there going to be some differences in  
2           the heat up because it's a MELCOR analysis versus a  
3           SCDAP core heat up analysis? And so if you've done the  
4           Westinghouse with MELCOR would you get the same method  
5           uncertainties?

6           MEMBER STETKAR: The only reason I bring  
7           this up is to me there's a lot of analogies in the way  
8           we do seismic stuff.

9           If you just look at point estimate  
10          fragility, mean fragility and mean hazard you might  
11          conclude that there is low likelihood of something  
12          failing.

13          On the other hand, if you looked at the  
14          uncertainties the whole analysis is out in the  
15          uncertainties if you don't treat the uncertainties  
16          correctly or reasonably.

17          DR. SALAY: I'll admit you can't treat  
18          them correctly.

19          MEMBER STETKAR: Reasonably you're going  
20          to have optimistic results.

21          MEMBER POWERS: I fully --

22          MEMBER STETKAR: So that's the only I'm  
23          asking about here is how carefully did you think about  
24          the uncertainties in these different times in the  
25          models to support those times.

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1                   MEMBER POWERS:    I wonder -- I fully  
2                   support your concern about the uncertainties, but I  
3                   would like, you know, if what you see in this block,  
4                   the hot leg, the surge line, and the tubes coming up  
5                   to temperature fairly shortly, but that said, the  
6                   temperature is not in the condition it is when it gets  
7                   up to a temperature where a creep rupture becomes very  
8                   broad, and in a case the hot leg would cross that  
9                   temperature during the rise, whereas you don't cross  
10                  these temperatures in the other locations to  
11                  substantially in the clean parts of the legs.

12                  And so the sharp rise might fool you that  
13                  it's really not the 10-minute gap where everything's  
14                  coming up, it's where the hot leg comes up versus the  
15                  60 minutes later when the --

16                  I mean the way the creep rupture works in  
17                  these things is slow, slow, slow, bing, it just goes  
18                  and so don't let that fool you. Nevertheless, your  
19                  point is correct.

20                  But I think that when you go through the  
21                  details of analysis they quickly come to the conclusion  
22                  that it's how much mixing we get in the lower plenum  
23                  that really controls all of these temperatures in the  
24                  tubes whereas the hot leg is really controlled by what  
25                  goes on in the core.

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1 MEMBER STETKAR: Okay.

2 DR. AZARM: And just one point of  
3 correcting the opinion, I am not going to say that the  
4 uncertainty evaluation done is 100 percent complete,  
5 but when I see the Westinghouse shift is so large I think  
6 even with the incompleteness of our uncertainties we  
7 have I certainly do not change my position in the  
8 Westinghouse --

9 MEMBER STETKAR: And I'm not advocating  
10 trying to, you know, do a perfect uncertainty analysis  
11 here. I'm trying to understand how broad those  
12 uncertainties might be and where there might be areas  
13 of overlap that haven't been considered.

14 And the uncertainties might be broad, but  
15 as long as there's enough margin I'm not worried about  
16 a minuscule part of overlap. That's all, so I'm trying  
17 to sort of probe to see how much of that thought had  
18 been put into the analyses or how much you thought about  
19 it outside of the context of what's written in the  
20 report anywhere.

21 MEMBER POWERS: Well I think I do share  
22 with Dr. Rempe the concern and within the computer codes  
23 themselves there are probably capable of the  
24 performing. Assumptions have been made that could  
25 affect the calculations, and certainly the entropy, the

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1 gas coming into the piping system.

2 They are assumptions that are made and  
3 developed into codes so operating the codes that were  
4 made were not, nobody ever wrote it down exactly what  
5 they were thinking.

6 With time they are carried on by tradition  
7 and things like that --

8 MEMBER STETKAR: Well and they may have  
9 been made --

10 MEMBER POWERS: You don't know what they  
11 are.

12 MEMBER STETKAR: You don't know where they  
13 are and they may have been made for other purposes.

14 MEMBER POWERS: Oh, yes, I would agree.

15 MEMBER STETKAR: Theoretically a  
16 conservative treatment of some other issues.

17 MEMBER POWERS: But what happens is the  
18 codes, things get developed and sequences don't and the  
19 issue of induced steam generator was not on anybody's  
20 mind when the code was written.

21 MEMBER STETKAR: Right, yes.

22 MEMBER POWERS: And some of these things,  
23 you know, a comprehensive uncertainty analysis to  
24 identify is a formidable job.

25 CHAIR REMPE: It is, but if there is a

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1 difference that is just because of what MELCOR would  
2 predict versus SCDAP and we're saying oh, the CE Plant's  
3 worst, is it because, is there something that's  
4 different in the way those codes are predicting the  
5 scenario that would show --

6 MALE PARTICIPANT: No, I think --

7 MEMBER POWERS: I mean I think we trace it,  
8 like I say, back to the mixing in the lower plenums would  
9 get you into trouble.

10 CHAIR REMPE: Well then the CFD analysis  
11 would justify that, but I'm just wondering about time  
12 because I don't have --

13 MEMBER POWERS: No, I don't think, I mean  
14 you just don't see how you alter that conclusion by  
15 changing the accident analysis very much because it's  
16 really an entity of dilution that's affecting --

17 CHAIR REMPE: But if it were done -- Okay,  
18 but if the BWR with MAAP and MELCOR we know that it does  
19 delay in how the melt progression occurs.

20 MEMBER POWERS: That one would shift  
21 everybody, okay?

22 CHAIR REMPE: Yes.

23 MEMBER POWERS: To shift CE versus  
24 Westinghouse you got to have something very imaginative  
25 to even see, but it's hard to see how you get into that

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1 trouble if you ask me. I mean that's --

2 MEMBER STETKAR: In the code world.

3 MEMBER POWERS: Yes.

4 CHAIR REMPE: Okay.

5 DR. AZARM: Also there's a good news. I  
6 always like to look at the good news --

7 MEMBER STETKAR: Why?

8 DR. AZARM: The good thing is that these  
9 are coming from a code. So the hot leg temperature is  
10 going to drive your hottest tube temperature, so all  
11 of these curves are correlated. We know they are.

12 So even if the curves are shift, they're  
13 relative two times is still, you know, there are, you  
14 are right, the big margin between the two --

15 MEMBER STETKAR: That hurt. Yes, it's  
16 still, you know, the shift does this.

17 DR. AZARM: Yes.

18 MEMBER STETKAR: What I'm worried about is  
19 how far apart these distributions are.

20 DR. AZARM: Yes. But, you know, the  
21 margin I think is the main thought process we have  
22 regarding Westinghouse.

23 MEMBER STETKAR: Okay.

24 DR. AZARM: Okay. I am now in the step  
25 three of PRA that we talked about. We basically tried

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1 to see if I have different sizes of flaw in my steam  
2 generator I can take it one flaw at a time, what is the  
3 probability of C-SGTR, what is the probability of flaw  
4 tube fails before hot leg.

5 When I look at Westinghouse and I look at  
6 one flaw at a time and it looks like if I use the average  
7 hot temperature I couldn't see anything under 50  
8 percent.

9 Actually the first time I start  
10 calculating numbers, that 70, 75 percent deep flaw, and  
11 similarly in the hottest tube almost nothing  
12 interesting happens unless you have flaws that is 70  
13 percent or more.

14 So it's obvious in Westinghouse the  
15 probability that you have one or two flaw bigger than  
16 75 percent is going to drive the C-SGTR up. When we  
17 look at the CE Plant basically if you look at the hottest  
18 tube almost anything's going to --

19 (Laughter)

20 DR. AZARM: So, yes, you are hoping that  
21 you don't have a flaw where the temperature has gone  
22 this --

23 MEMBER POWERS: Probably didn't even do  
24 you good in the hottest tube if it's pristine.

25 (Simultaneous speaking)

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1 DR. AZARM: Yes. Well even with pristine  
2 might fail, but at least with the pristine one I don't  
3 know what is leak area and I can justify the leak area  
4 might be small, but I can have a long shallow area and,  
5 you know, and the average hot tube, you know, it's you  
6 have to have greater than 50 percent in order to get  
7 some number.

8 So, again, just for the information if I  
9 have 20 hottest tube the chance that one of them is  
10 flawed, that is the way we, we are not accounting for  
11 pull moving around and affects more tubes, but if I am  
12 talking about 20 hottest tube and I have 4000, 5000  
13 tubes and I have a hundred flaws the chance of one of  
14 them shows up in hot test is going to be a small.

15 So that's why we don't get one like what  
16 the TH got, but it basically tells you I need to focus  
17 on different sizes of flaws when I do the Westinghouse  
18 and when I do for CE Plant, even if I take the average  
19 flaw bins I should get more or less a good calculation  
20 of the mean and perhaps I do a few sensitivity analysis  
21 to get some idea for the uncertainties with this one.

22 I think that's what the next slide is  
23 saying. So for the representative of Westinghouse  
24 Plants we used limited samples of large flaws,  
25 estimated frequencies that there could be one, two, or

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1 more large flaws within a cycle.

2 For the representative CE Plants we  
3 basically had an expected average number of flaws  
4 within each flaw bins and we used that as a sample.  
5 This is shown in the next slide.

6 The next slide basically is telling you for  
7 the Westinghouse first of all, so what is the  
8 probability that if I'm on Cycle 15 and going to Cycle  
9 16 what is the probability that I have a flaw between  
10 16 to 17 percent depth, it's 10 times 10 to the minus  
11 3, and if I have X number of flaws the probability that  
12 I see one is 0.4.

13 And, you know, the same thing for other  
14 bins. So it's lower probability that I see a single  
15 flaw. For the CE Plant I actually create a bin of 10  
16 percent, 20 percent, 30 percent, so on in depth and the  
17 length and I can calculate from my flaw distributions  
18 how many flaws do I expect to see in the CE steam  
19 generators.

20 And, you know, yes, there is probability  
21 that I have a big flaws but I didn't try to put 0.1,  
22 0.01 there because I know that the smaller flaws are  
23 going to dominate it anyway.

24 And this is a graph that I showed earlier.  
25 So when you do that and you run the Westinghouse and

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1 CE Plant for one of the cases you basically see totally  
2 different behavior of the probability plot of RCS  
3 survival in a C-SGTR.

4 For Westinghouse versus CE, in  
5 Westinghouse you have this larger margin that's  
6 separating them saying that yes, most probably the RCS  
7 is going to fail, the hot leg going to fail, where in  
8 CE plants you say hey, I have to do calculations.

9 The next slide basically, I'm not going to  
10 even go through it, when we say you have bunch of time  
11 steps and each time step you got accumulative  
12 probability, now in each time step you have to calculate  
13 incremental probability of containment bypass and you  
14 have to compute them and integrate them.

15 So all I'm saying is that in all the routine  
16 that does this post-processing integration, et cetera.  
17 So after we do all of those steps what do we get?

18 Let's first look at the CE Plant is 692 and  
19 then in parentheses I have put the sensitivity case when  
20 might assume the SRVs and the steam generators are stuck  
21 open from beginning.

22 So for the base case I get C-SGTR of  
23 containment for bypass probability of 0.22. For the  
24 case that SRV is open I get 0.99, I get one. This is  
25 just because of we have capability to calculate.

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1                   For Westinghouse I get about 1.3 times 10  
2                   to the minus 2 considering all these large flaws  
3                   happening with certain probability if it is made out  
4                   of Inconel 600. If it's made out of Inconel 690 I get  
5                   a little bit lower.

6                   We did not do the sensitivity case with no  
7                   --

8                   MEMBER STETKAR: With the stuck open --

9                   DR. AZARM: Yes. I do believe we have  
10                  some runs but there was reason that we couldn't use the  
11                  data.

12                  (Simultaneous speaking)

13                  MEMBER STETKAR: That would certainly be  
14                  -- You know, from my perspective I'd be interested in  
15                  that one to see how it affects the --

16                  DR. AZARM: Yes. I also want to mention  
17                  for Westinghouse we also included the loop circular and  
18                  probability, because as I said earlier the  
19                  Westinghouse, when the RCP seal leakage hit 450 it  
20                  cleared the seal.

21                  So we assume for RCP seal leakage between  
22                  350 and 450. At 450 probability one, at 350  
23                  probability 0.1, and we included that. So if I add RCP  
24                  seal leakage in this scenario --

25                  MEMBER STETKAR: And the tubes fail --

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1 DR. AZARM: Of course. When the seal  
2 clears --

3 MEMBER STETKAR: So, for example, in the  
4 context of another project that shall remain unnamed  
5 that Kevin is interested in where they explicitly track  
6 those different seal leakage rates they would have much  
7 different consequential steam generator tube rupture  
8 probabilities, right?

9 DR. AZARM: Correct, you should.

10 MEMBER STETKAR: But for the larger end of  
11 the seal.

12 DR. AZARM: But basically we assume when  
13 the loops are clear that we basically assume the hot  
14 leg is circulating and not that much mixing or cooling,  
15 so basically tubes saw what hot leg's seen.

16 MEMBER STETKAR: Yes.

17 DR. AZARM: And they fail, yes.

18 MEMBER BLEY: Let me take you back to your  
19 last slide, you don't have to go back to it. Your  
20 bullet talks about you can do the calculations using  
21 a Fortran routine or an Excel worksheet. What did you  
22 do?

23 DR. AZARM: Okay.

24 MEMBER BLEY: Let me tell you where I am  
25 headed. I don't, you know, if I write a Fortran routine

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1 I know exactly where, usually, where the calculations  
2 are going.

3 If I use Excel, Excel has some things built  
4 into it that I might not fully understand and the order  
5 it does things might generate funniness. I've seen  
6 that somewhere. I haven't played with that enough to  
7 know.

8 If you used Excel how did you make sure it  
9 was doing all the calculations right for you?

10 DR. AZARM: Let me tell you the story  
11 behind it because it's much more involved than what we  
12 saw. The Westinghouse was relatively very easy.  
13 There was one run.

14 We didn't differentiate between loop with  
15 pressurizer and loop without pressurizer. You put all  
16 your flaws in one steam generator and you have the hot  
17 legs and basically what we did in Excel, since we have  
18 one run, one result, we did even the integration  
19 numerically. We didn't use anything of the imbedded  
20 Excel function, so it was easy to perform.

21 MEMBER BLEY: Okay.

22 DR. AZARM: When we got to CE Plant times  
23 to mark, it gave us different TH for Loop A than Loop  
24 B, so instead of we do two runs now we do four runs.

25 We have to integrate Loop A and Loop B,

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1 first come up with those results then come up with it  
2 over time, it was a nightmare to do it with Excel. I  
3 have a bunch of routine, Fortran routine for  
4 convolutions and we basically modified that and used  
5 it for Fortran.

6 MEMBER BLEY: You stretched out, okay.  
7 That makes me more comfortable because I know when you  
8 get those complicated situations --

9 (Simultaneous speaking)

10 DR. AZARM: Yes, it was complicated. I  
11 couldn't do it with Excel anymore.

12 MEMBER BLEY: Okay.

13 DR. AZARM: Okay. Now we are going to get  
14 to Level 2. This is the most simplified analysis we  
15 did and we will tell you why.

16 MEMBER BANERJEE: Just one question for  
17 clarification.

18 DR. AZARM: Yes?

19 MEMBER BANERJEE: How sensitive are the  
20 results to loop seal clearing, the what you assume for  
21 that?

22 DR. AZARM: Basically the one case that we  
23 run we basically said if loop seal clears there's no  
24 constant current flow and the temperature that hot leg  
25 sees is more or less the same temperature the tube sees.

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1                   So we did a sensitivity analysis and the  
2                   tube failed when it sees the same high temperature as  
3                   hot leg.

4                   MEMBER BANERJEE:   Yes, so that also given,  
5                   is going to fail, yes.

6                   DR. AZARM:   If loop seal happens, the good  
7                   thing about the Westinghouse is that, or Westinghouse  
8                   analysis it says loop seal will not happen unless you  
9                   have a very large RCP leakage, which is by itself is  
10                  a probability of Level 1.

11                  So that's why instead of we get 0.1 we got  
12                  0.013 when we included loop seal.   It was a small  
13                  contribution.   Again, because of to get loop seal clear  
14                  based on RELAP/SCDAP analysis you have to have a very  
15                  large RCP seal leakage on all four pumps.

16                  MEMBER BANERJEE:   Yes, I can see that.  
17                  Okay.

18                  DR. AZARM:   Okay.   When we started doing  
19                  Level 2 analysis, actually at the beginning we had a  
20                  very good intention.   We did understand if I do a  
21                  complete Level 2 analysis I can differentiate between  
22                  large and the small releases and I can account for all  
23                  the actions in SAMG and hopefully we can get timings.

24                  And, again, this is four years ago when we  
25                  started this, we were very idealistic, so we can do a

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1 good Level 2 analysis. We started working on  
2 developing the event trees.

3 The first thing that happens is that these  
4 are post-core damage sequence. So as soon as I am post  
5 core damage and I am saying what is the probability of  
6 PORV opens, it's not qualified for that environment.

7 What is the probability of SRV to operate?  
8 Is SRV going to be jammed or is it going to be open?  
9 I don't know. What are the HRAs associated with SAMG?  
10 This is now core damage for us, C-SGTR.

11 And it always easy to say I'm going to  
12 depressurize my secondary and fill it up with fire  
13 water, but am I going to do it under this condition with  
14 the high radiation on the secondary side?

15 So there is a slew of problems that we  
16 couldn't handle, not in this small scope project. So  
17 it was NRC and our agreement to go to a very simplified  
18 conversion analysis.

19 MEMBER BLEY: You know, those things you  
20 talked about, bounding might not be so bounding given  
21 some of those issues.

22 DR. AZARM: Yes. Our bounding you will  
23 see it is --

24 (Simultaneous speaking)

25 DR. AZARM: I'm going to go through it.

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1       You basically give credit to nothing.

2                   MEMBER BLEY:   Okay.

3                   DR. AZARM:   This is just to show you that  
4       we did go through SAMG, we understand SAMG, we tried  
5       to model them, we understand , or it was we are guiding  
6       to do and, you know, describing in the secondary by  
7       filling up, but we didn't model them.

8                   When we look at SAMG a couple of issues are  
9       important in this slide.   So we did look at SAMG, we  
10      tried to understand it, but we decided not to model  
11      them, but we saw two things that might be important.

12                  One is that sometimes if they recover AC  
13      after core damage they try to bump RCPs and now they  
14      are going to clear the seal and they are going to put  
15      us in the problem that we had before, failing the tubes.

16                  However, it does require that your AC to  
17      be recovered and we are not modeling that.   If your AC  
18      is recovered than you can fill up your steam generator,  
19      you can do many things that, you know.

20                  But, yes, bumping RCP may not, may clear  
21      your seal, but you have so many ways to help you to,  
22      so.   The other thing was injection of cold water into  
23      a dry steam generator as a part of SAMG.

24                  Again, we didn't verify it just to be aware  
25      that they have this guidance document.   They are aware

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1 of the issue and supposedly, you know, they do a slow  
2 injection, whatever, so they have addressed it. We did  
3 not.

4 Okay. Now I'm going to get to this  
5 simplified LERF analysis. Basically it's a six factor  
6 formula. We know the frequency or the probability that  
7 we enter the accident condition.

8 We know from the calculator and other stuff  
9 I described how to calculate the probability of C-SGTR.  
10 So those two we know how to do. Well actually it's a  
11 five factor formula.

12 There's three other factors that we don't  
13 know about. One is the conditional probability that  
14 RCS is not depressurized. The other one is failure  
15 probability of SAMGs, and the last one is evacuation.

16 We basically do not give credit to neither  
17 SAMGs or depressurization post-core damage, so we are  
18 very bounding. So if you enter this accident scenario,  
19 severe accident scenario, and you have got the C-SGTR,  
20 the only thing else we care is evacuation and that's  
21 why we call it bounding. Nothing is credited.

22 And evacuation I believe we used a timeline  
23 that comes from SOARCA, I think it's ten hours or  
24 something like that for 95 percent to be evacuated. So  
25 if the short-term SBO becomes a LERF or the long-term

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1 SBO, most of them, not become a LERF.

2 And this basically shows you those  
3 factors, you know, that the C-SGTR due to the single  
4 tube break. If loop seal clears we assume C-SGTR is  
5 conditional one, and, you know, the other factors is  
6 one. The same thing for the CE Plant.

7 This slide basically shows the summary  
8 results that we have got for changing in LERF. It is  
9 basically showing you CE, this half of Calvert Cliffs  
10 is higher than Westinghouse.

11 When you look at all hazard model for  
12 internal and external event we get for Calvert Cliffs  
13  $5.7E$  to the minus 7. Remember Calvert Cliffs has two  
14 turbine-driven AFW.

15 So really for other CE Plant might be a  
16 factor of ten higher, okay. So that's why we are saying  
17 CE Plants is most susceptible. Now look at the  
18 all-hazard model for Westinghouse, we get about 2 times  
19 ten to the minus 8 and Zion had only one turbine  
20 drive-AFW and they were kind of generic.

21 So we think that CE Plant is one to two  
22 orders of the magnitudes after LERF than Westinghouse  
23 Plants.

24 MEMBER BLEY: And that's kind of  
25 compounded because it's both in the fractional approach

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1 to LERF as well as the case feeding it.

2 DR. AZARM: Yes. For Calvert Cliffs.

3 MEMBER BLEY: Yes.

4 DR. AZARM: Now we are going back, so I'm  
5 done with severe accidents. I have fewer slides on the  
6 pressure-induced just to tell you a short activity we  
7 did and what results we got.

8 Pressure induced is basically we look at  
9 all the scenarios that we think the delta P across the  
10 two is at least twice what is in nominal operation. We  
11 develop scenario frequency from existing PRAs in some  
12 modifications we do.

13 We basically used a very simplified  
14 bounding pressure-temperature curves, okay. For  
15 example, I think for ATWS, because we didn't have it  
16 for ATWS, we used a pressure of 3200 and nominal  
17 temperature, et cetera.

18 We had some results for the main steam line  
19 breaks or we idealized that. So we kind of generated  
20 the TH we want but in a very established manner. This  
21 doesn't come for MELCOR or RELAP.

22 We again tried to look at the leak area that  
23 at least is one or more tube, but frankly what we look  
24 at is six centimeters squared. I shouldn't say one or  
25 more tube.

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1                   We modified the existing PRA accident  
2 progression to reflect that everything is more complex  
3 when you have this DBA accident and you have a  
4 consequential steam generator tube rupture on top of  
5 it.

6                   It's bad enough to have ATWS, if you get  
7 the C-SGTR you are gone, okay.

8                   MEMBER BLEY: Let me ask you something  
9 because I'm a little, I'm remembering some work done  
10 a long time ago looking at ATWS and to get to pressures  
11 twice normal, operating pressure, there's probably  
12 other things that are going to blow out that will limit  
13 the pressure long before you get to that point, reactor  
14 coolant pump seals, a whole variety of things, so I'm  
15 not sure what this tells us.

16                  DR. AZARM: Okay. An ATWS was a specific  
17 and, again --

18                  MEMBER BLEY: Well I --

19                  DR. AZARM: Yes.

20                  MEMBER BLEY: No, no, I'm not --

21                         (Simultaneous speaking)

22                  MEMBER BLEY: Okay. During looking at  
23 ATWS's when pressure was going up people looked to see  
24 what would break first.

25                  DR. AZARM: Yes.

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1                   MEMBER BLEY:   And it sure wasn't the  
2                   loops, but it was things that would keep you from  
3                   continuing to pressurize up.

4                   So this kind of sets a bound that says if  
5                   you get there, I don't know whether tubes would break  
6                   or not, probably not at twice nominal pressure, but I  
7                   just don't know what the point of this is because I  
8                   didn't think you can get there.

9                   DR. AZARM:   Let's perhaps let's look at  
10                  this.

11                  MEMBER BLEY:   Okay.

12                  DR. AZARM:   And going back to your  
13                  question about ATWS, first of all it's not a big  
14                  contributor.

15                  MEMBER BLEY:   I didn't raise a question  
16                  about ATWS. I said the idea of --

17                  (Simultaneous speaking)

18                  MEMBER BLEY:   Okay.    I just was  
19                  referencing --

20                  (Simultaneous speaking)

21                  DR. AZARM:   And just we go back to your  
22                  comment. So we looked at ATWS and we did the nominal  
23                  that if the ATWS hits the 3000 psi ASME limit we are  
24                  going to rupture, but we don't know that, are we going  
25                  to break?

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1                   So we had to style it as we look at a steam  
2                   line break inside containment and outside containment.  
3                   Now that gives you almost twice because the secondary  
4                   side depressurized, primary stays at HPI, okay.

5                   We look at established opening of a steam  
6                   generator relief valve. I know we looked at some PRAs,  
7                   we even looked at it due to fire and non-fire causes.

8                   We looked at some of the plant have a very  
9                   high pressure pump for feed and bleed --

10                  MEMBER BLEY: I'm getting confused again.  
11                  You know, when you say you depressurize the secondary  
12                  side, well, that then gives you 2000 instead of 1000  
13                  pounds differential, but the tubes aren't designed for  
14                  1000 pounds, they're designed for full system pressure  
15                  and they're hydro'd to that line, in fact something  
16                  above that.

17                  DR. AZARM: Yes. The tubes, if they are  
18                  pristine, can take easily 5000 psi. We are putting a  
19                  probability of flaw of 75 percent in this stuff.

20                  MEMBER BLEY: Okay.

21                  DR. AZARM: So we have still our  
22                  calculator calculates flaws that are big enough that  
23                  can fail during --

24                  MEMBER BLEY: At these pressures.

25                  DR. AZARM: At these pressures. And that

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1 is the probability that I see a flaw of that big size.  
2 So these numbers are coming, not only taking the  
3 existing PRA, modifying it, changing HRAs, but also on  
4 top of that multiplying it with the probability that  
5 I have such a large flaw that it's going to rupture.

6 Again, it's done just to get a feeling  
7 about how, about how good these things are, and the very  
8 conservative bounding calculation which we explained  
9 in the document, and I don't know what the details right  
10 now, we got about 2 times ten to the minus 7 and we think  
11 it's below that.

12 And we did the same thing for CE and for  
13 CE was a little bit higher and I think indicative to  
14 what Dr. Stetkar was saying because they have twisting  
15 generators, we got 4 times 10 to the minus 7, but we  
16 have addressed, we tried to address that issue and we  
17 have documented each of these accident sequences.

18 MEMBER STETKAR: Now your conditional  
19 probabilities of core damage given the initiating event  
20 and a consequential tube rupture runs through that  
21 little simplified event tree that's got a whole bunch  
22 of operator actions in it that you say things, oh, this  
23 is kind of a 10 to the minus 3 and this is kind of a  
24 10 to the minus 2, and without really doing a real human  
25 reliability analysis.

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1 I will point you to an event that occurred  
2 at a real plant where they had an uncontrolled cool  
3 down, not due to a stuck open valve, but due to heater  
4 drains that blew through because of the power failure,  
5 and the operators never figured out what was going on.

6 The only thing is a guy bumped a DC circuit  
7 breaker that happened to interrupt power and the  
8 interruption of power closed the MSIVs and stopped the  
9 cool down miraculously.

10 The operators never figured out what was  
11 going on. Now they didn't have a tube rupture to  
12 contend with in this thing, they just never figured out  
13 what was causing the cool down in the beginning.

14 DR. AZARM: Oh, yes. I --

15 MEMBER STETKAR: So the simple models  
16 about saying well the operators can equalize pressure  
17 across the ruptured steam generator the same as if this  
18 is a steam generator tube rupture initiating event kind  
19 of ignore --

20 MEMBER BLEY: But that was partially  
21 because they thought that was normal.

22 MEMBER STETKAR: Yes. Well, yes.  
23 That's a different part of the story, that's right. So  
24 my point is that a lot of these numbers without the  
25 context of a fully integrated PRA treatment are just

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1       that, they're numbers, and that's okay as long as you're  
2       not trying to draw global conclusions about how  
3       important or how unimportant this issue is to overall  
4       public health and safety.

5               I honestly don't know how important it is  
6       and I'm willing to say that I don't know how important  
7       it is because I haven't seen anybody really investigate  
8       it, which is okay, but I know this isn't a thorough  
9       investigation.

10              DR. AZARM: I agree it's not.

11              MEMBER STETKAR: So that's another  
12       concern is about what message comes across in this NUREG  
13       in terms of is this issue, not necessarily from the  
14       research of more thermal-hydraulic analysis or more  
15       material science because my sense, knowing nothing  
16       about those topics, is that it's pretty mature in those  
17       areas. Again, knowing nothing about those topics.

18              But in terms of drawing overall  
19       conclusions about, you know, are we ready to check off  
20       the box that we look at everything and can conclude that  
21       it's not important, that is not as clear to me.

22              DR. AZARM: I think I do agree. I think  
23       --

24              MEMBER STETKAR: And essentially, you  
25       know, what I'm challenging in this particular slide is

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1       that center column there that says the conditional  
2       probability of core damage given the initiating event  
3       frequency, I have reasonable confidence in all because  
4       I have no other reason to doubt it by your 4 times 10  
5       to the minus 3 conditional tube rupture probability.

6               I'm just not sure that I have any  
7       confidence at all about 3.2E to the minus 2 conditional  
8       core damage probability given those conditions,  
9       because that relies, my recollection, heavily on a  
10      whole bunch of operator actions.

11             DR. AZARM: If I may, and I hear you, I do  
12      agree we should not make a conclusion, but perhaps I  
13      should do a better job.

14             The first column just gives you the  
15      frequency of initiating events. The second column,  
16      which is added because of this work, it says given what  
17      we know, and, yes, there are, better analysis can be  
18      done, this is the probability that you get C-SGTR.

19             MEMBER STETKAR: Right.

20             DR. AZARM: So what is the probability of  
21      conditional core damage given IE and C-SGTR.

22             MEMBER STETKAR: Right. There's a model  
23      in there for that now.

24             DR. AZARM: And that's the one that you are  
25      questioning and that's the one --

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1 MEMBER STETKAR: Exactly.

2 DR. AZARM: I do -- Again, we tried to be  
3 bounding but I can't define every details of it. Yes,  
4 we shouldn't have made the conclusion. And the left  
5 column, of course, it's all one or zero.

6 MEMBER STETKAR: Well I mean in this case  
7 you've assigned it to LERF, so I, you know, I can't  
8 believe that it can be worse than that.

9 DR. AZARM: Yes. No, I agree with you. I  
10 do agree. The first conclusion talks about we do  
11 believe at least an order of magnitude is higher for  
12 CE than it is for Westinghouse when we talk about the  
13 severe accident caused the C-SGTR.

14 We say PRAs indicates delta LERF, delta  
15 CDF. For the C-SGTR for this pressure-induced  
16 accident, the one we just said, we think it's less than  
17  $5E$  to the minus 7 with some grain of salt.

18 We don't say for this not important. To  
19 me, when you have a criteria of  $1E$  to the minus 6,  $5E$   
20 to the minus 7, doesn't say it's insignificant, it  
21 doesn't say it is dominating either, but, yes, I agree  
22 with your point.

23 I think the next bullet it comes from the  
24 summary or abstract. Basically it's emphasizing that,  
25 you know, there are ways, you know, like adding

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1 additional turbine-driven AFW or diesel generator pump  
2 can help you.

3 It talks to concisely and clearly says that  
4 some work was done in loop seal clearing for  
5 Westinghouse Plant as I said, nothing is done for CE.  
6 So the Staff we tried to control, avoid large and deep  
7 steam generator tube.

8 At least now we know large and deep means  
9 70 percent or more when we talk about Westinghouse. It  
10 is not 40 percent, so we have enough margin there that  
11 I think that's an important thing we are trying to say.

12 We talked about the inlet plenum and surge  
13 leg plenum, hot leg geometry, et cetera. The design  
14 features are an important contributor.  
15 Depressurization of reactor, intention of  
16 depressurization could help you here and also in other  
17 places. For the DBA accidents we feel, again, that the  
18 deep flaws is the one that is contributing.

19 One area that we just weren't for sure and  
20 we haven't talked about it, where does the six  
21 centimeters square coming from? Why do we assume this  
22 critical area of six centimeters squared?

23 There's a summary of reason for it. When  
24 we start a big drop we wanted it to be sufficient to  
25 pressurize the secondary side such that it forced the

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1 opening of the secondary relief valve.

2 So we wanted to have a leakage area that  
3 even the 1/2-inch hole it still can open up your  
4 secondary. We wanted to depressurize primary. We  
5 wanted it to provide sufficient release path that it  
6 can be considered from the source as a LERF. If you  
7 have a very small hole it may not be.

8 And we didn't it want it to be too large.  
9 If I got 22 failure I wanted if I still had the counter  
10 current flow, so we didn't want it to be that large.  
11 So we put all these things together.

12 I think initially we did some back of  
13 envelope calculations and we came up with the six  
14 centimeters squared and we also looked at the input from  
15 both RELAP, SCDAP and MELCOR.

16 Now I think the last item talks about  
17 increasing the battery life to facilitate longer  
18 operation of TDAFW and support SAMG operation and  
19 probability of equipment survivability post onset of  
20 core damage. I think that's a million dollar question.

21 If we want to do Level 2 I still don't know  
22 how we can do it if we don't know how a PORV, SRV, and  
23 others are going to operate.

24 MEMBER STETKAR: Now before we -- I'll  
25 stay on the horse that I've been riding for the last

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1 hour and a half.

2 But when I first started to think about  
3 this stuff, we thought about it 25 years ago and people  
4 concluded ah, induce your consequential tube ruptures,  
5 no big deal, and so we kind of dropped it, probably  
6 wrongly.

7 But I started thinking about it again  
8 saying well, gee, are our PRA models actually capturing  
9 all of the scenarios for which this phenomenon may  
10 present a vulnerability, I quickly came to the  
11 conclusion that no, we're not.

12 I've done some work at a plant several  
13 years ago that had a concern about pressurized thermal  
14 shot for their reactor vessel, not a U.S. plant, it will  
15 be unnamed, so we for that particular plant because of  
16 that concern looked pretty carefully at overcooling  
17 scenarios, but from that perspective.

18 So we started looking at stuck open  
19 secondary side valves, you know, how fast could you cool  
20 down, all that sort of stuff, but from that perspective  
21 and at the same time recognized that oh, gee, it's true,  
22 if the operators, if you have a faulted steam generator  
23 they're going to isolate that steam generator so that  
24 indeed there was -- The good news is that the  
25 overcooling scenarios for that particular plant we

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1       could justify it didn't have much of a chance of really  
2       harming the reactor vessel but indeed there were  
3       visible contributors to core damage because they put  
4       the operators in situation that was more confusing to  
5       them and, in fact, removed one of their steam generators  
6       as a cooling mechanism, but then never thought about  
7       it in the sense of getting the high-dry-low condition.

8               DR. AZARM:   Right.

9               MEMBER STETKAR:   And I have not seen PRAs  
10       really look at that.   So I'm curious about why an  
11       insight from this whole study is that PRAs may not  
12       actually be looking for these scenarios.

13              They're looking for the -- You found them  
14       in places like your, you know, main steam line break  
15       or your stuck open secondary relief valve initiating  
16       event, you found them in station blackout with whatever  
17       timing you want to give on failure of your auxiliary  
18       feedwater flow.

19              But you didn't say are the PRAs actually  
20       identifying these scenarios.   So I'm curious about why  
21       that's not a PRA insight or should it be?

22              MEMBER BLEY:   Yes, see, to me --

23              (Simultaneous speaking)

24              MEMBER BLEY:   I've kind of sat back and  
25       thought maybe people were waiting to see where the

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1 researcher was going before they started addressing  
2 that.

3 MEMBER STETKAR: Yes. Well, but I mean  
4 some of the feedback from this says well it's not a big  
5 deal contributor, it's certainly not a big deal  
6 contributor to core damage, and furthermore it's not  
7 even a big deal contributor to LERF, so what incentive  
8 do I have to go out and look for it.

9 But it's a self-fulfilling issue that if  
10 you've only looked at what you could see and people  
11 haven't looked for the other things you don't know how  
12 important those other things might be.

13 And, again, I don't have a sense, I  
14 honestly don't. If I had, you know, any example  
15 believe me I would've been screaming about it that look,  
16 you know, this study had been done and it's a 50 percent  
17 contribution to something or other, but I don't have  
18 that.

19 But I do know that the results that you're  
20 looking at are not complete in that sense. And that  
21 it's not a simple, it's not just a simple binning of  
22 things because the actual accident progression  
23 becomes, the event scenario, I won't even, I need to  
24 stay away from this design basis and core damage thing,  
25 the scenario progression becomes much more complicated

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1 because the operators now have to deal, if they follow  
2 the procedures and isolate the faulted steam generator  
3 that's good from their perspective, but it reduces  
4 their ability to cope perhaps with other things that  
5 are going on and their performance might not  
6 necessarily be all that well in an integrated sense.  
7 So I'm just curious. It's a comment.

8 DR. AZARM: I think your comment is well  
9 taken. I haven't seen also, or I haven't seen neither  
10 any PRA systematically look for all possible scenarios  
11 and the complications involved.

12 And what we did, you know, just trying to  
13 pick up the low hanging --

14 MEMBER STETKAR: I can't -- As I said I  
15 did, this was several years ago because of that one  
16 particular issue that we went and looked at, in  
17 particular looking for overcooling scenarios that we  
18 had not looked for before because typically we'd use  
19 models like these that said do we have enough steam  
20 relief --

21 DR. AZARM: Right.

22 MEMBER STETKAR: -- and if no, it's a bad  
23 day, as long as you have enough, you don't ask anymore  
24 about do I have too much and what happens if I do have  
25 too much.

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1                   After that one plant then I put it in models  
2                   that I'd work on for other plants. Typically it wasn't  
3                   a big --

4                   OPERATOR:           Please       pardon       the  
5                   interruption. Your conference contains less than  
6                   three participants at this time. If you would like to  
7                   continue press star 1 now or the conference will be  
8                   terminated.

9                   MEMBER STETKAR:    The interruption is  
10                  pardoned. None of the plants that I worked on was at  
11                  a, yes, I have to be careful. I'll just stop the  
12                  discussion there.

13                  DR. AZARM:   Regarding your --

14                  MEMBER STETKAR:   It's we've identified  
15                  some interesting scenarios by looking at it. Things  
16                  that make life pretty complicated for the operators and  
17                  can indeed have impacts on core damage.

18                  I have never looked at consequential tube  
19                  rupture. I've never built a model so I have no insight,  
20                  you know.

21                  OPERATOR:           Please       pardon       the  
22                  interruption. Your conference contains less than  
23                  three participants at this time. If you would like to  
24                  continue press star 1 now or the conference will be  
25                  terminated.

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1                   MEMBER STETKAR:   This is an indication  
2                   that the line is not there.

3                   CHAIR REMPE:   Anything else?

4                   MEMBER STETKAR:   No.

5                   CHAIR REMPE:   Okay.

6                   DR. AZARM:   Thank you so much.

7                   DR. COYNE:       Can I get a quick  
8                   clarification on it just to make sure that we understand  
9                   this feedback?

10                  DR. AZARM:   Sure.

11                  DR. COYNE:   So my impression on how we  
12                  identify and bin these scenarios is that if you had a  
13                  loss of aux feedwater from whatever the cause you would  
14                  count that as a dry scenario which our assumption would  
15                  lead you to also put a low secondary pressure scenario  
16                  then you could systematically look for higher pressure  
17                  scenarios in the RCS.

18                  So those scenarios seem more likely to be  
19                  counted with the current PRAs we have.

20                  OPERATOR:   Please pardon the interruption  
21                  Your conference contains less than three participants  
22                  at this time.  If you would --

23                  MEMBER STETKAR:   Yes, I'm assuming that it  
24                  was stopped midstream that it's been intercepted.  Let  
25                  me just --

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1 DR. COYNE: The one thing that causes me  
2 pause is the scenarios you brought up where I've had  
3 a faulted steam generator then I then have the operators  
4 isolate it and then get myself into a core damage  
5 scenario where I may not have the cut set that tells  
6 me I completely lost aux feedwater.

7 MEMBER STETKAR: Right.

8 DR. COYNE: So therefore I may have aux  
9 feedwater available to other steam generators but I  
10 have this steam generator potentially in a vulnerable  
11 state.

12 Is this an example of the majority of the  
13 scenarios you're thinking of?

14 MEMBER STETKAR: Kevin, I don't know.

15 DR. COYNE: Okay.

16 MEMBER STETKAR: I don't, you know, I  
17 don't know is the key because I have not thought about  
18 the consequential tube rupture.

19 I have to say I've never built a model  
20 that's got consequential tube rupture in it, so I'm not  
21 right now able to say well here are the class of  
22 scenarios that you wouldn't otherwise identify that are  
23 important for this.

24 But I know that the typical PRA models do  
25 not quantify the frequency of scenarios that actively

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1 isolate feedwater to a faulted steam generator such  
2 that that steam generator is sitting there open, big  
3 hole open to the outside world and dry waiting for  
4 whatever other combination of things finally get you  
5 into trouble.

6 I just, you know, that's all I can say. I  
7 haven't done, you know, I haven't done the study.

8 MEMBER SKILLMAN: Ali, you made a comment  
9 about the origin of the one square inch or the six  
10 centimeters squared. In the late '60s and early '70s  
11 all of the PWR designers, Babcock, Combustion, and  
12 Westinghouse, were designing for a 1-inch break hands  
13 off makeup system coverage.

14 And so the CDCS on the Westinghouse and the  
15 Combustion systems and the makeup and purification on  
16 the B&W Plant could ride through a 1-inch break and if  
17 the 1-inch break was in the steam generator that'll be  
18 this half, then the only thing you would see changing  
19 is your makeup tank level changing because your  
20 pressurizer level would hold because of your  
21 pressurizer level primary system control systems.

22 And so in time you begin to see a reduction  
23 in inventory. So that was a purposeful design and that  
24 became kind the knee in the curve for what's a real small  
25 break and what's a break that you could communicate to

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1 the NRC, we've had a leak but we can handle it.

2 It's handleable within the normally  
3 operating equipment.

4 DR. AZARM: Normal --

5 MEMBER SKILLMAN: But that was a number  
6 that all of us were branded with back in the late '60s  
7 and early '70s and we designed all the equipment for  
8 that.

9 As time went on it became clear that  
10 actually it wasn't a one square inch it was a one inch  
11 Schedule 160, which is about a 5/8 of an inch, just a  
12 little bit smaller.

13 But that's I believe where that number came  
14 from. It was a nominal 1-inch break.

15 DR. AZARM: Now I can tell you honestly how  
16 we calculated that number. It wasn't based on charging  
17 and perhaps we didn't document it. We basically tried  
18 to look at, again I am getting myself in trouble.

19 So what is created, we created a 1-inch  
20 hole, we tried to assume a choke flow through that  
21 assuming no pressure in the secondary and so it dried  
22 out, and see how fast it can depressurize that primary  
23 because now you have nothing, because uncovered you  
24 have all the steam, et cetera.

25 So that was one and I think we had the

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1 criteria for those or something. And the other thing  
2 we looked at, we did a bunch of calculations. We  
3 thought, again I think Sanjoy is going to jump over me,  
4 but what we did we did some fraud analogy.

5 Basically saying if I have a counter  
6 current flow, like the one I have in tunnels, the fire,  
7 how much leakage I should have before that counter  
8 current flow breaks, and then we calculated that.

9 I think we got equivalent to three, which  
10 was 18 centimeters. And then we did some other  
11 sensitivity analysis and finally we said okay, six  
12 centimeters squared looks like conservative.

13 Also we looked RELAP and SCDAP and if you  
14 look at that it shows that if you have one tube breaks  
15 and you have half an inch hole you are not going to even  
16 pressurize.

17 But if you have two tubes break you are  
18 going to pressurize the secondary, open up the  
19 secondary SRV and you are going depressurize the  
20 primary.

21 So then with all of these factors that came  
22 together and we tried to pick up a conservative lower  
23 bound, which was the six centimeters squared, which  
24 coincidentally is the 150 gpm of charging from CVCS that  
25 is designed. But that's the way it came up.

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1 MEMBER STETKAR: Interesting. Thank  
2 you.

3 DR. AZARM: You're welcome.

4 MEMBER STETKAR: Thank you.

5 CHAIR REMPE: Okay. Well we're running a  
6 little bit behind schedule, but why don't we switch to  
7 the last presentation, which is fairly short and, even  
8 though this isn't bad.

9 DR. AZARM: Thank you very much.

10 CHAIR REMPE: Thank you very much for your  
11 presentation.

12 MR. ZOULIS: I think I'll bring you back  
13 to schedule.

14 CHAIR REMPE: I don't know, you've only  
15 got one slide. I don't think --

16 MEMBER STETKAR: No, no, Antonios is the  
17 master.

18 (Laughter)

19 MR. ZOULIS: Now there is prioritization  
20 -- Oh, sorry, so wrong presentation. Yes, we're  
21 talking about the severe accident induced steam  
22 generator tube rupture and we appreciate all the hard  
23 work that Research has done in the last past five years  
24 researching this phenomenon.

25 And, of course, NRR endorses the

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1 completion of the draft NUREG and we're looking forward  
2 for the review and public comment period, assembling  
3 all of this information that we've created in the last  
4 five years.

5 Now we've planned to develop the RASP, Risk  
6 Assessment Standardization Project, handbook  
7 guidance, we've already, Kevin didn't know this  
8 earlier, but we have revised the current user need that  
9 we're going to send to Research recently to incorporate  
10 an update to that guidance.

11 We also may look at updating 0609 Appendix  
12 J, which is the steam generator significance  
13 determination process attachment --

14 MEMBER BLEY: Antonios, but the RASP, and  
15 that began as like a, just a collection of tools, right?

16 MR. ZOULIS: Right. That's right.

17 MEMBER BLEY: But now you are going to  
18 formalize that?

19 MR. ZOULIS: Well we have the RASP, I mean  
20 Kevin can speak to that better than I, but we have the  
21 RASP handbook, it's available publicly, and in there  
22 we provide ways to make sure that the senior reactor  
23 analysts are using standard methods of when they do  
24 their risk assessments.

25 Again, it's guidance, it's not a

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1 procedure, it's not a requirement. It was more  
2 developed to kind of try to assist the senior reactor  
3 analysts when they are performing -- Any of the accident  
4 sequence progression analysts --

5 MEMBER BLEY: Is it a NUREG or how is it  
6 --

7 MR. ZOULIS: Kevin? I'm sorry.

8 MEMBER BLEY: I thought it was just a place  
9 on your website that had the tools sitting on it.

10 DR. COYNE: It's in ADAMS, but it's not a  
11 NUREG.

12 MEMBER BLEY: It is in ADAMS, okay.

13 DR. COYNE: It actually came about from a  
14 commitment to the, well it had started and then we had  
15 an OIG audit about how we ensure that our risk  
16 assessments match the as-built as-operator plant.

17 One of the commitments we made was that we  
18 were going to update the RASP handbook to include some  
19 quality assurance aspects, and that's what's used by  
20 both the ASP analysts and research and the SDP analysts  
21 and NRR and the regions.

22 And over time it's grown, it's a 4-volume  
23 set now. It has volumes on quality assurance, volumes  
24 on external hazards, shutdown, and internal events.

25 MEMBER BLEY: Okay.

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1 MR. ZOULIS: So those efforts we're going  
2 to pursue immediately, right now I guess, and the next  
3 thing that we plan to do or considering are issuing an  
4 information notice with the issuance of the NUREG once  
5 it's available and final, which we've already  
6 communicated with the generic communications branch  
7 and that's an acceptable process, and perhaps  
8 evaluating the issuing under the generic issue  
9 programs, whether it meets further action and we, of  
10 course, have that process in Research to evaluate those  
11 issues.

12 That's all I really have today. Thanks  
13 again for the opportunity to present to you today. I  
14 really appreciate all the work that Kevin has done. I  
15 think Raj hit the nail on the head when he mentioned  
16 that Kevin has been a big supporter of this and kind  
17 of the engine that's been driving this for the last five  
18 years over the bumps that we've had.

19 CHAIR REMPE: So I have a question,  
20 because we don't want you to get us ahead of schedule.

21 (Simultaneous speaking)

22 CHAIR REMPE: We've listened to what John  
23 was saying about a self-fulfilling prophecy with  
24 respect to the risk assessment results and if you would  
25 put this under the generic issues program, unless

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1       there's some change in the risk assessment or the  
2       results from LERF and the CDF changes, would it really  
3       go anywhere?

4                   MR. ZOULIS: I can't speak for the generic  
5       issues program, but I was kind of thinking about John's  
6       comment before, or Dr. Stetkar's comment, and just from  
7       my personal experience if you have already a faulted  
8       steam generator and now you've somehow lost the ability  
9       to feed to the other steam generators and you have now  
10      a consequential steam generator later on, my gut says  
11      to tell me that it's a very low probability sequence,  
12      but I mean that's just my, that's just my gut --

13                  MEMBER STETKAR: I don't know. I'm not  
14      try to be coy here, I honestly don't know and one of  
15      the things that we try to do in risk assessment is what  
16      can happen, what's the frequency and what are the  
17      consequences of that.

18                  I've identified something that can happen.  
19      I don't know what the combination of the frequency and  
20      consequences taking it all the way out to releases are,  
21      I just don't know.

22                  MR. ZOULIS: Yes, right. Well I'll tell  
23      you, John, when we did a lot of the modeling back when  
24      I was the licensee we would test whether, so if you had  
25      a consequential steam generator fault, I'm sorry, a

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1 steam generator fault, you would then test whether you  
2 still have offsite power, whether you still have your  
3 emergency -- If you did it would take you then to a  
4 station blackout tree.

5 You would then see whether you get offsite  
6 power recovery or not and then you would continue to  
7 progress down the line. And, again, just my, kind of  
8 my gut --

9 MEMBER STETKAR: But, again, that's --

10 MR. ZOULIS: I'll come back.

11 (Simultaneous speaking)

12 MEMBER STETKAR: The SPAR models are very  
13 heavily influenced by this notion that the world  
14 revolves around station blackout and failures of  
15 turbine-driven aux feedwater pumps.

16 There are things in the world that can make  
17 life really complicated, failures of DC power, partial  
18 failures of DC power --

19 MR. ZOULIS: In particular --

20 MEMBER STETKAR: An error in some place  
21 can get pretty darn interesting.

22 MR. ZOULIS: Yes.

23 MEMBER STETKAR: And I'm not saying that  
24 necessarily all plants have the same vulnerability. I  
25 personally tend to worry a lot more about two plants,

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1       only because they only have two steam generators and  
2       if you're giving up one you have a lot less available  
3       to you. But, again, I don't know.

4               MR. ZOULIS: We could look and I think we  
5       have the ability to look into it. I mean we can  
6       probably --

7               MEMBER STETKAR: Having the ability to  
8       look into it requires some fairly clever changes to  
9       event models, that's all I have to say is it's not, you  
10      can't just look at preexisting cut sets, you can't look  
11      at, you know, it's --

12              MR. ZOULIS: Oh, no, no, No --

13                      (Simultaneous speaking)

14              MEMBER STETKAR: You actually need to walk  
15      yourself into these things systematically.

16              MR. ZOULIS: I'm sure Selim would love to  
17      do that analysis for us.

18                      (Simultaneous speaking)

19              MEMBER SKILLMAN: Building on John's  
20      comment, loss of half of vital DC or half of vital AC,  
21      a portion of the battery, or part of the instrument air  
22      system can really push the operating team to their limit  
23      because of the permutations and combinations of  
24      squirrely behavior.

25                      I mean all kinds of crazy things happen and

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1 none of it is diagnoseable right on the front end, and  
2 so I'm with John in just maintaining a challenging  
3 curious attitude on this.

4 MR. ZOULIS: I think we've done that by  
5 continuing this project and if there's any other areas  
6 that we need further evaluation we'll take it back for  
7 consideration.

8 MEMBER STETKAR: I mean one thing that  
9 this project has least educated me on is that the  
10 conditional probability for a consequential tube  
11 rupture is not inconsequential.

12 I mean we're not talking about numbers that  
13 are 10 to the minus fifths largely, we're talking about,  
14 you know, somewhere between a 1 percent conditional  
15 probability up to perhaps 100 percent conditional  
16 probability depending on the plant design and the  
17 nature of the scenario and so forth, which is enough  
18 to get my interest in terms of thinking about the  
19 effects on what are already very, very low frequency  
20 scenarios.

21 You know, it's not too difficult to get  
22 factors of two when you're talking about very, very low  
23 frequencies, if not more.

24 CHAIR REMPE: Okay. Anymore questions?

25 MEMBER BALLINGER: This is only my second

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1 time around this because I come late to this, but I just  
2 look at this and say to myself there isn't a single here  
3 that's not uncertain in a lot, in a big way.

4 And so am I -- Is that wrong? Just having  
5 a computing of a probability without getting a pretty  
6 good handle on what the uncertainty is on that  
7 probability just seems to me like in this case just not  
8 a good thing to do.

9 It's just extracting more information from  
10 the calculations that we do than we're justified in  
11 doing.

12 MR. ZOULIS: The only thing I could say is  
13 that we're risk informed, so if it's uncertain then  
14 we'll have either defense in depth guidelines, or we  
15 have FLEX, or other ways that perhaps the licensee could  
16 assure that the steam generator maintain water  
17 inventory.

18 And so we understand that there is some  
19 sort of vulnerability and I think that's half the battle  
20 and the rest we need to decide how we're going to move  
21 forward.

22 I mean knowing the exact number I think is  
23 not the most important thing.

24 MEMBER BALLINGER: Yes, I just worry that  
25 a calculation that gets done, somehow gets enshrined,

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1 and is a number which has a very large uncertainty which  
2 at this point doesn't make any difference.

3 But somewhere down the line who knows what  
4 happens and all of a sudden that number does make a  
5 difference for some other unforeseen set of  
6 circumstances that we have to deal with and then not  
7 having quantified the uncertainty becomes a big  
8 albatross around your neck. That's all.

9 DR. COYNE: If I could add to Antonios's  
10 comment, I think the comments about needing to identify  
11 areas of uncertainty in particular areas that we  
12 believe introduce large uncertainties is very  
13 important in the report so we really appreciate that  
14 feedback.

15 You know, a lot of the discussions on the  
16 timing and these high temperature effects, you know,  
17 I had the same issue when I first encountered this  
18 phenomenon six years ago of, you know, wow, these things  
19 are, you know, three minutes seem to be a big  
20 uncertainty from expert judgment from Argonne National  
21 Lab, that's what they put on these timings, three  
22 minutes.

23 It turns out that probably isn't so far off  
24 given how fast things are happening. So we will  
25 probably never be able to tell exactly that it's at

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1 14,210 seconds, but the relative behavior and the  
2 shifting, you know, that part I'll probably --

3 (Simultaneous speaking)

4 MEMBER STETKAR: Yes, a picture like this.  
5 This might be, I have small hands so I can't get the  
6 uncertainties large enough, but if we have confidence  
7 that it works this way --

8 DR. COYNE: Right.

9 MEMBER STETKAR: -- and there's good  
10 reason to believe that despite the fact the  
11 uncertainties in both the, and here I'm talking about  
12 the relative times of hot leg and the tube rupture, I  
13 think that's, to me that's compelling information that  
14 indeed, yes, I have confidence in the physics.

15 DR. COYNE: Right.

16 MEMBER STETKAR: On the other hand if you  
17 hadn't thought about the uncertainties and indeed there  
18 is a substantial overlap such that even though you might  
19 show right now 20 minutes, which is sort of what that  
20 shows, the uncertainty is plus or minus an hour, you'd  
21 have a problem.

22 DR. COYNE: So where we are when we started  
23 this work is we had the detailed work for Westinghouse.  
24 I forget the exact words we used at that time, but it  
25 was not a large contributor to LERF but it was not an

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1 insignificant contributor, so it was something that was  
2 worth paying attention to.

3 CE we expected behaved, the CE style  
4 designs I should say, behaved worse than the  
5 Westinghouse style designs. We had not done the  
6 calculations to show that.

7 So that was the big contribution from this  
8 work is being able to show that for CE you had that  
9 overlap that you were demonstrating for Westinghouse  
10 much less so.

11 I acknowledge the uncertainties hadn't  
12 been quantified honestly, they probably won't be  
13 quantified because of resource limitations that we have  
14 and would it appreciably change how NRR would use the  
15 final regulatory product.

16 But I do agree that the report needs to  
17 identify those areas of uncertainty and if it can be  
18 easily or readily quantified we should pursue that, but  
19 a lot of these issues that came up today would be  
20 multi-year research projects in and of themselves and  
21 probably beyond our practical ability to do that  
22 quantification.

23 MEMBER BALLINGER: Can you identify the  
24 areas of uncertainty and then make some kind of  
25 statement about what your judgments are as to what the

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1 effect of that uncertainty might be?

2 DR. COYNE: Well that would be up to the  
3 individual technical aides for the various aspects of  
4 the project and I, you know --

5 MEMBER BALLINGER: Okay.

6 MEMBER STETKAR: I think I heard Kevin say  
7 that they try to at least identify a little bit more  
8 clearly the areas of uncertainty, unless I'm putting  
9 words in our mouth.

10 DR. COYNE: We're trying to and I, you  
11 know, we got a lot of feedback today, which is good,  
12 and there is some areas that we probably need to clarify  
13 in the report to further make it clear of what's feeding  
14 into the uncertainty on the evaluation.

15 CHAIR REMPE: Antonios mentioned  
16 something that hasn't really been brought up much today  
17 or if at all of FLEX and how it impacts the results  
18 currently documented in the report, which doesn't  
19 really discuss FLEX very much, and so that's another  
20 issue to --

21 DR. COYNE: Out of my scope, but honestly  
22 --

23 (Simultaneous speaking)

24 DR. COYNE: -- when we started this work in  
25 2010, and I think I might have mentioned this offline

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1 to several people, one of the potential outcomes was  
2 the identification of having alternate means for plants  
3 with CE style steam generators to be able to mitigate  
4 this better, and by mitigating having alternate means  
5 of adding water to the steam generators.

6 Since we started this work we have the FLEX  
7 program that has come about, which probably addresses,  
8 we haven't looked at it as part of the project, but it  
9 probably addresses a lot of the need that we initially  
10 thought would probably arise from the initial work when  
11 we started in 2010.

12 But we didn't evaluate that as part of this  
13 project though it would be a beneficial outcome from  
14 the FLEX program in general.

15 MEMBER STETKAR: I mean in a sense,  
16 although it's not called FLEX, there is at least some  
17 discussion about SAMGs in this, and I'm still not quite  
18 sure about where the distinct black line is between FLEX  
19 and SAMGs because there seems to be some overlap in  
20 those areas, so in some sense it does address some of  
21 those issues about depressurizing and alternate ways  
22 of feeding steam generators, which now might be called  
23 be FLEX, but in the context of this report might have  
24 been called SAMG.

25 CHAIR REMPE: Okay. So if there are any

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1 more comments or questions before we go around the table  
2 we usually open up the line for public comments and  
3 while we're dealing with that are there any folks in  
4 the audience here today and you feel obliged to want  
5 to make a comment?

6 MR. ZOULIS: Thank you very much. Thank  
7 you.

8 CHAIR REMPE: Okay, are we open?

9 MR. BROWN: Yes.

10 CHAIR REMPE: Is anyone out there, because  
11 we don't have any way of checking you're out there  
12 unless you'll speak up and just say the public's out  
13 here and I have, you know, let us know you're there.

14 So based on the no response I am assuming  
15 that we have no public --

16 MR. HOFFMAN: There is one member.

17 CHAIR REMPE: Oh, good, good.

18 MEMBER STETKAR: Thank you.

19 CHAIR REMPE: Thank you. Do you have any  
20 comments today?

21 MR. HOFFMAN: Yes, I had a couple of  
22 comments.

23 CHAIR REMPE: Please identify yourself  
24 and then go ahead and give your comments.

25 MR. HOFFMAN: Yes. My name is Ace Hoffman

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1 and I live near the San Onofre Nuclear Generating,  
2 former nuclear generating station, so I've been very  
3 interested in the steam generator issue for a number  
4 of years now.

5 There were a lot of times when it was very  
6 hard to hear what was going on and when there were less  
7 than three listeners the machine wanted to cut us off  
8 rather repeatedly, so I wasn't able to pay as close  
9 attention as I would have liked.

10 But I did hear a lot of condemnations of  
11 the way PRAs are used and I couldn't agree more with  
12 that, and also the 95 percent evacuation figure, I  
13 wonder how carefully that's been decided whether or not  
14 it's accurate and whether or not it wouldn't be a good  
15 idea to go to say oh, 98 percent or 99 percent because  
16 those percentages can each be tens of thousands of  
17 people, and so it could make a huge difference.

18 And I heard talk about the operators making  
19 mistakes in not understanding what the real situation  
20 is with the steam generators as one of them loses  
21 pressures and various issues like that are just not  
22 going to come out in a PRA.

23 So I think that based on everything I heard  
24 today that the NRC needs to rethink the use of PRAs.  
25 That's about the only comments that I could make

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1 because, again, it was rather hard to hear a lot of times  
2 during the day.

3 But thank you very much for a very  
4 interesting discussion. Thank everybody.

5 CHAIR REMPE: Thank you for your comments.  
6 Are there any other individuals out there on the public  
7 line who'd like to make a comment?

8 So with that I'll ask you to close the  
9 public line and this is the time when we usually go  
10 around the table and ask for comments. As you start  
11 making your comments, because the current plan right  
12 now is to have a full committee meeting to discuss this  
13 document.

14 The document will not be changed, right,  
15 Kevin, before the full committee meeting and so it is  
16 what it is.

17 DR. COYNE: Correct.

18 CHAIR REMPE: And then they will, actually  
19 the document is already apparently available to the  
20 public if the delve into it, the NRC system, and so at  
21 that point then they'll make some changes and issue it  
22 officially for public comment at the end of this year,  
23 or however they can with the schedule.

24 DR. COYNE: Correct. Following NRC's  
25 feedback, whatever feedback we receive following the

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1 June meeting we'll reflect those comments as best we  
2 can in the document and do some other cleanup and  
3 editorial work and then with the goal of hopefully  
4 issuing it formally as a draft NUREG for public comment  
5 by December.

6 CHAIR REMPE: Okay. So as you go around  
7 the table and you're making your comments, maybe  
8 highlight your key points you'd like to have mentioned  
9 at the end of this meeting to help Kevin a bit more.

10 MEMBER BANERJEE: So, Joy, can you give us  
11 a timeline again? I'm a little confused, this will be  
12 discussed in the full committee meeting in June?

13 CHAIR REMPE: Yes.

14 MEMBER BANERJEE: We'll write a letter in  
15 June?

16 MALE PARTICIPANT: Yes.

17 CHAIR REMPE: You know, that's always the  
18 full committee's decision, but that is the potential  
19 hapticure and so if you have some thoughts now that would  
20 be interesting for me to hear, things that, I mean  
21 they'll probably have an hour or two of full committee  
22 meetings, things you think they should highlight at the  
23 meeting, those are the issues to bring forward at this  
24 time.

25 MEMBER BANERJEE: We've written a lot of

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1 letters, right, on this, and what would be the  
2 particular issues that we would, just the new material  
3 we are seeing or is it about the CE Plant, I'm just  
4 trying to grapple with --

5 CHAIR REMPE: Okay, so the letters that  
6 have been written were on the older steam generator  
7 program, not since the user need was issued and their  
8 work.

9 MEMBER BANERJEE: Okay.

10 CHAIR REMPE: And so, no, there's not any  
11 letters from ACRS since this addressing of --

12 MEMBER BANERJEE: In 2009 or something,  
13 right?

14 CHAIR REMPE: So it's this document,  
15 what's going to occur in the future, those kind of  
16 issues. Do you want to start or do you want a minute  
17 more to think about what you want to say?

18 MEMBER BANERJEE: Well I can start, but,  
19 you know, I need to be clear in my mind what the  
20 objectives are in what we are trying to accomplish with  
21 this letter.

22 In any case I can give you my views. I  
23 think that the Staff did a great job, at least for the  
24 part of it that I am more familiar with, which is the  
25 thermal-hydraulic part.

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1                   They presented their results very well and  
2                   I think I got a clear picture.   What I don't know, and  
3                   I think this is really also what Ronald brought up was  
4                   the effect of uncertainties, in this case primarily  
5                   related to the thermal-hydraulic calculations.

6                   As we were discussing earlier one of the  
7                   issues which is very important is how much mixing  
8                   occurs, you know, and that's sort of key to determining  
9                   what will happen and as your hot legs get larger, really  
10                  for the CE design, what you have is the possibility of  
11                  a core region which is not very well mixed so it sort  
12                  of gets into water in the plenum which is also  
13                  shallower.

14                  So that we've got a situation which is  
15                  somewhat different from what was happening to the  
16                  Westinghouse plants and where we were more sort of  
17                  willing and prepared to consider that because there was  
18                  quite a distance and the tube was sort of waving around  
19                  and the way the, you know, the technical details which  
20                  I don't want to get into, but which give us let's say  
21                  more assurance physically that mixing would occur.

22                  So we need to understand really what the  
23                  uncertainties in these calculations are in terms of the  
24                  mixing.   So at the bottom line that's the key parameter  
25                  that we have to look at.

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1 CHAIR REMPE: So with respect to the draft  
2 NUREG do you believe you have enough information or do  
3 you believe you need the underlying documents to better  
4 --

5 MEMBER BANERJEE: I'd have to go through  
6 the NUREG in sufficient detail to find out whether these  
7 types of thermal-hydraulic uncertainties have been  
8 taken into account or not.

9 CHAIR REMPE: Okay.

10 MEMBER BANERJEE: And maybe the Staff can  
11 address this, how they would address this issue.

12 CHAIR REMPE: Okay. Dick?

13 MEMBER SKILLMAN: I thank the Staff for a  
14 very thorough presentation. It's obvious there has  
15 been a tremendous amount of work. I have no comments.  
16 Thank you.

17 CHAIR REMPE: John?

18 MEMBER STETKAR: I've been admonished  
19 that I can't just say I have no additional comments what  
20 I said, so I have to say yet one more time --

21 CHAIR REMPE: That's the idea here.

22 (Laughter)

23 MEMBER STETKAR: But not all of it. The  
24 two things, short and sweet, are one, in that PRA  
25 insight is the thing that I had mentioned about are the

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1 current constructs of PRA models really looking for all  
2 of the scenarios which might have a vulnerability for  
3 these consequential tube ruptures.

4 In other words, are they complete in that  
5 sense, are the scenario definitions complete. So  
6 that's one thing in terms of PRA insights, if you will.

7 The other one is because of that use of  
8 extreme caution when you try to, if you try to derive  
9 any comprehensive PRA insights about how important this  
10 phenomenon might be either to core damage frequency,  
11 which is probably not all that much, but more  
12 importantly to large early release frequency that the  
13 analyses that had been done are the analyses that were  
14 done but they aren't necessarily a comprehensive look  
15 at the picture, so be careful in terms of selling the  
16 overall conclusion that way.

17 CHAIR REMPE: Okay. Ron?

18 MEMBER BALLINGER: Well I mentioned the  
19 uncertainty issue. I just, it's hard for me to think  
20 of being able to assign a value for LERF in a PRA sense  
21 without factoring in the uncertainty part.

22 It just, I don't know. It just makes, and  
23 I know you've guys have done an awful lot of work,  
24 obviously, very good work, and hampered by the fact that  
25 you have no data, especially on Alloy 600 and 690, you

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1 know, projecting where forward when you have zero data  
2 effectively is just a tough, tough, tough, job to do.

3 CHAIR REMPE: And, Dennis?

4 MEMBER BLEY: Yes. You know, I went back  
5 and I reviewed my notes from the original meeting we  
6 had on these issues and boy a lot has been done and a  
7 lot has gelled in the intervening years. It's  
8 impressive.

9 I found the meeting really helpful. There  
10 has been much more thorough thought on many of the  
11 sticky issues that affect the phenomenology and the  
12 risk assessment than one finds in the draft report and  
13 I hope they can eventually get that rectified in the  
14 document itself, especially with regard to  
15 uncertainties in the thermal-hydraulic analyses and  
16 the use of them in the PRA.

17 I do agree with Mr. Stetkar that the  
18 uncertainty in the scenario development and especially  
19 how the operators might interact with that is still a  
20 little bit on the weak side, but I think they made many  
21 of their cases pretty well.

22 The pressure-induced steam generator tube  
23 rupture piece of the NUREG and the presentation are  
24 certainly much less convincing than the other work.

25 CHAIR REMPE: Okay. I think that's it,

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1 right? So the --

2 MEMBER BLEY: That's all from me.

3 CHAIR REMPE: Okay. So I also wanted to  
4 congratulate the Staff on a lot of work and I realize  
5 that it's been difficult with other priorities coming  
6 into the NRC and I think they've done a good job.

7 In addition to documentation of the  
8 uncertainties I wish there would be also more  
9 documentation on the limitations of the analyses,  
10 that's always an issue no matter how much money you  
11 have, you have to stop somewhere and I don't think it  
12 sometimes has been brought out as clearly as it should  
13 be in the document.

14 I would really like to have, or at least  
15 to ACRS if possible before the full committee meeting  
16 and as soon possible the calculation reports or  
17 background for the MELCOR as well as the CFD analysis  
18 for the CE Plant.

19 I think that there are some differences in  
20 the way SCDAP does a core progression versus MELCOR and  
21 I think seeing more details might be educational  
22 because if we're going to write a letter I think it may  
23 be helpful so that we have a better understanding of  
24 what was done.

25 Sanjoy mentioned the CFD analyses and the

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1 fact that we don't have the underlying report, there  
2 just may be some information. If you think about the  
3 flaw analysis and what was done about the different  
4 plants and understanding how the assumptions were  
5 brought forward in the model it helps us to be more  
6 educated, so I would like to request that strongly.

7 I also would like to know a little bit more  
8 about what was going on about stainless steel  
9 oxidation, if the temperatures when you think about  
10 that they can occur at low temperatures at 600 degrees  
11 C.

12 I mean Dana has mentioned well if there's  
13 some hydrogen there it can delay that, but I mean that  
14 could really make a difference if you start having some  
15 issues with the iron oxide forming and becoming molten  
16 or if it's falling off it would change the situation,  
17 and so it would be good to know if there is some hydrogen  
18 there and, again, maybe the analysis reports will give  
19 us that information.

20 And so with that if there's nothing else  
21 from the Staff I'd like to --

22 (Simultaneous speaking)

23 CHAIR REMPE: Oh, Dr. Powers, you're back  
24 in time to make some comments.

25 MALE PARTICIPANT: Finally closing --

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1 MEMBER POWERS: Oh, on this --

2 (Simultaneous speaking)

3 MEMBER POWERS: On this particular  
4 subject or am I free to talk about anything?

5 (Laughter)

6 CHAIR REMPE: If you don't mind let's keep  
7 it to the subject.

8 MEMBER BALLINGER: You're not aloud to not  
9 make comments.

10 MEMBER BANERJEE: Why? It would be more  
11 amusing if he could --

12 CHAIR REMPE: We'll do that after I bang  
13 the gavel, okay, if any of us would like to stay.

14 (Simultaneous speaking)

15 MEMBER POWERS: Yes. We're working on a  
16 tough little issue here. The things we saw were very  
17 enlightening, very useful. It is clear that the  
18 uncertainties we have and how they affect the results  
19 here are pretty serious in this.

20 We need serious consideration in this  
21 analysis because yes, we see a horse race between  
22 failure at the vessel nozzle versus failure at other  
23 locations and it makes a difference in that.

24 But that's a fairly formidable job to take  
25 into account a full epistemic so I tend to look on this

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1 work here as a snapshot of what we think we know now  
2 and maybe identifying some of the crucial  
3 uncertainties, and I think we've captured some of those  
4 areas of uncertainty.

5 I think one of the things that we need to  
6 think about is in ACRS when we talk on the research  
7 report is where should we be looking for some  
8 experimental support to help this along so we're not  
9 just totally relying on the computer grids to do this.

10 And I guess my final comment is I really  
11 appreciated learning about this gamma distribution,  
12 that was something I had not appreciated how useful a  
13 tool that was for multiple mechanisms affecting things  
14 and I learned something here.

15 CHAIR REMPE: So with that, let's close  
16 the meeting.

17 (Whereupon, the above-entitled matter  
18 went off the record at 5:03 p.m.)  
19  
20  
21  
22  
23  
24  
25

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# **Severe Accident-Induced Steam Generator Tube Rupture (SGTR)**

## **Opening Remarks**

Dr. Raj Iyengar, RES/DE

**Consequential Steam Generator Tube Rupture (C-SGTR) Subcommittee Briefing**

**April 7, 2015**

# Purpose and Background



- NRR User Need Request “Developing Analytical Bases and Guidance for Future Risk Assessments of Consequential Steam Generator Tube Rupture (C-SGTR) Events” issued December 2009
  - Requested development of improved analytical bases and guidance for probabilistic risk assessments of C SGTR events
- Subsequent to an April 2011 ACRS sub-committee briefing, NRR Management requested RES to restructure project to focus on near-term deliverables and to allow for an incremental approach
  - RES issued a document (Jan. 2012) identifying “hold-points” to resolve near-term deliverables before proceeding with the full scope
- Informal meetings with lead ACRS member for C-SGTR issues (Dr. Rempe) held January 2012, January 2013, and April 2013
- ACRS full-committee meeting in May 2013
- Subsequently, staff prepared a draft NUREG (transmitted to ACRS staff on Feb 19, 2015)



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# **Severe Accident-Induced Steam Generator Tube Rupture (SGTR)**

## **Thermal Hydraulic Analyses**

Dr. Michael Salay, RES/DSA  
Dr. Christopher Boyd, RES/DSA

**Consequential Steam Generator Tube Rupture (C-SGTR) Subcommittee Briefing  
April 7, 2015**



# Topics

- CSGTR Scenario Description
- TH analyses
- Method (CFD & System Code)
- Experimental Basis
- Differences Between CE and Westinghouse Plants
- Combustion Engineering MELCOR analyses

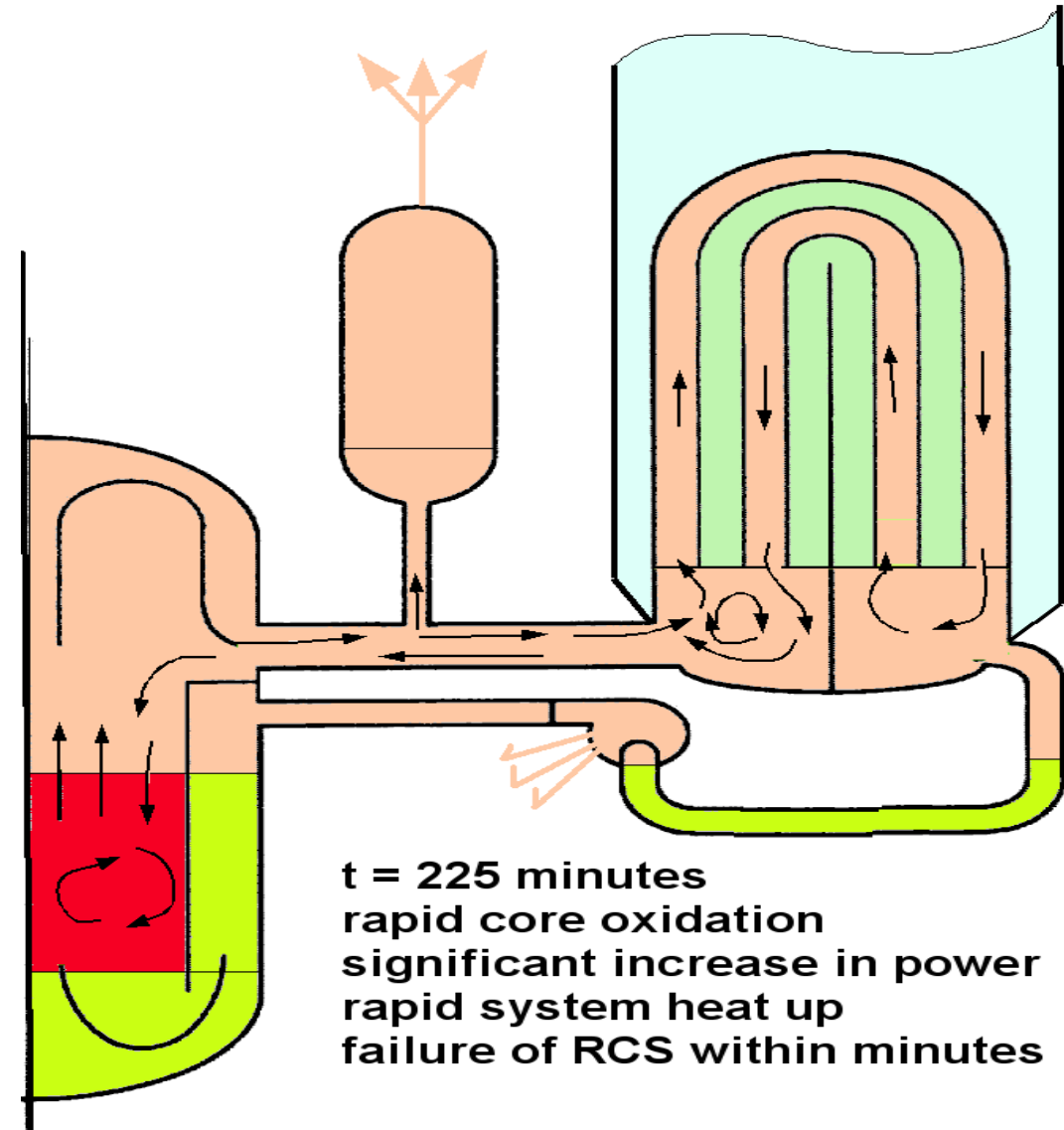
# The Station Blackout

- A low probability station blackout event with immediate or subsequent loss of feed water to the steam generators.
- Reactor inventory boils off resulting in fuel damage and high temperature and high pressure conditions within RCS.
- Failure of the RCS boundary is induced by these conditions.
  - If SG tubes fail first, then a flow path is created that bypasses the containment
  - Failures of other RCS components (hot leg or surge line), RCS blow down into the containment
  - Determining SG tube failure is important in consequence analysis

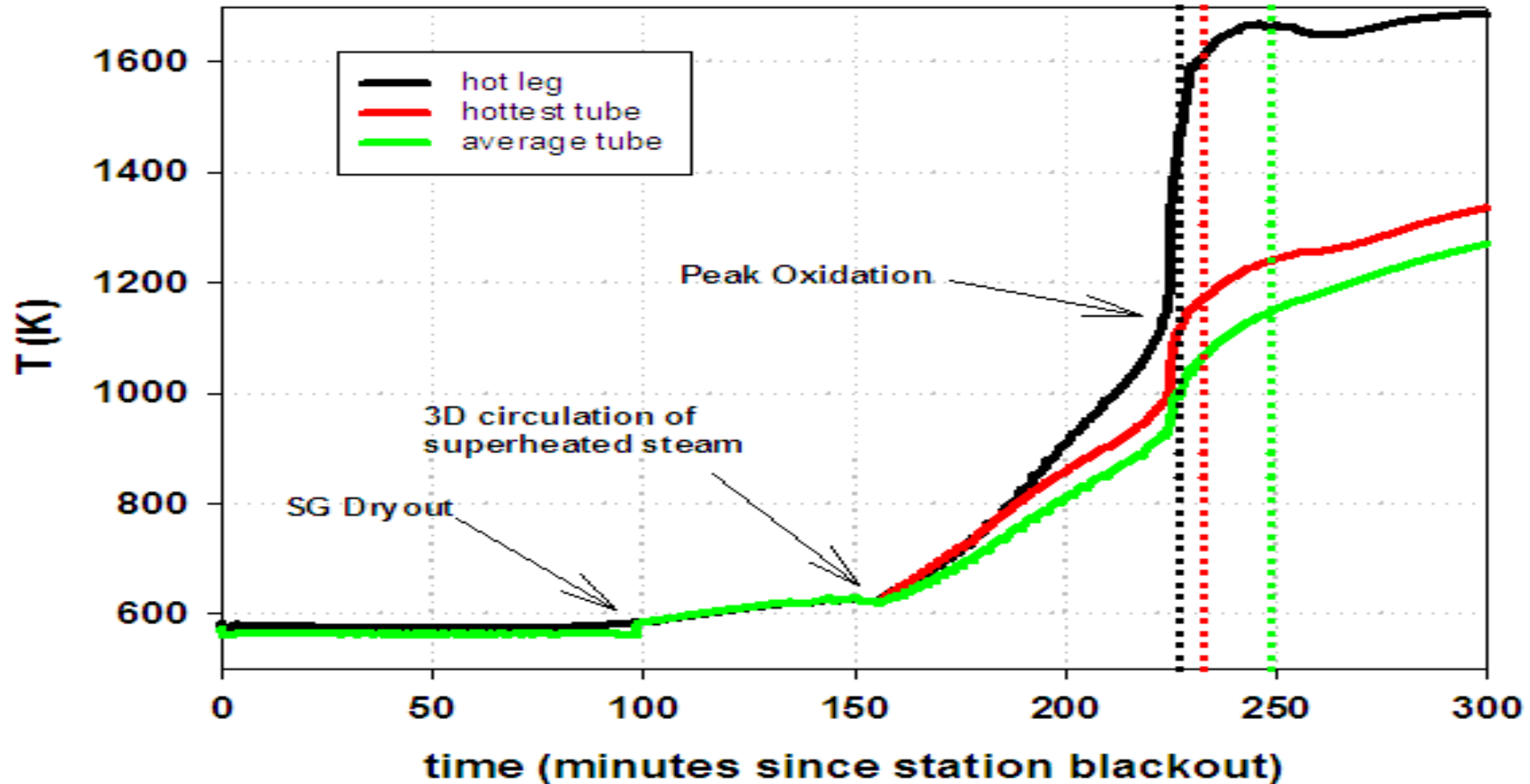
# A Fast Scenario

RCS failure within 4 hours

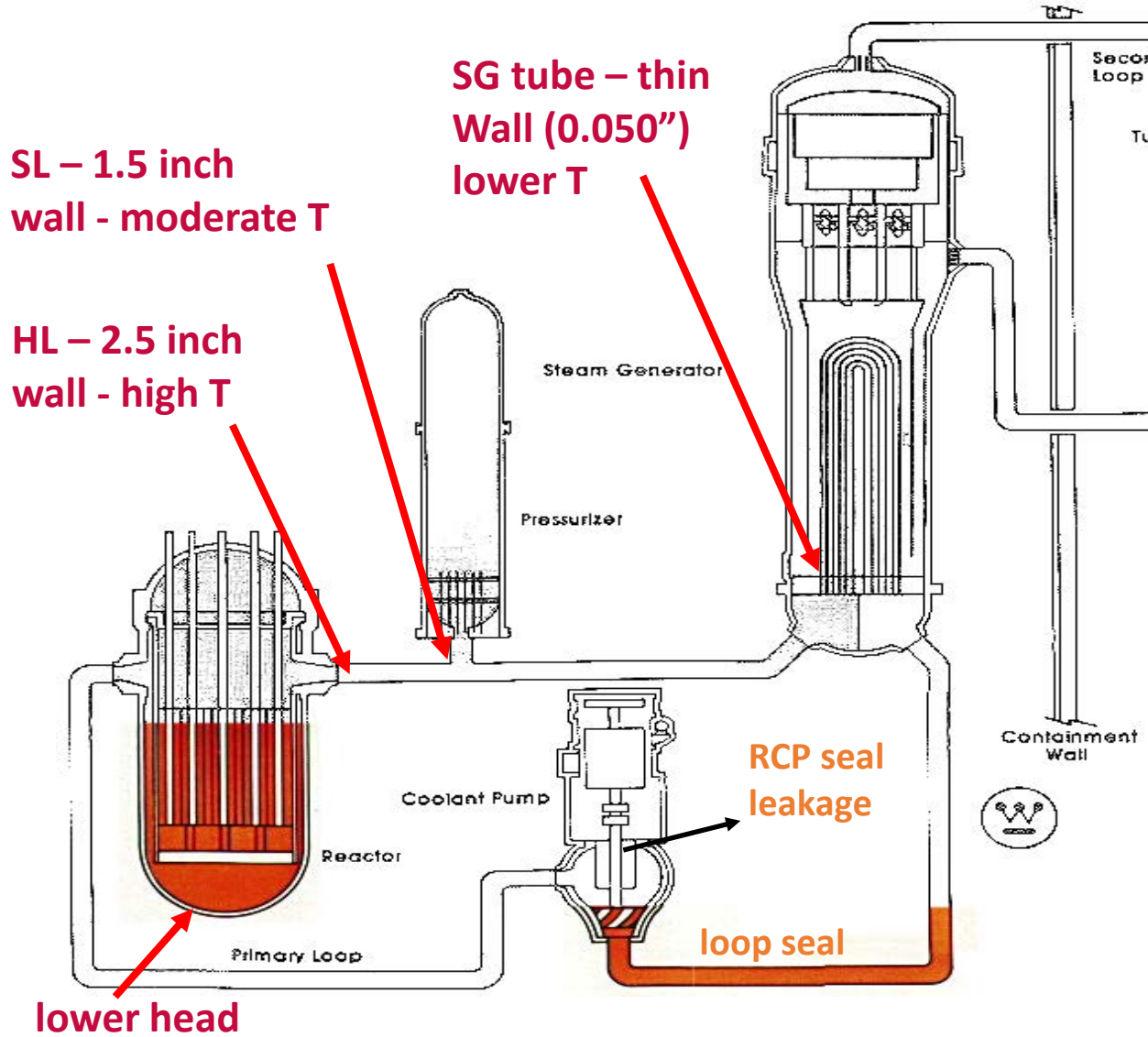
- loss of offsite power, failure of diesels, and failure of auxiliary feedwater systems
- primary inventory lost through reactor coolant pump seals. Secondary side boils off
- secondary side dry, primary inventory lost through safety valve cycling and pump seals
- loop natural circulation stops as primary inventory falls in SG tubes.
- natural circulation of superheated steam begins as inventory falls below hot leg. Core and system heat up.
- Core uncovers, core oxidizes and produces significant power, system heat up accelerates and induced failure is predicted for RCS components.
- More likely scenarios involve some auxiliary feedwater or operator actions that significantly delay the failure time.



# RCS Structure Temperatures –Fast Scenario



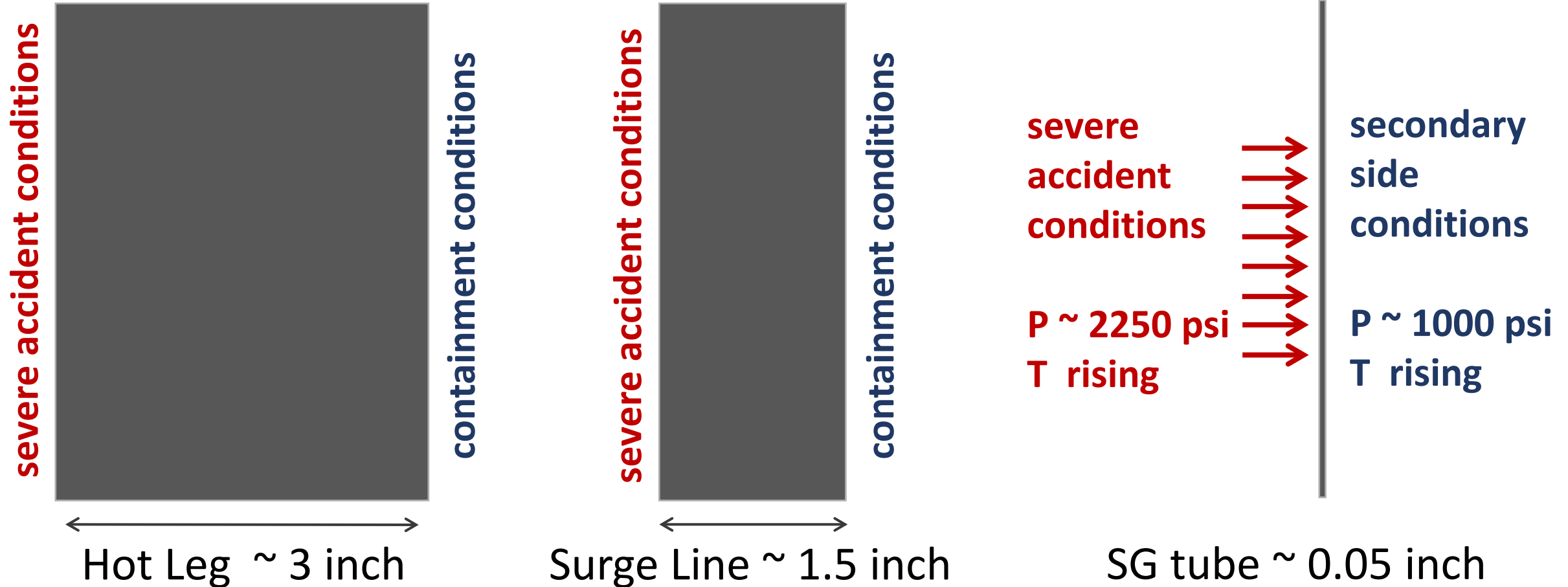
# RCS Points of Interest



## Considerations

- ~  $T=1475$  K, start of rapid Zirc Oxidation
- ~  $T=1725$  K, Melting Stainless and Inconel
- ~  $T=2030$  K, Melting of Zircaloy-4
- ~  $T>1175$  K, tubes fail at system Pressure
- Rapid temperature rise and pressure difference leads to induced failure.
  - failure location affects consequences
- SG tube ruptures provide a path for fission products to bypass containment.

# RCS Boundaries



# High-Dry-Low

## Primary Side

### High Pressure

\* no significant leakage to reduce pressure

## Secondary Side

### Dry

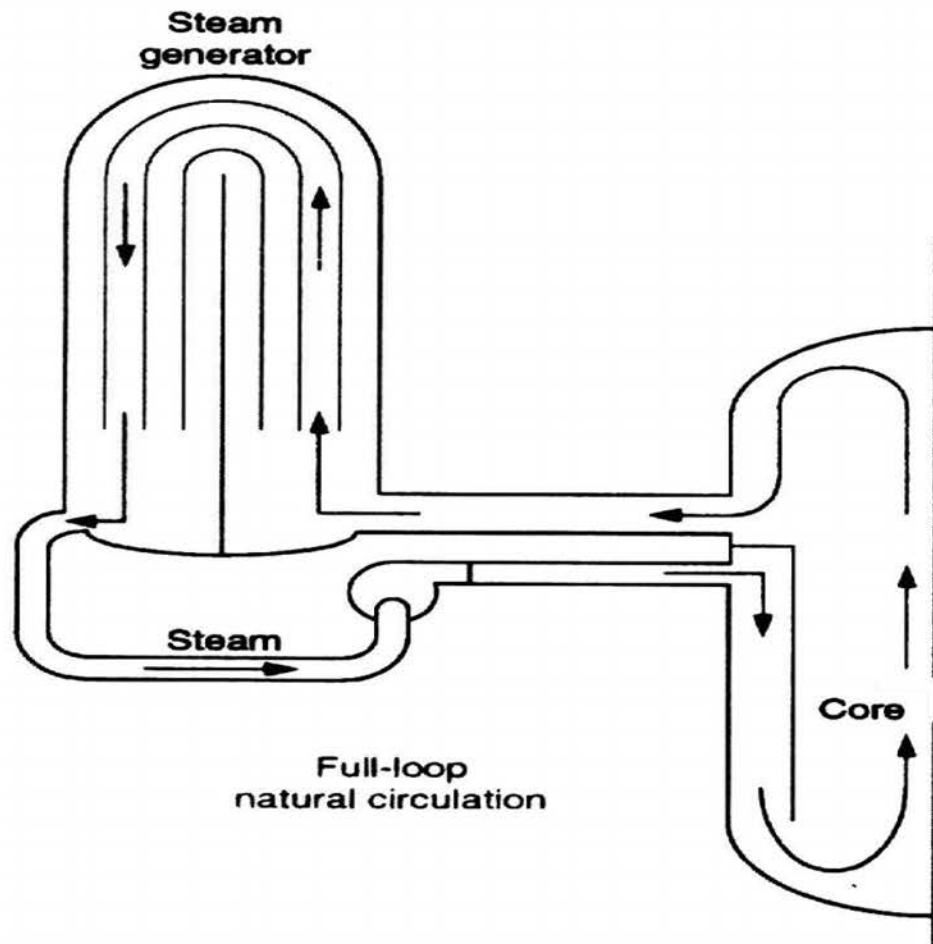
\* Loss of water allows tubes to heat up

### Low Pressure

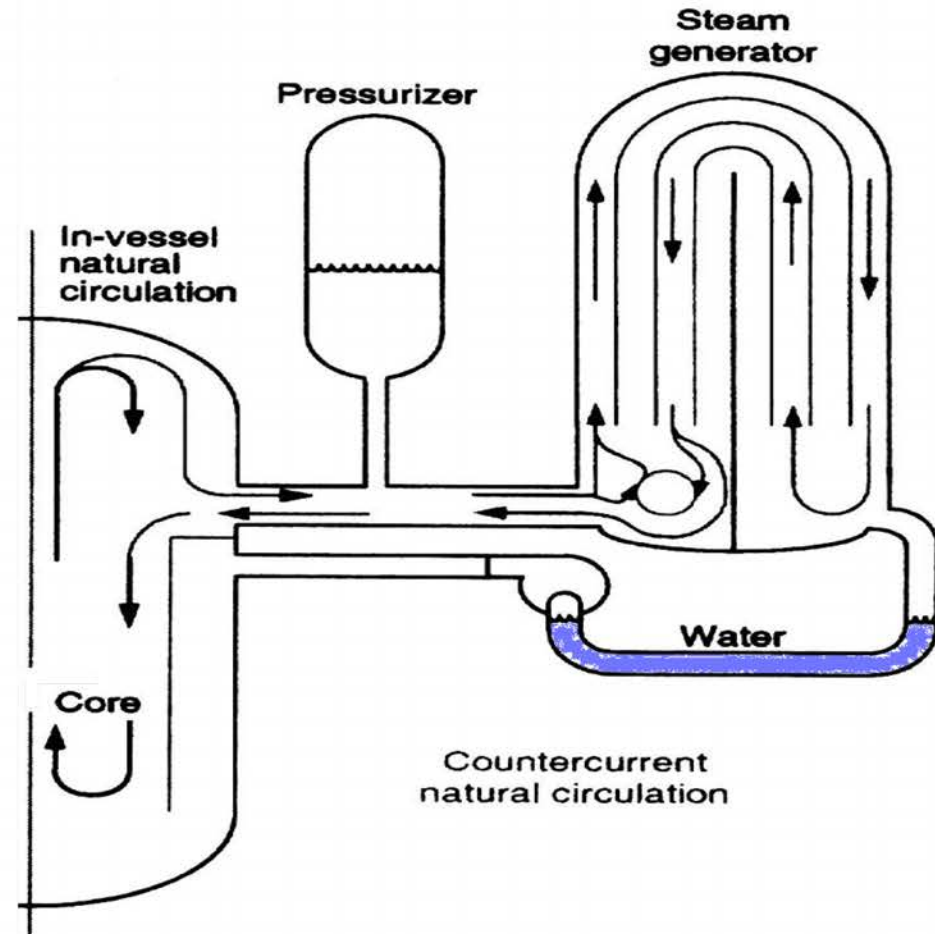
\* Secondary side leakage increases pressure difference (i.e. mechanical load on wall)

SG tube  
wall

# Two Flow Patterns - PWRs with U-Tube SGs



**full-loop natural circulation**

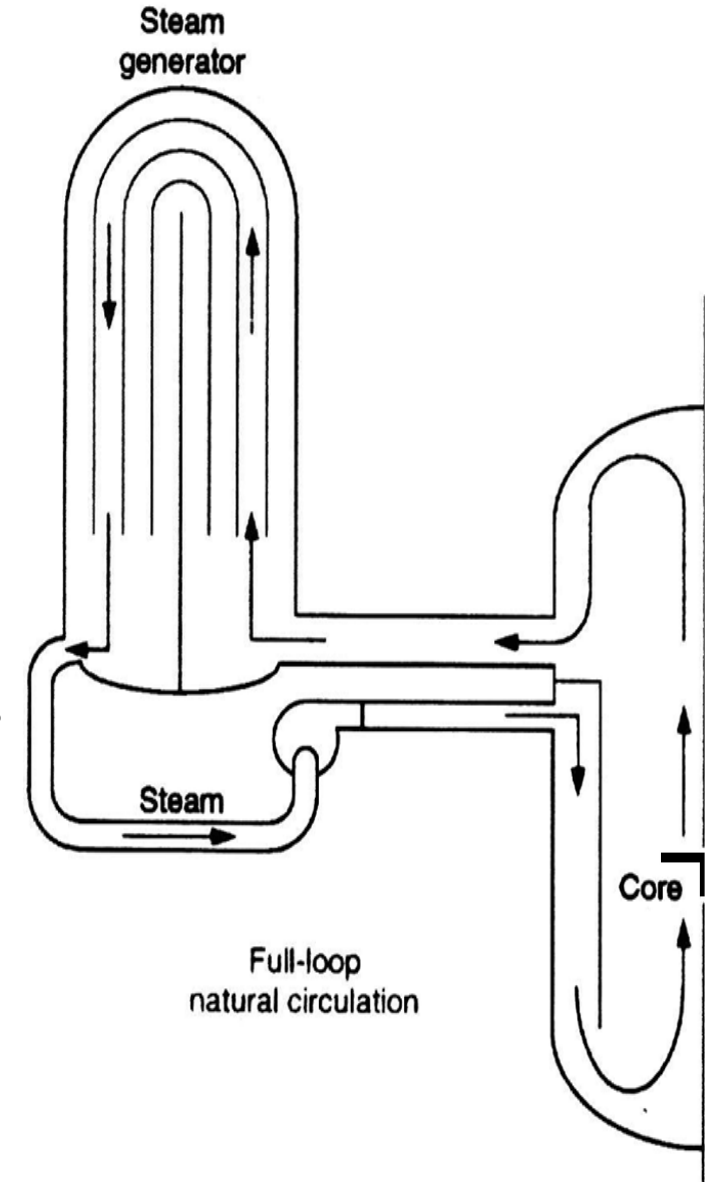


**Counter-current natural circulation**

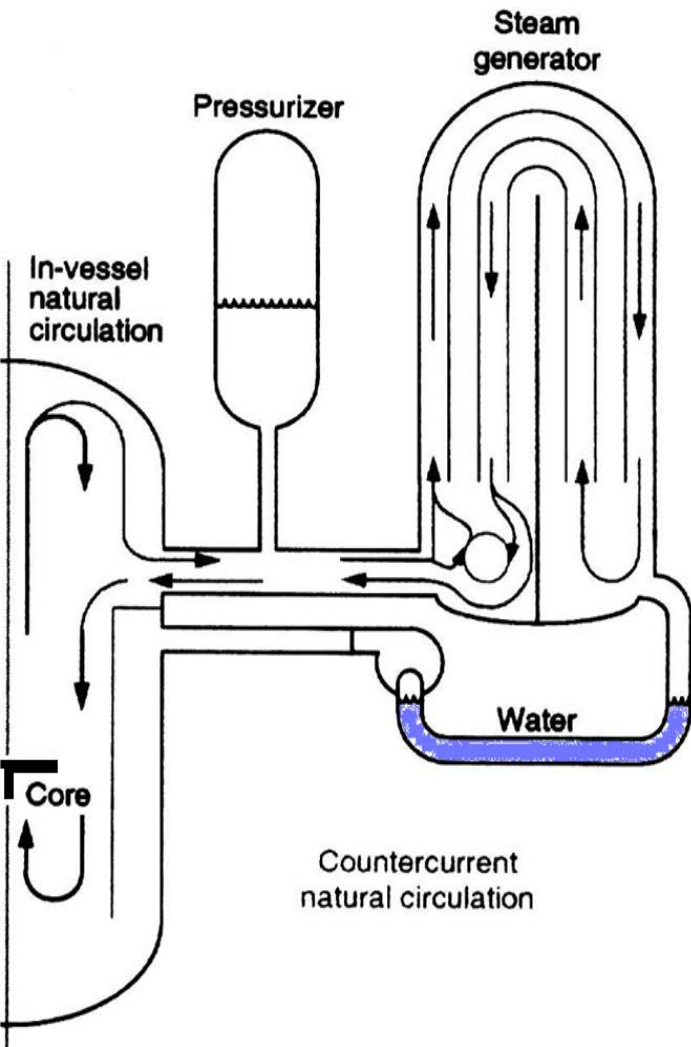


# Full-Loop Natural Circulation

- Water cleared from the reactor coolant pump loop seal (and lower downcomer).
- Loop seal clearing is affected by:
  - depth of the pump loop seal and water temperature
  - reactor coolant pump seal leakage rate and elevation
  - primary side depressurization rates
  - downcomer bypass flows
- Westinghouse PWR studies have indicated that loop seals are more likely to remain blocked with water.
- Careful modeling and benchmarking is important to build confidence in predictions of loop seal clearing.
- Full loop circulation reduces mixing of the hot gasses that enter the SG tube bundle. A severe thermal challenge.
- System analysis tools such as MELCOR or SCDAP/RELAP5 are used to predict the system flows and heat transfer.



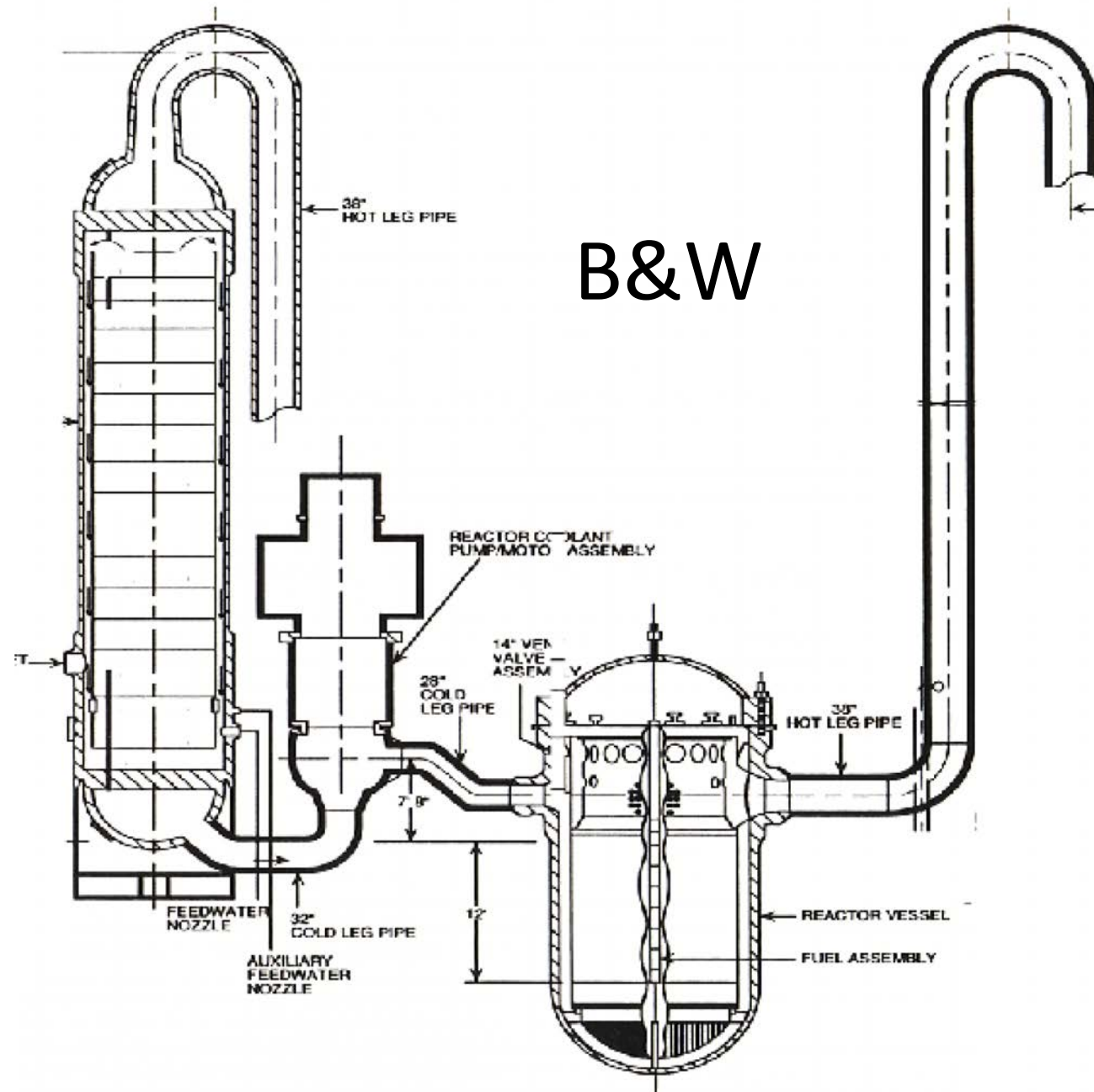
# Counter-Current Natural Circulation



- With the pump loop seal filled with water, a counter-current flow field is established.
  - This flow pattern mixes the hot gases with cooler flows returning from the SG. The thermal challenge to the tubes is reduced but not eliminated.
- System code models require external information to ensure consistency:
  - hot leg flows, mixing, and heat transfer
  - inlet plenum mixing and entrainment
  - pressurizer surge line mixing
  - SG tube bundle flows, temperatures, and distribution
- System codes account for the overall response but are not designed to explicitly predict the three dimensional mixing and entrainment.
  - MELCOR and SCDAP/R5 models are adjusted to ensure consistency with experiments and/or CFD predictions

# What about B&W Plants?

- Vigorous natural circulation flows are not expected due to the elevations and design of the hot legs and steam generators.
- These plants have not been part of the recent severe accident induced failure studies.



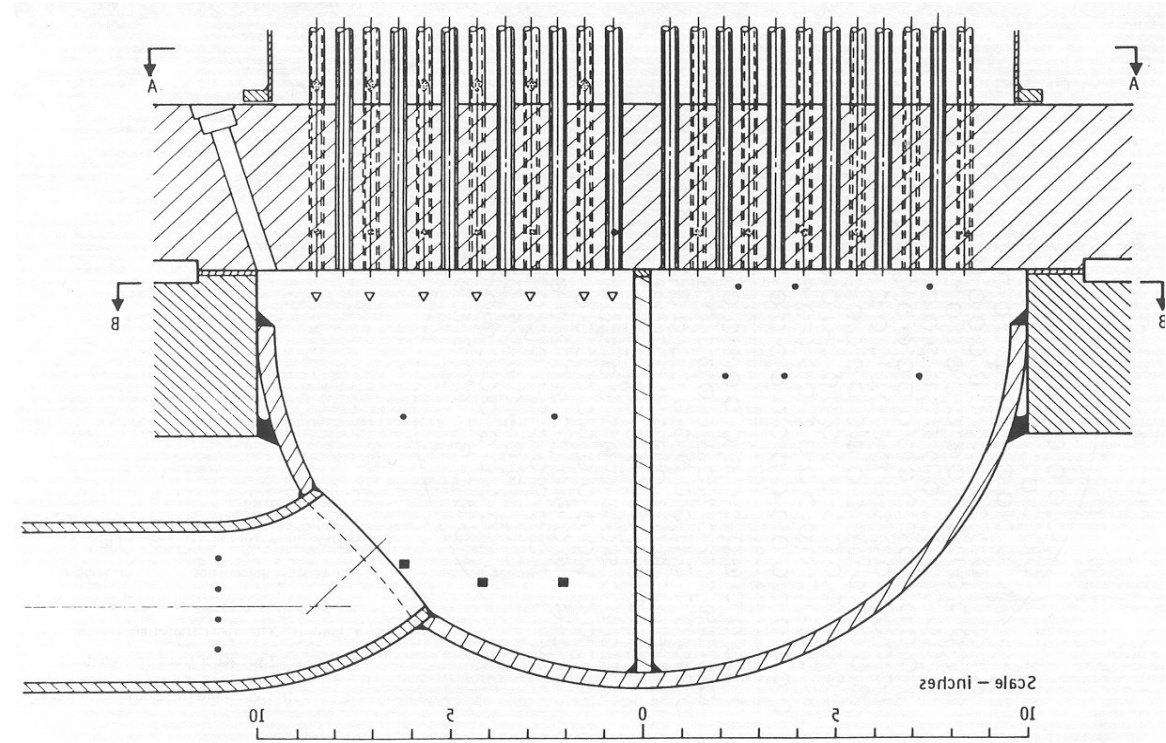
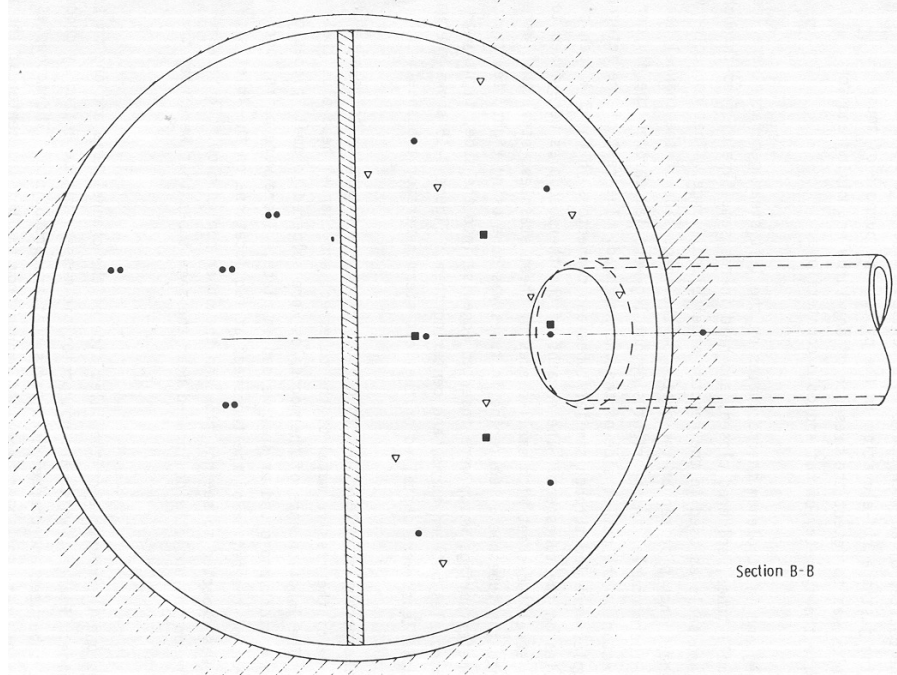
# TH Analyses

- Both Westinghouse and Combustion Engineering TH analyses used
  - Input to tube-failure calculator and Finite Element Models
- Westinghouse TH analyses performed for the Steam Generator Action Plan (SGAP)
  - Documented in NUREG/CR-6995
  - TH analyses for Combustion Engineering (CE) plants did not receive the same level of attention
- TH analyses conducted with CE under C-SGTR project

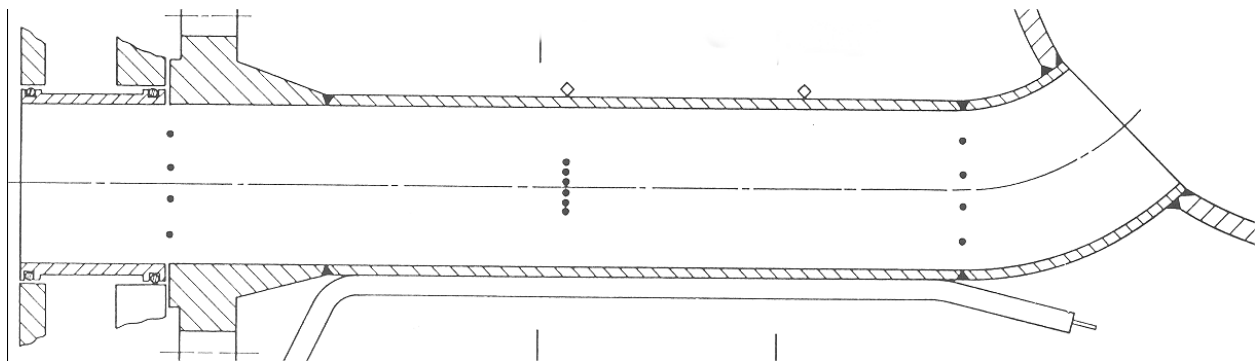
# Method

- Computational Fluid Dynamics (CFD) and System Code
  - CFD predicts spatial flow and temperature distribution
  - System code predicts transient behavior
    - Uses CFD results for counter-current flow in hot leg
    - Results can be combined with those of CFD to obtain a transient spatial temperature distribution
- CFD approach validated using Westinghouse 1/7<sup>th</sup> scale tests

# Westinghouse 1/7<sup>th</sup> Scale



- \* 4 inch hot leg
- \* 216 SG tubes
- \* Temperature measurements
- \* Facility included vessel, electrically heated core, and two steam generators.

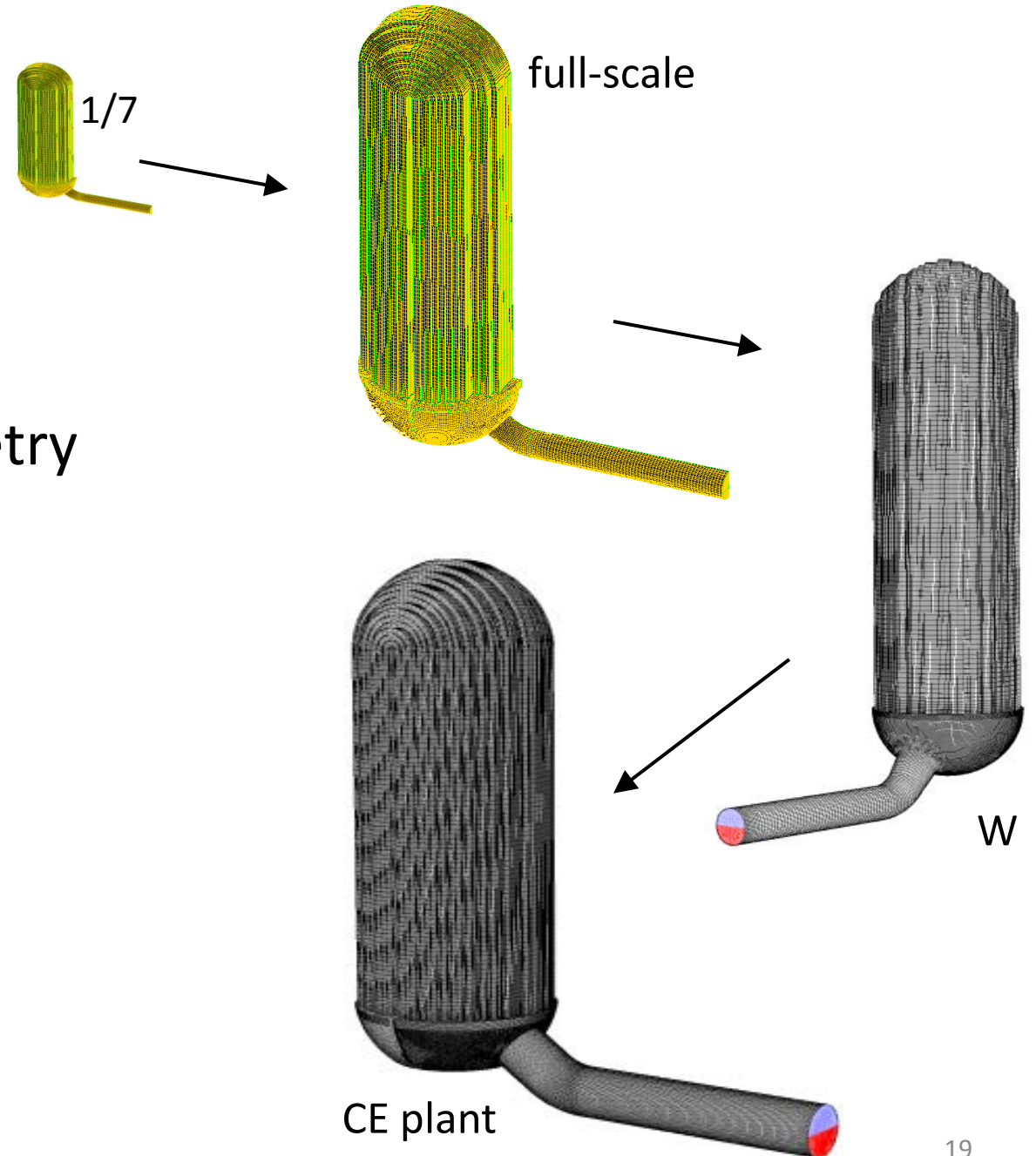


# Westinghouse 1/7<sup>th</sup> scale tests

- Demonstrated the counter-current flow path
- Not focused on tube integrity but provide valuable insights
- Many scaling studies demonstrate applicability to full-scale
- Results helped inform modifications made to system codes (SCDAP/RELAP5 or MELCOR) used to study the station blackout scenarios.
- Around 2001, CFD was used to study these tests

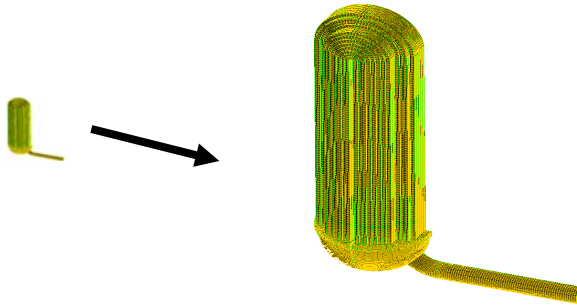
# CFD Developments

- Benchmark at 1/7<sup>th</sup> scale
- Scale-up to full-scale conditions
  - Using test facility geometry
- Prototypical W. Model 44 SG Geometry
  - Compare to test facility
- Sensitivity studies
  - Heat transfer
  - Surge Line orientation
  - Hydrogen Content
  - Tube Leakage rates
- Combustion Engineering Design





# Scale-Up

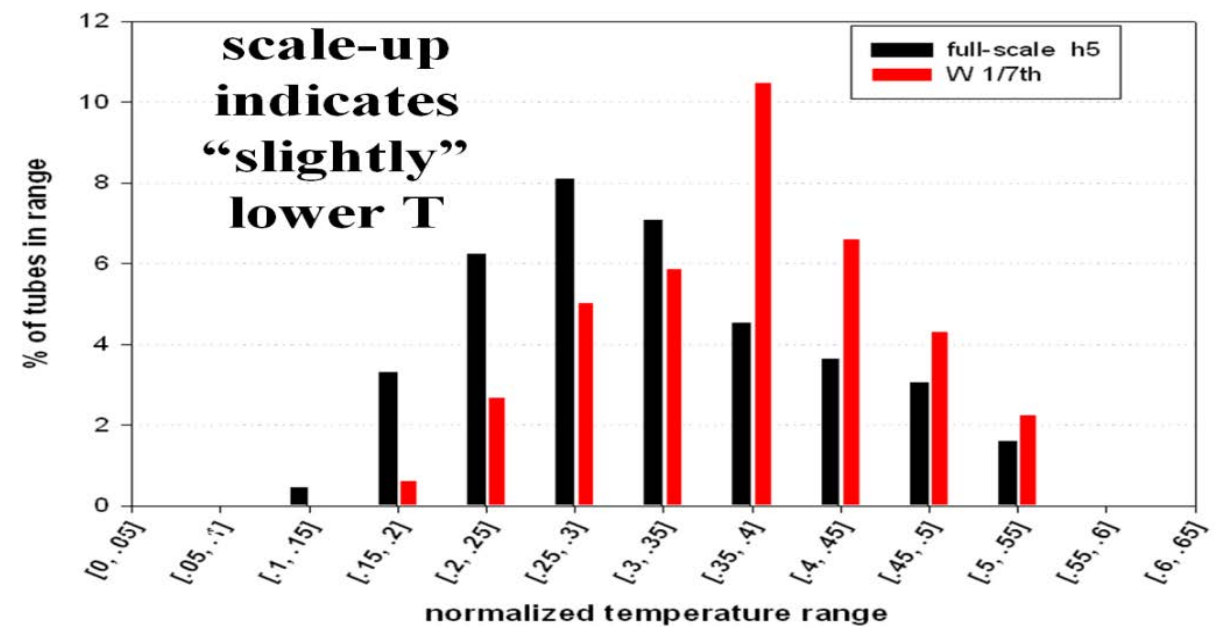


$1/7^{\text{th}}$  scale /  $SF_6 \gg$  full scale  
severe accident conditions

Solutions are similar when heat transfer rates are scaled.

Heat transfer rates under severe accident conditions are different, however, and the geometry is not similar.

Impact of these distortions needs further analysis

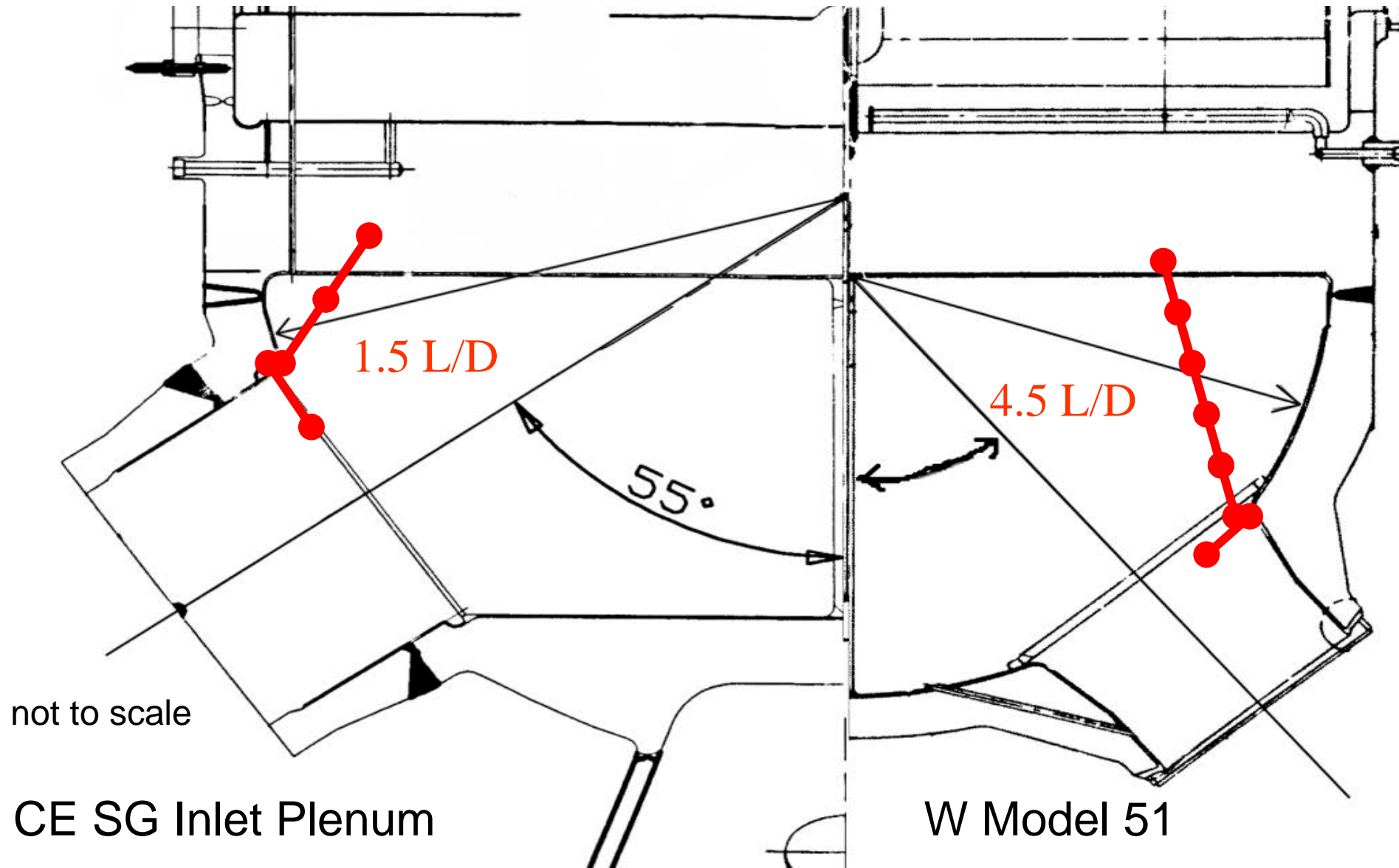


|   | full-scale<br>h5 | 1/7 <sup>th</sup> scale<br>case |
|---|------------------|---------------------------------|
| Tube heat loss (kW)                                 | 5047             | 3.7                             |
| m (hot leg flow – kg/s)                             | 4.2              | .059                            |
| Th (hot leg hot temp)                               | 1404 K           | 428 K                           |
| Th <sub>t</sub> tubes (average tube hot temp)       | 1046 K           | 373 K                           |
| m <sub>t</sub> (tube flow - kg/s)                   | 9.1              | 0.12                            |
| <b>m<sub>t</sub> /m<sub>L</sub> (recirc. Ratio)</b> | <b>2.16</b>      | <b>2.06</b>                     |
| <b>% of Hot Tubes</b>                               | <b>38</b>        | <b>38</b>                       |
| <b>f (mixing fraction)</b>                          | <b>.92</b>       | <b>.81</b>                      |

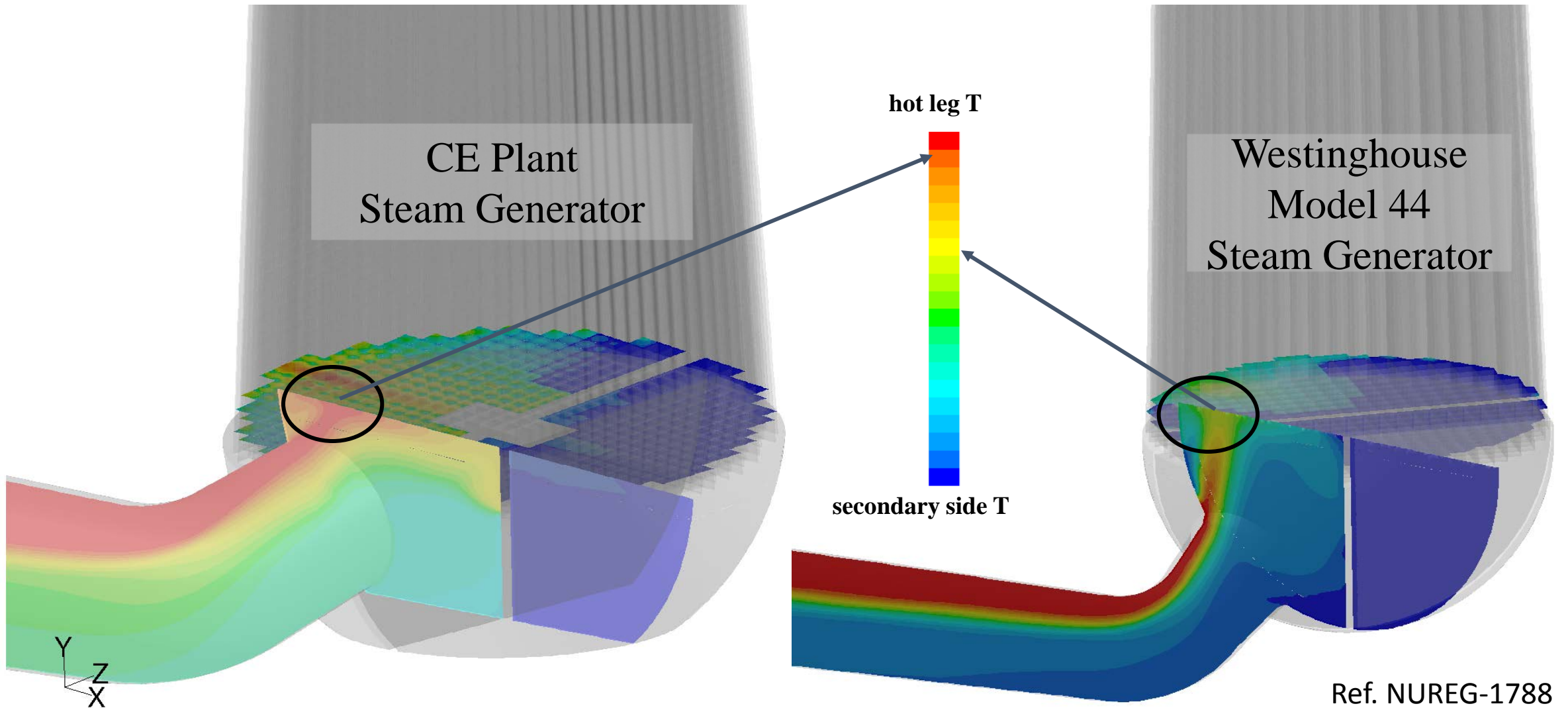
# CE SGTR Behavior Differs from Westinghouse Plants

- Less mixing of hot gases before reaching SG tube inlets
  - Lower hot leg Length/Diameter ratio
  - Some CE plants have shallower inlet plena
- In CE SG tubes are exposed to similar gas temperatures as hot legs
- Under certain conditions unflawed tubes could rupture before hot legs
- Unlike for the rupture of a flawed tube, multiple unflawed tubes could potentially reach the failure condition nearly simultaneously resulting in a rupture large enough to depressurize the RCS sufficiently fast to prevent failure of other RCS components.

# The CE inlet plenum (compared to W model 51)



# CFD Predictions - Westinghouse and CE (hottest tube region circled)



(temperature contours on vertical centerline plane of hot leg)



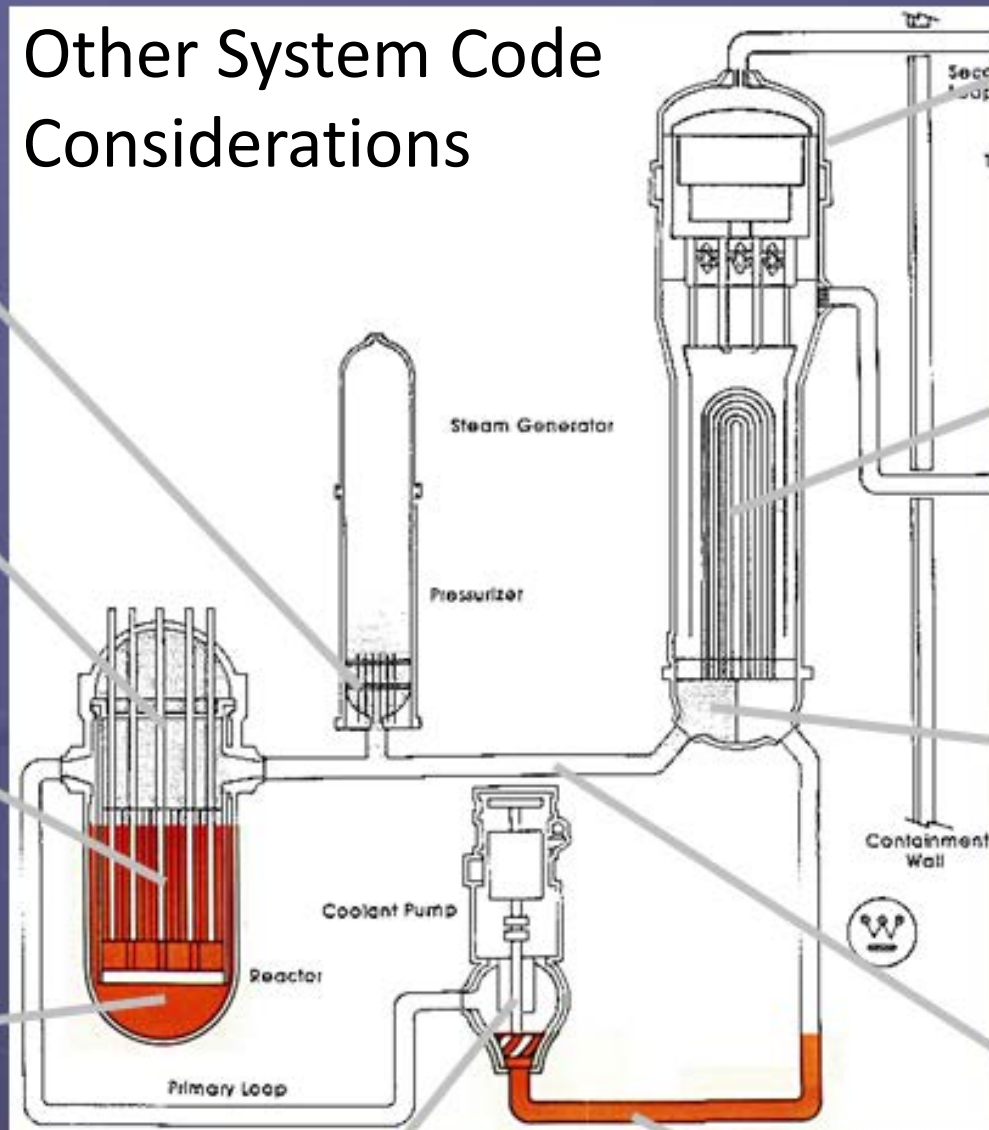
## Other System Code Considerations

pressurizer draining  
surge line orientation

natural circulation  
core bypass flow

oxidation rate  
core blockage  
nodalization  
natural circulation

nodalization  
downcomer clearing



shell heat loss  
SG depressurization

tube heat transfer  
secondary flows  
mass flow  
tube fraction  
leakage  
plugging  
vertical node count

inlet Plenum mixing  
recirculation ratio  
plume T distribution

HL Flow rate  
entrainment  
radiation modeling  
entrance effects

pump seal leakage  
suction height

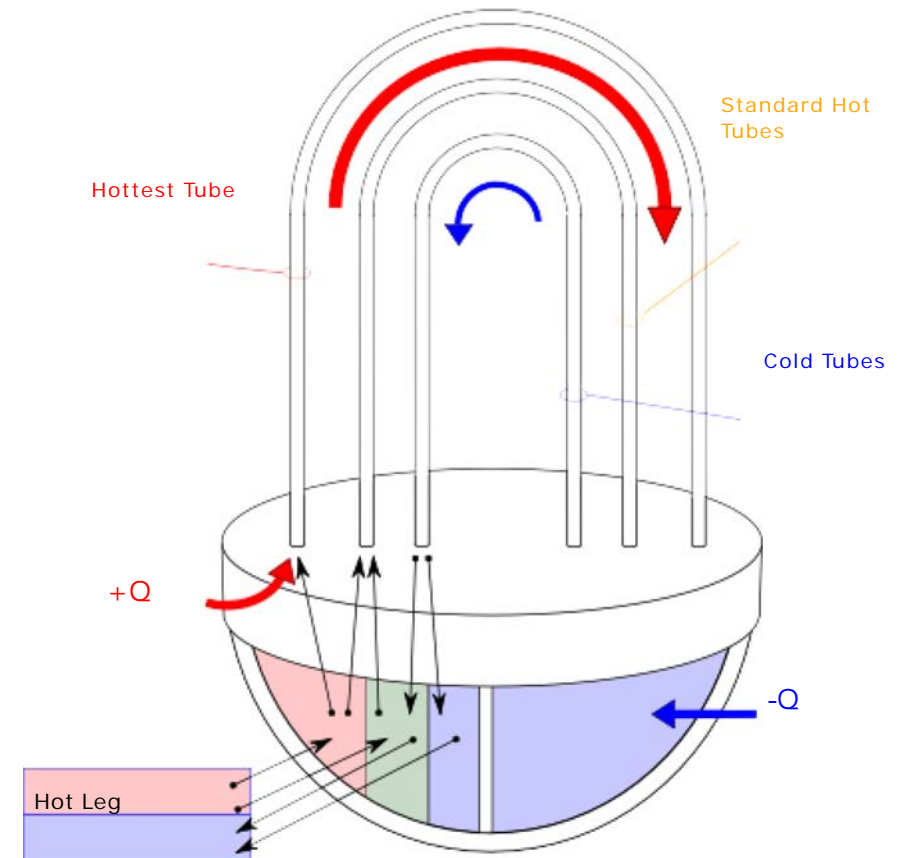
loop seal clearing

# MELCOR CE calculations

- SNL generated Combustion Engineering deck
  - based on previous RELAP and MELCOR decks
- Areas of focus
  - Addition of Hottest Tube
  - Estimation of tube temperature profile
  - Secondary relief valve opening criteria
    - Valve sticks open after n cycles
    - Valve sticks open upon high T cycling
    - Valve sticks open as far as it has opened
    - Operator opens valve to depressurize secondary
- Results

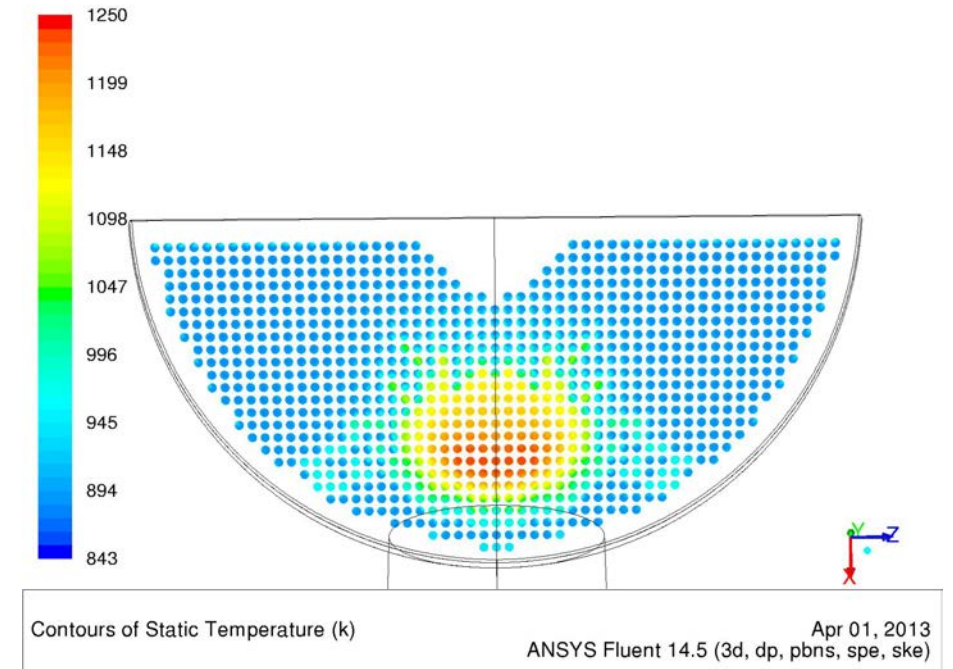
# Addition of Hottest Tube

- Hotter tubes fail earlier
  - Need to capture peak T
- Calc based on CFD results
  - Provides “anchor” to estimated temperature field
- A few methods were tried
  - Postprocessing method
    - Reasonable results
  - Side-calculation method
    - CF link to main calc
    - similar to SGAP RELAP calculations
    - issues with CF copy
  - Heat addition method
    - similar to more recent calculations
    - Used this method



# Approximation of Tube Temperature Field

- MELCOR calculates  $T(t)$  for 2 sets of hot tubes (hot and avg)
  - Apply CFD-calculated profile to get time-dependent  $T$  field for tube failure calculations
- CFD SG temperature field approximated using parabolic shape
  - plume assumed circular, symmetric, and to reach top of SG tubes
  - radius at bottom set to match the number of in-plume tubes calculated by CFD
- Can map flaws to  $T(t)$  field
  - Lower  $T$  on average than current methods
  - Still bounds CFD results
- SG Inlet Plume  $T$  Profile





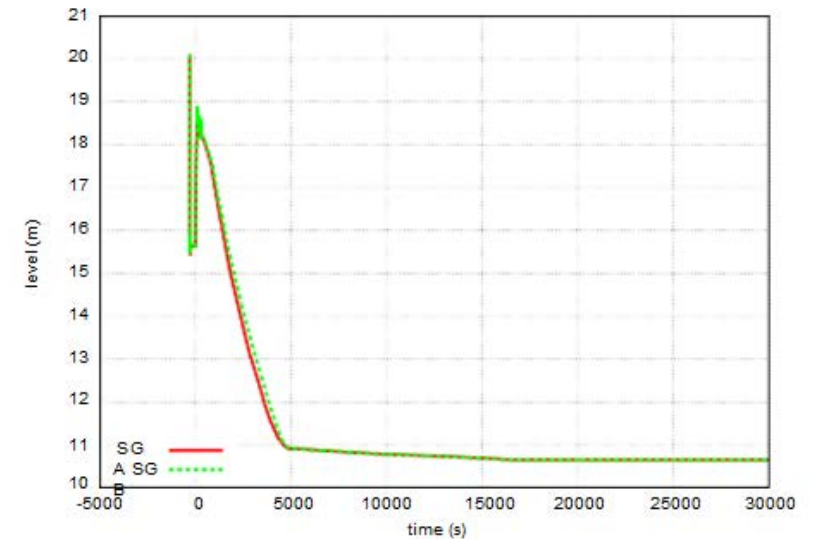
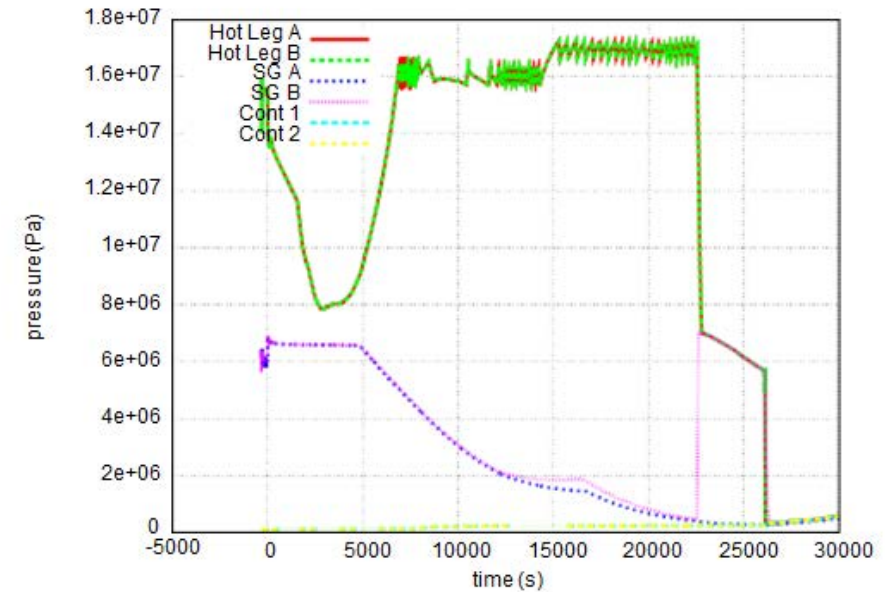
# Results

- Most results for STSBO

- Early TDAFW failure
- Small SG secondary leak

- Features

- Primary P ↓ when SG wet
- Secondary P high until SG dry
- Primary P increases as SG dries out
- Primary P limited by SRV setpoint
- Structure T ↑ when Zr oxidizes
- P Primary and SG equilibrate upon tube rupture
- P remains high enough to rupture HL



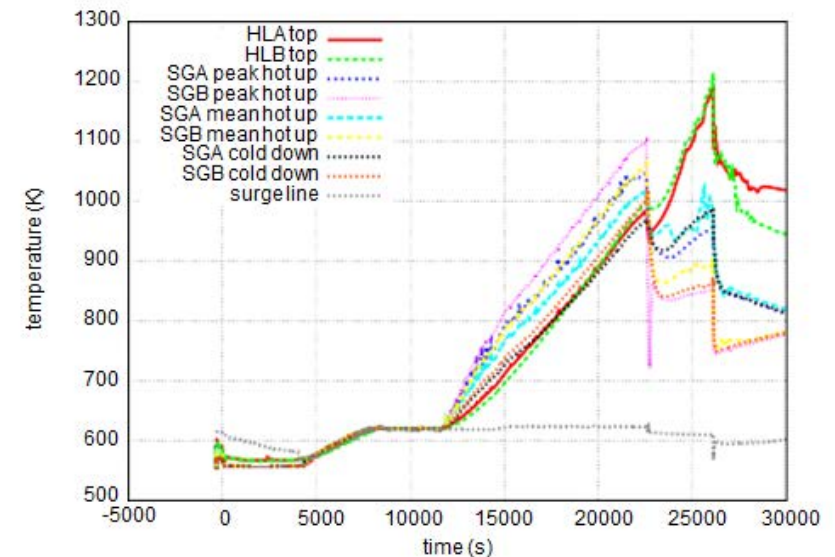
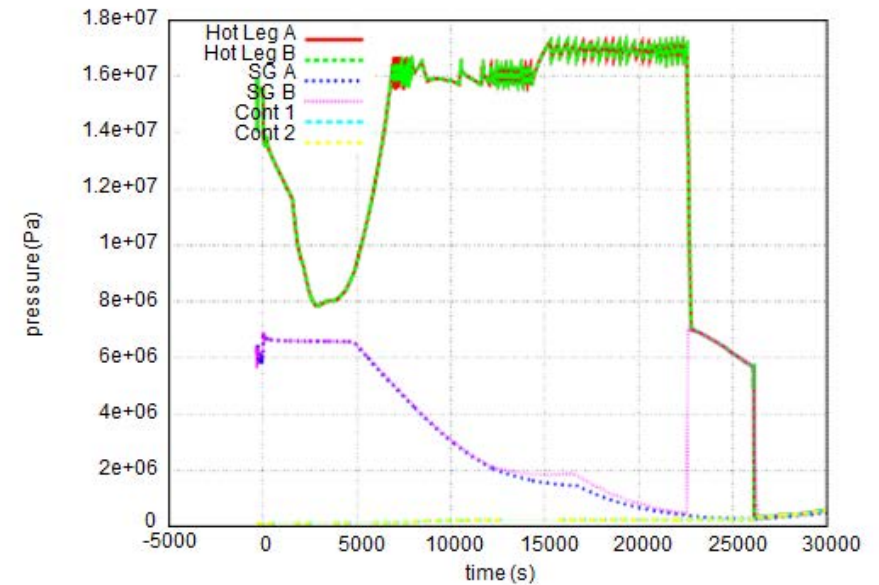
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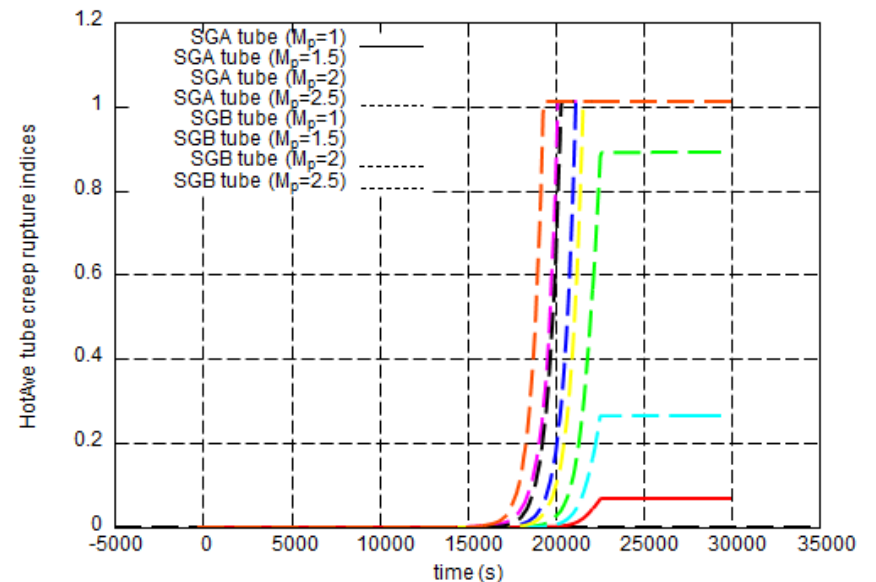
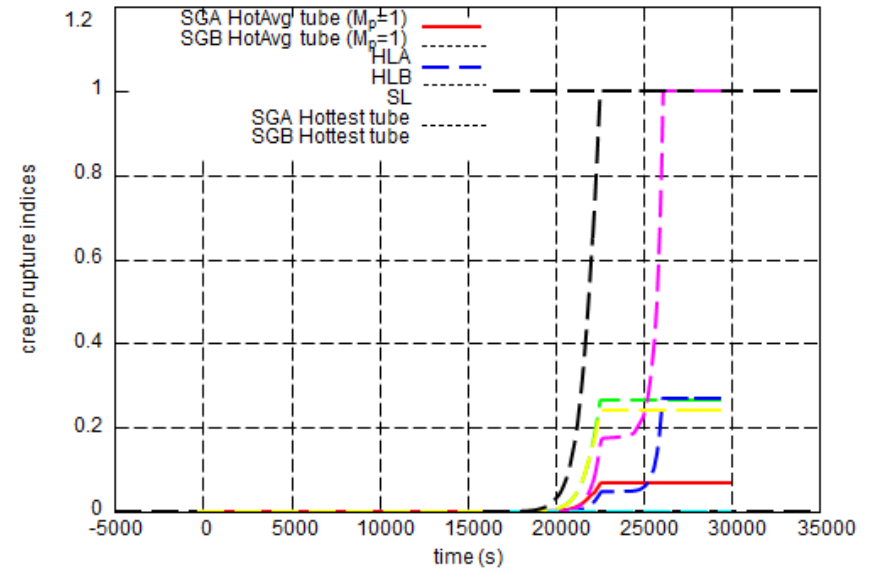
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# Rupture Behavior

Rupture also calculated with MELCOR as screening check

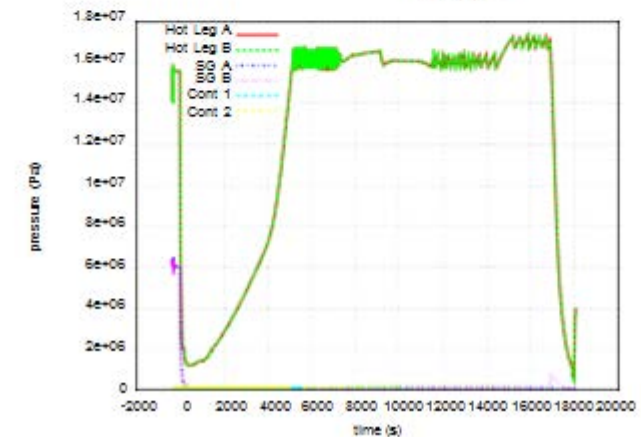
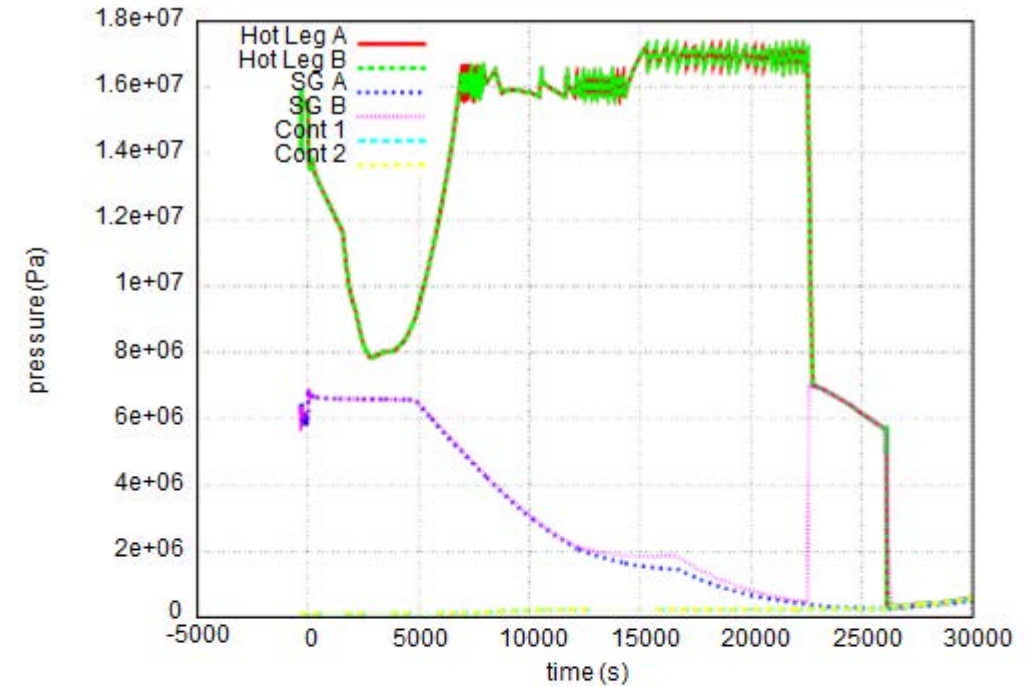
- Rupture behavior for STSBO case
  - Loop B hottest tubes fail first
  - Loop B Hot legs fail some time after
  - Other components did not reach failure conditions
  - Only unflawed average-T and hottest-T plume tubes considered
- Also considered tubes with different stress multipliers
  - Represents different flaws
  - Can be used to characterize rupture behavior after the fact



# Some sequence variations

A few of the variations that were run

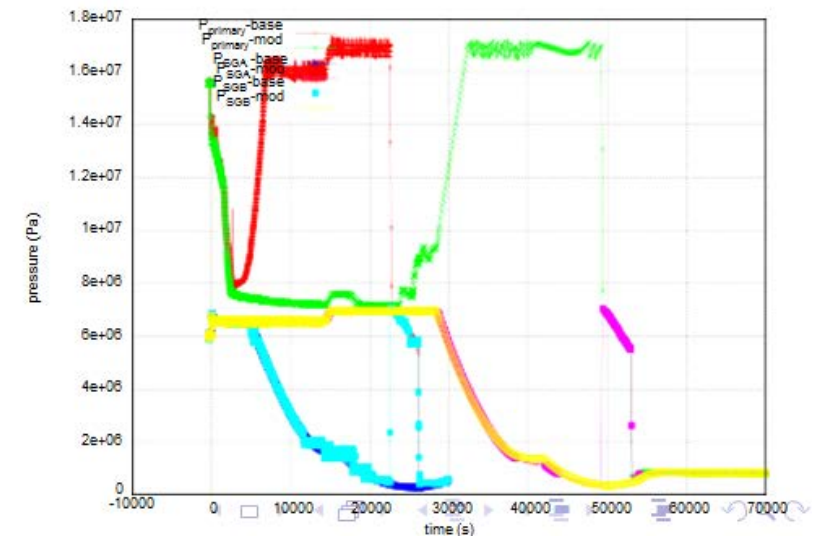
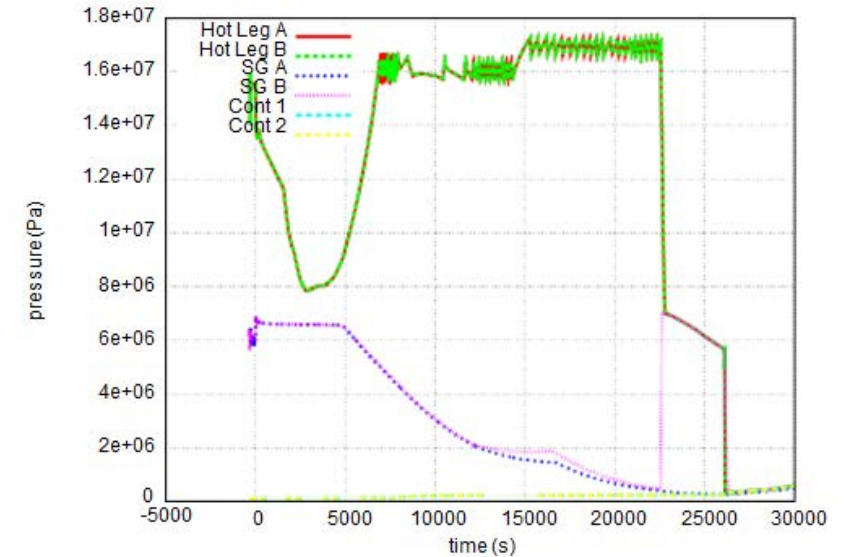
- Compare operator of opening secondary relief valves
  - Depressurization to enable low-P SG injection
  - Much faster and stronger depressurization of primary system
  - Earlier SG tube rupture
- Compare long term station blackout
  - TDAFW assumed to operate for 4 hours
  - Similar, but 4 hour shifted, behavior



# Some sequence variations

A few of the variations that were run

- Compare operator of opening secondary relief valves
  - Depressurization to enable low-P SG injection
  - Much faster and stronger depressurization of primary system
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- Compare long term station blackout
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  - Similar, but 4 hour shifted, behavior



# Summary/Conclusions for MELCOR CE Analyses

- CE CSGTR behavior differs from Westinghouse behavior
  - This is caused by less mixing of hot gases before reaching SG tubes
    - Smaller hot leg length-to-diameter ratio
    - Shallower SG inlet plena, especially for some replacement SGs
  - Because of this CE SGs are thermally stressed relative to HL in comparison to W plan
    - Greater likelihood that tubes will fail earlier relative to Westinghouse plants
- RCS components failed first in most simulations





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# **Severe Accident-Induced Steam Generator Tube Rupture (SGTR)**

## **RCS Modeling and Failure Prediction**

Dr. Raj Iyengar, RES/DE

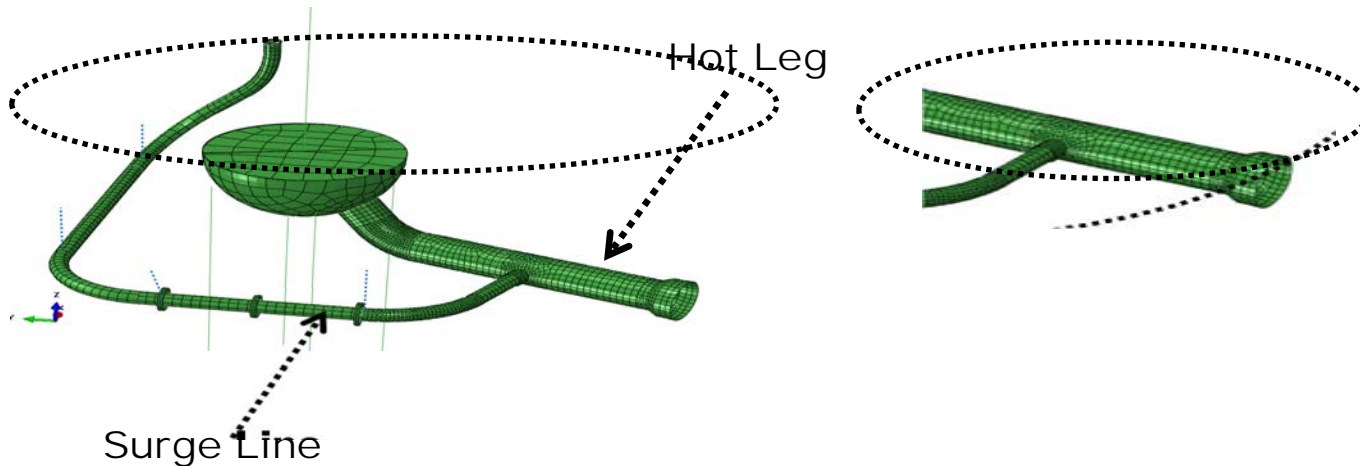
**Consequential Steam Generator Tube Rupture (C-SGTR) Subcommittee Briefing**

**April 7, 2015**

# Hot Leg-Surge Line Model Aspects

## Finite Element Model

- System-level model for Westinghouse plant – Three-dimensional Shell Elements



- Sub-model of hot-leg used for additional simulations

## Material Behavior Model

- Total strain = elastic + plastic + creep
- Creep Law – time and rate-dependent
- Plasticity Law – rate-independent
  - piecewise-linear stress-strain input from experimental data



# Analysis Procedure

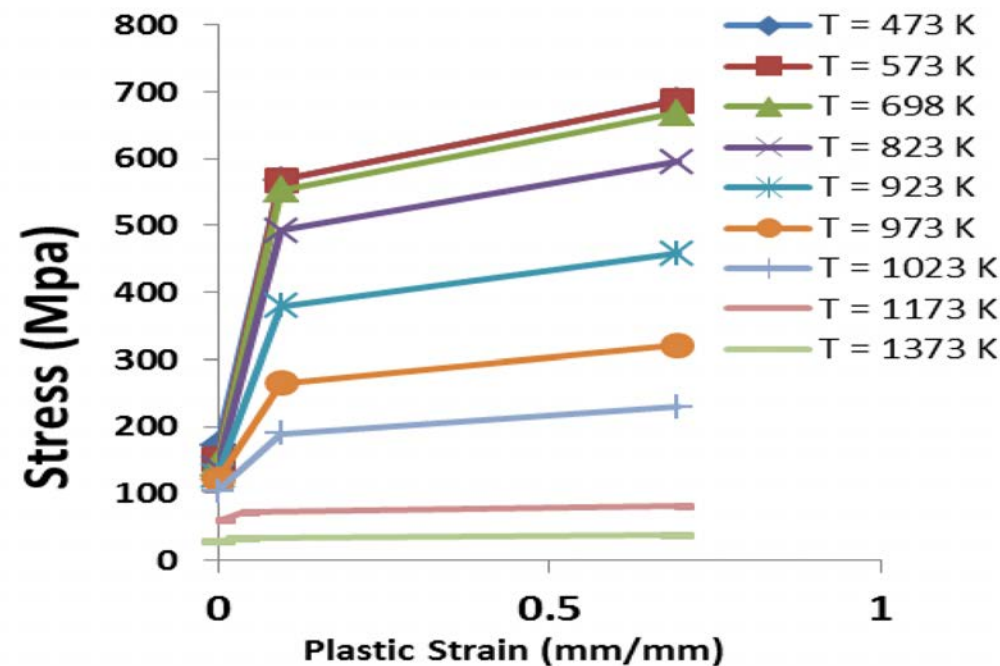


- HL/SL structural temperatures for initial conditions (steady-state condition)
- Spatial-temporal distribution of gas temperatures (RELAP) - Use time-dependent heat transfer coefficient
  - Assume upper and lower temperature split
- Heat transfer coefficient spatially adjusted in the hot-leg region (based on the developing curve provided in NUREG-1922)
- Model heat loss to the ambience due to convection and radiation
- Apply gravity load and temporal distribution of internal pressure
- High temperature (up to 1373K) material properties (316 SS)
- Run a thermal-mechanical simulation

# Material Model – SS316 SS (HL)

Combined rate-independent plasticity and power-law creep models

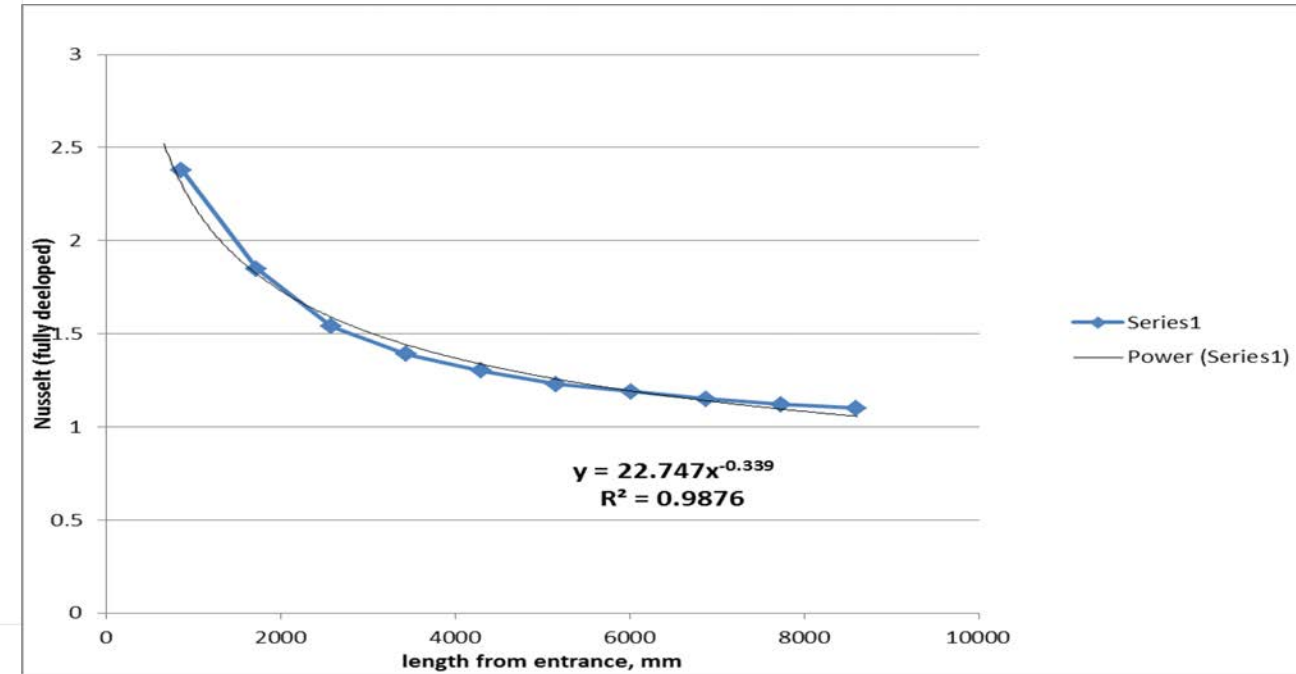
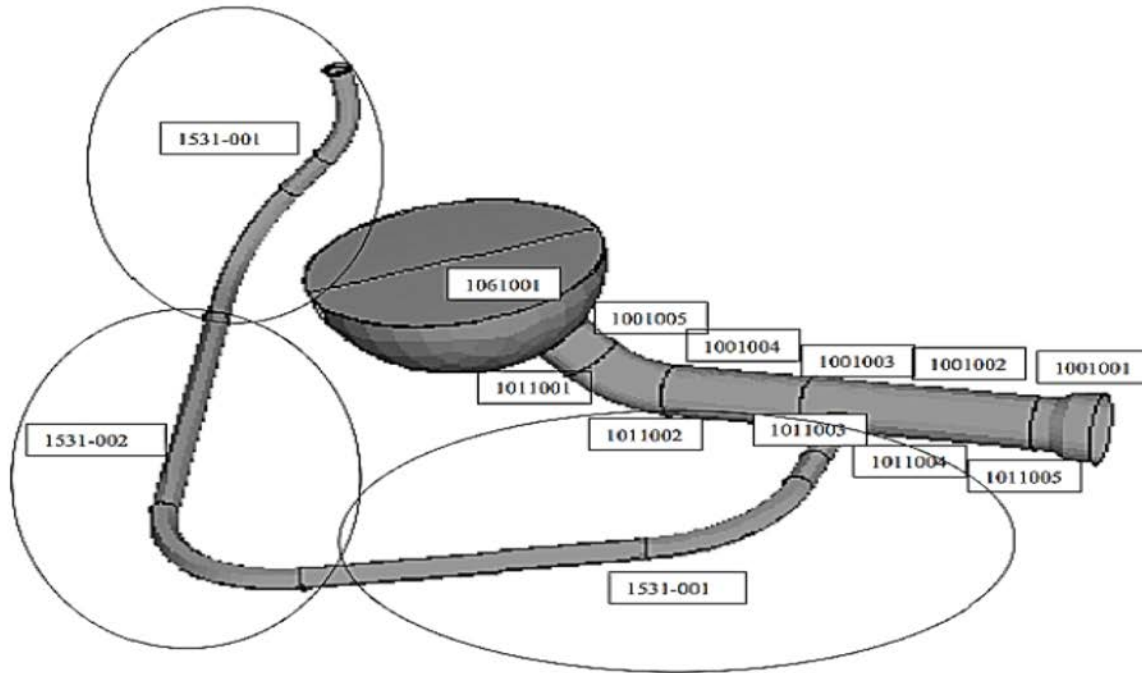
$$\frac{\dot{\epsilon}^{cr}}{\epsilon} = A\tilde{q}^n t^m$$



Temperature dependent stress strain curves for 316 stainless steel

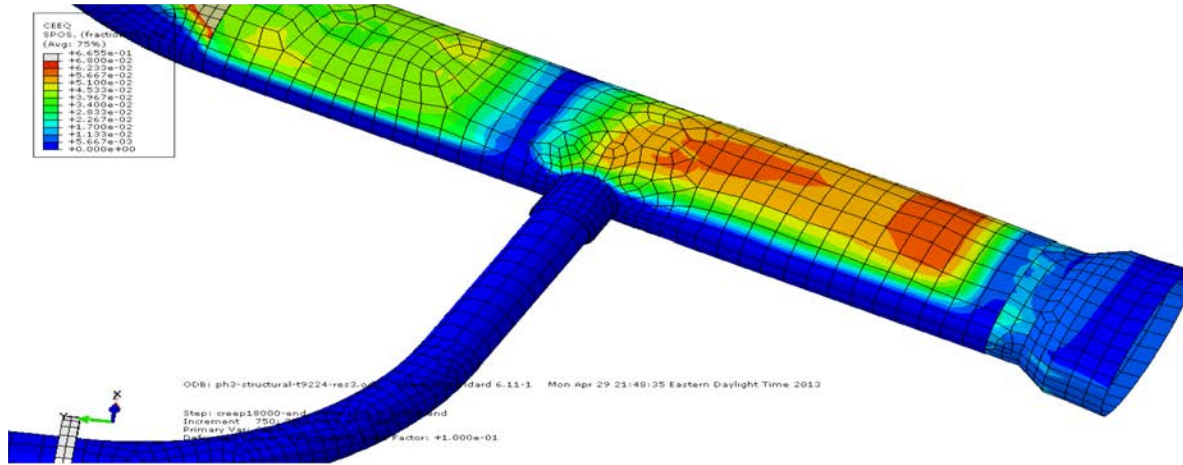
| A        | m    | T (K) |
|----------|------|-------|
| 1.23E-43 | 4    | 294.1 |
| 1.62E-36 | 9.78 | 748   |
| 5.68E-36 | 9.97 | 773   |
| 1.15E-32 | 9.06 | 798   |
| 1.47E-29 | 8.2  | 823   |
| 1.02E-28 | 8.2  | 848   |
| 6.31E-28 | 8.2  | 873   |
| 4.49E-27 | 8.18 | 898   |
| 2.88E-26 | 8.16 | 923   |
| 5.68E-24 | 7.42 | 948   |
| 8.56E-22 | 6.72 | 973   |
| 3.34E-20 | 6.25 | 998   |
| 1.30E-18 | 5.77 | 1023  |
| 1.56E-17 | 5.89 | 1100  |
| 9.39E-17 | 5.85 | 1150  |
| 2.21E-15 | 5.85 | 1250  |
| 8.91E-15 | 5.85 | 1300  |
| 1.08E-15 | 5.85 | 1400  |

# Thermal heat flux model



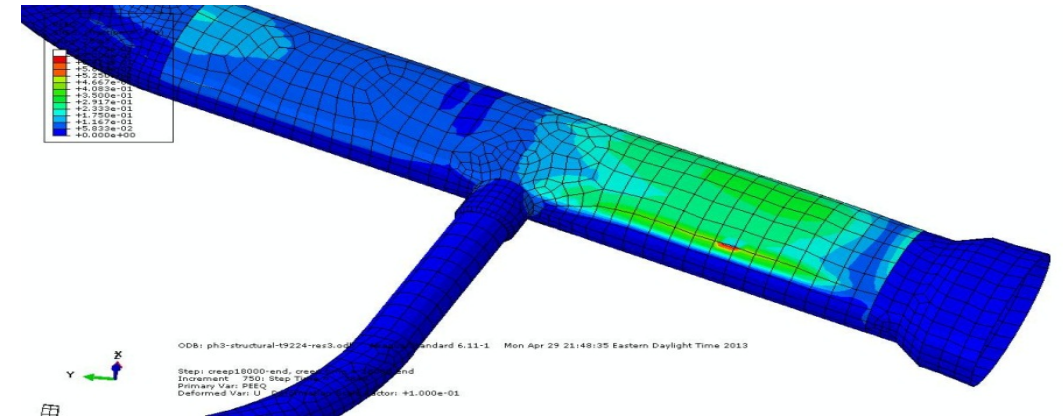
Spatial adjustment for heat transfer coefficient (based on information in NUREG-1922).

# Creep and Plastic Strains



**Accumulated Creep Strain**

**$t = 12302$  seconds**



**Accumulated Plastic Strain**

# Damage Prediction

**Damage at any material point determined using  
Larsen-Miller Parameter (LMP)**

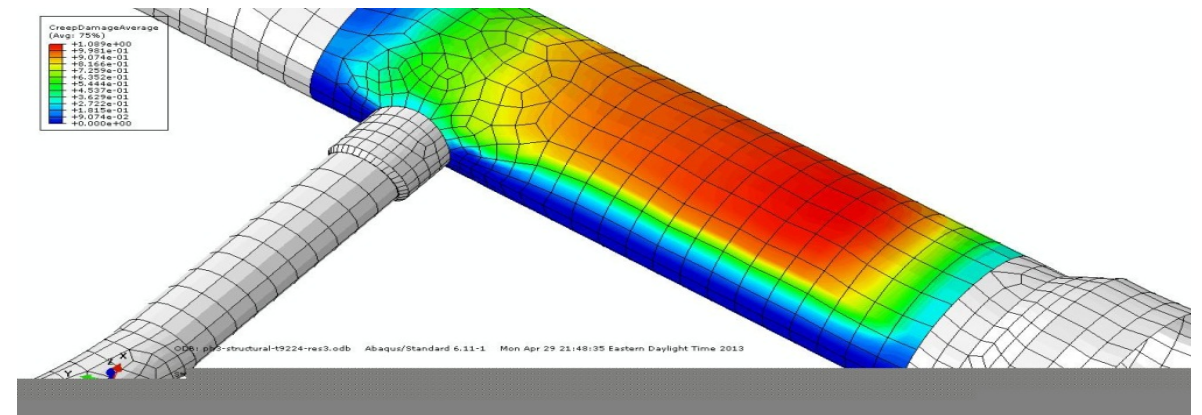
$$\text{LMP} = A * \text{Log}_{10}(\sigma) + B$$

$\sigma$  - effective stress;  $T$  - temperature

Time to rupture

$$t_r = 10(\text{LMP}/T - C)$$

A, B, and C - constants



**Failure time - 12302 seconds**

**Damage is averaged through thickness  
to determine failure time.**

# Failure Behavior of RCS Components



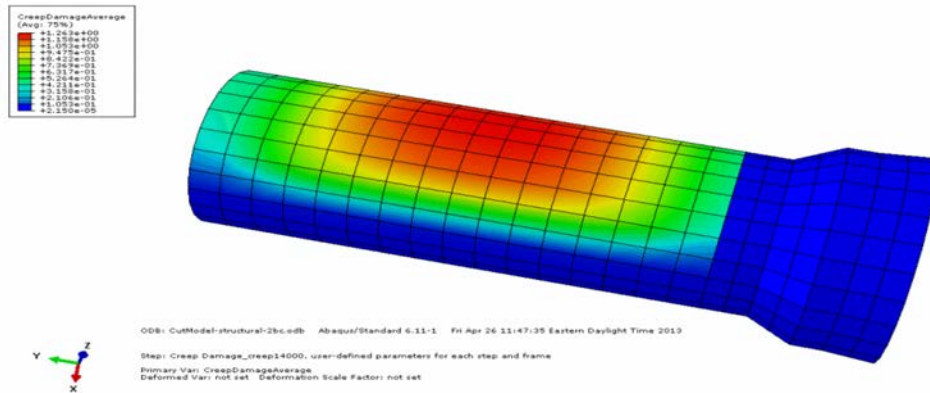
- System-level model simulations
  - computationally intensive
  - poses issues with convergence
  - Not well-suited for understanding sensitivities to input parameters
- Failure location in the hot-leg region predicted by the system model
- A sub-model of hot leg and reactor pressure vessel nozzle used for additional simulations
- Results of hot-leg model similar to the system model



# Failure Time

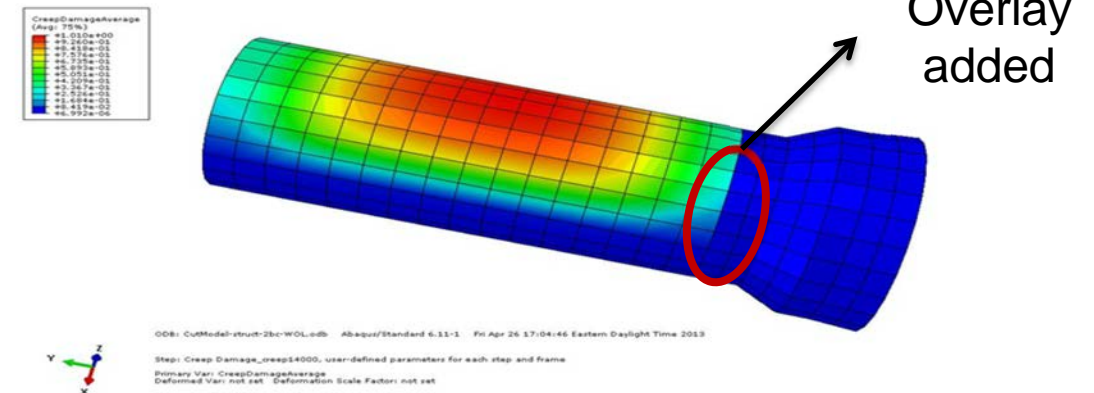
Red - Through Thickness Damage > 1  
Blue – Little or No Damage

No Weld Overlay



$t_r = 12428$  secs

Weld Overlay



$t_r = 12500$  secs

Failure time increases by 72 seconds with weld overlay

Failure location does not change

# Failure Behavior of Hot Leg

SBO with Early Failures of TDAFWs (Westinghouse)

| Finite Element Model | Features  | Weld Overlay | Failure Time (seconds) |
|----------------------|---|--------------|------------------------|
| System               | Creep and Plasticity;<br>Spatially adjustment of<br>HTC | No           | 12302                  |
| Hot leg only         | Creep and Plasticity;<br>Spatially adjustment of<br>HTC | No           | 12428                  |
|                      | Creep and Plasticity;<br>Spatially adjustment of<br>HTC | Yes          | 12500                  |
|                      | Creep only; Spatial<br>adjustment of HTC                | No           | 12140                  |
|                      | Creep and Plasticity;<br>HTC not adjusted<br>spatially  | No           | 12560                  |
|                      |   |              |                        |

*Using the simplified procedure in C-SGTR Calculator, predicted failure times for hot leg:*

- 1) 12800 s (5<sup>th</sup> percentile), 13000 s (50<sup>th</sup>), 13100 s (95<sup>th</sup>) (considering one hot-leg model)*
- 2) 12700 s (5<sup>th</sup>), 12900 s (50<sup>th</sup>), 13000 s (95<sup>th</sup>) (considering a mode of four hot leg and a surge line)*



## Summary

- Hot-leg model yields similar failure location and time compared with the system model (Westinghouse).
- Weld overlay has very small influence in failure time and no influence in failure locations.
- Failure mainly influenced by temperature and stress redistribution due to counter-current circulation.
- Most importantly, the complex analyses predict lower failure times compared with the simplified analysis used in the C-SGTR calculator.

## BACKGROUND SLIDES

# Background

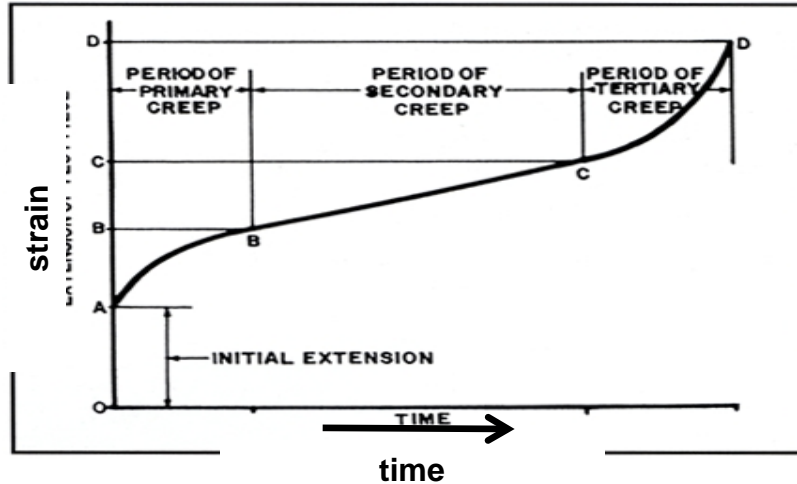
## Pre-C-SGTR



- NUREG-1570 – Issued March 1998
- Steam Generator Action Plan – Initiated November 16, 2000 (Revised May 11, 2001)
- RIL 09-03 Issued – August 21, 2009 – Closes SGAP Item 3.5
- SGAP Closed – December 3, 2009
- User Need NRR 2010-005 Issued December 16, 2009
  - a) T-H Analyses of CE Plants and Evaluation of Incore Instrument Tube Failures
  - b) Updated SG Flaw Distributions and Enhanced RCS Structural Analyses
  - c) Development of Guidance and Tools for Future Risk Assessments
  - d) Preparation of a document compiling and summarizing the key research.

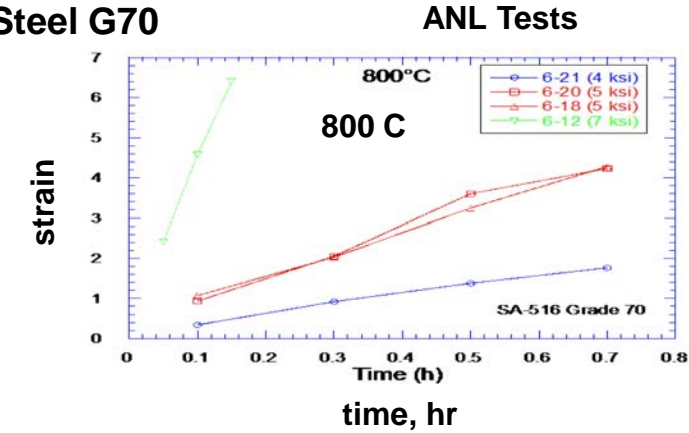
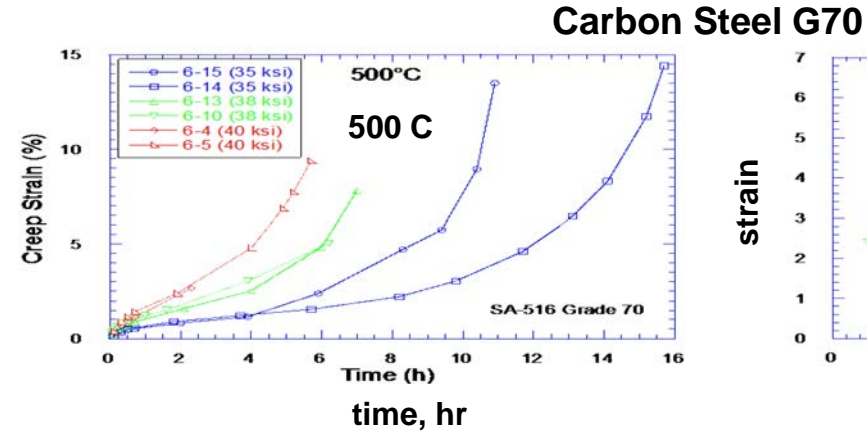
# **High Temperature Behavior of RCS and SGT Materials**

# High Temperature Deformation Metals

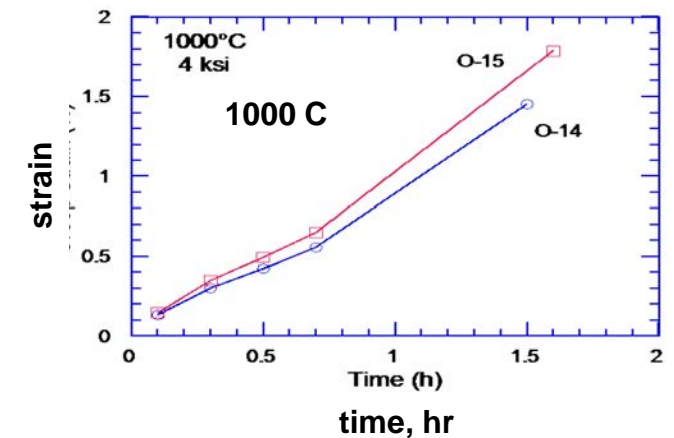
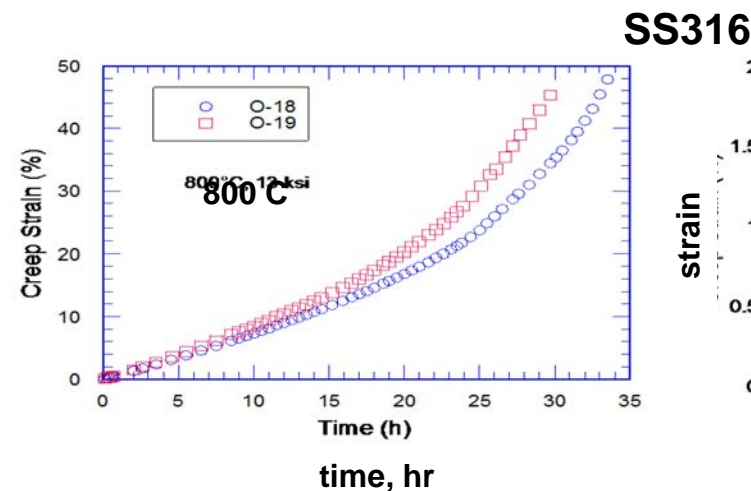


<http://www.nationalboard.org>

- Primary (transient) creep
  - Increase in creep resistance
  - Low temperature
- Secondary creep
  - constant creep rate
  - power law behavior
- Tertiary creep
  - rapid increase in creep rate
  - damage accumulation



**Increase in stress or temperature accelerates creep deformation and damage**

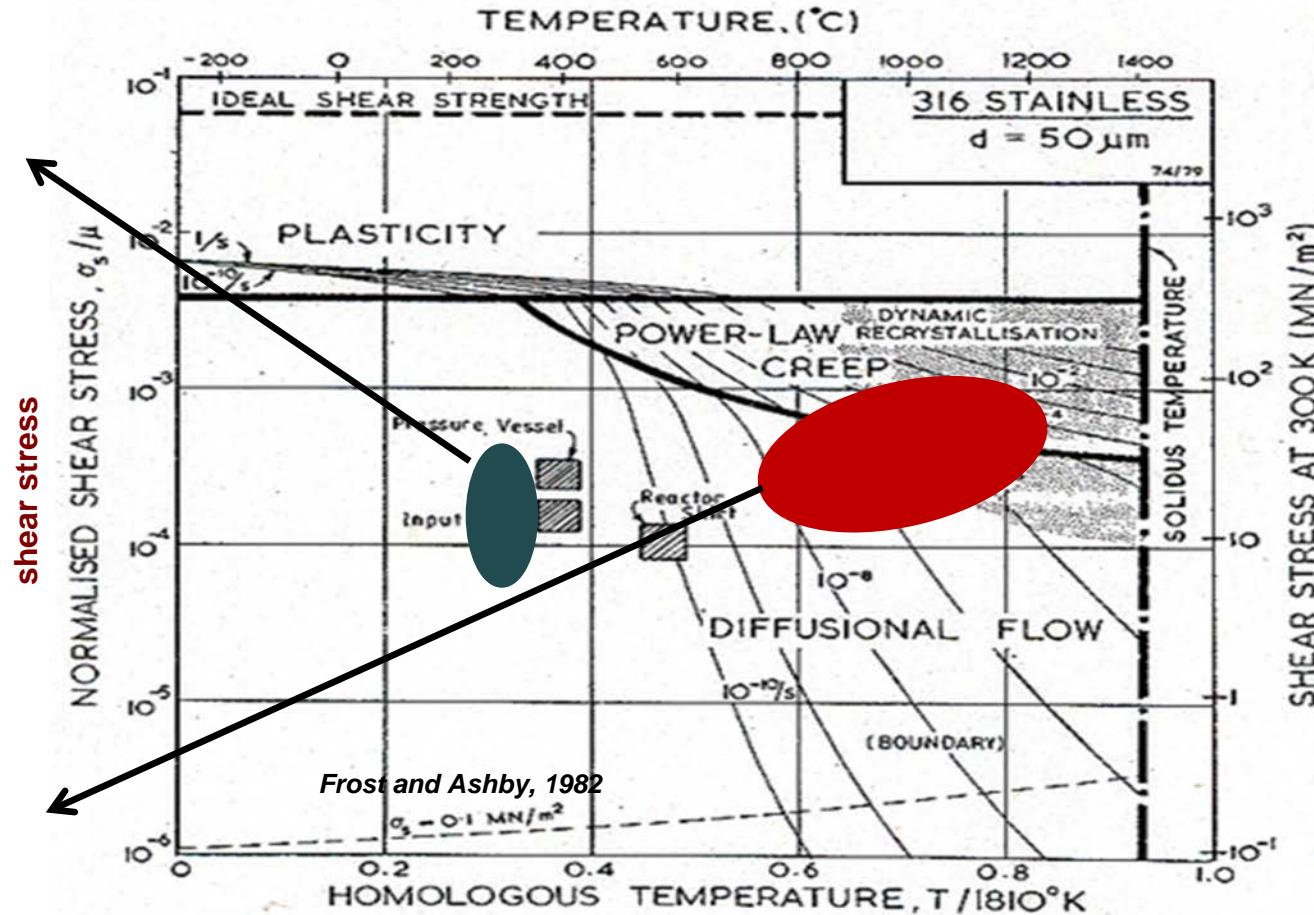


# Deformation Map

## 316 Stainless Steel

temperature

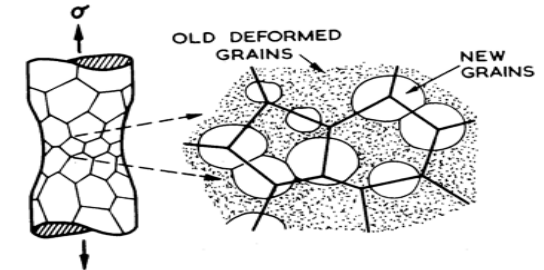
Normal  
Operating  
Conditions



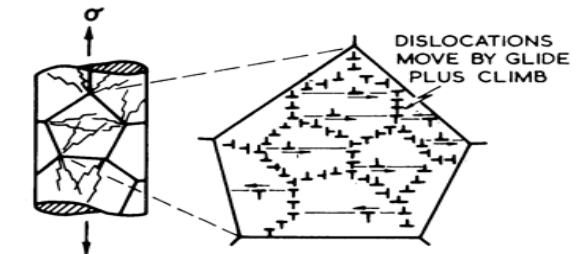
Severe  
Accident  
Conditions

- Transient effects influence extent and appearance of various regions
- Diffusion effects in stainless/alloy steels at high temperatures not well understood

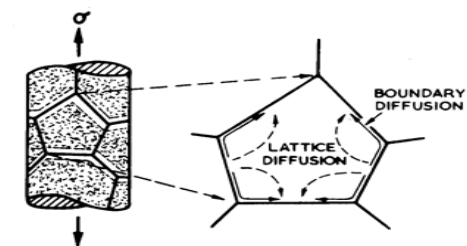
### Dynamic Recrystallization



### Deformation by Dislocation Glide and Climb



### Deformation by Diffusion (Lattice and Grain Boundary)





### Ductility-driven Damage (dislocation motion)

#### DUCTILE, AND TRANSGRANULAR CREEP, FRACTURE.

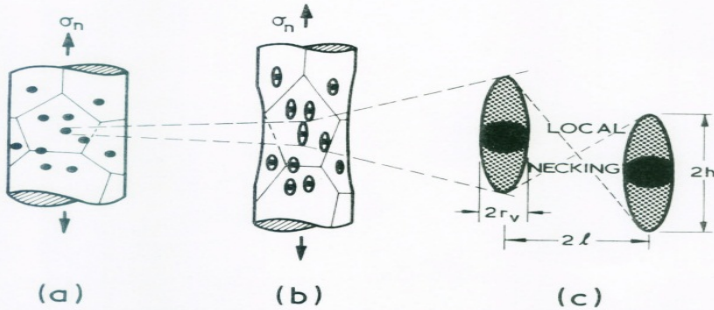


Fig. 3. (a) Ductile fracture and transgranular creep fracture requires either that holes pre-exist or that they nucleate at inclusions which concentrate stress. (b) The holes elongate as the specimen is extended. (c) They link, causing fracture, when their length,  $2h$ , is about equal to their separation  $(2l - 2r_v)$ .

### Diffusion-driven Damage (grain boundary sliding)

#### INTERGRANULAR, CREEP CONTROLLED, FRACTURE

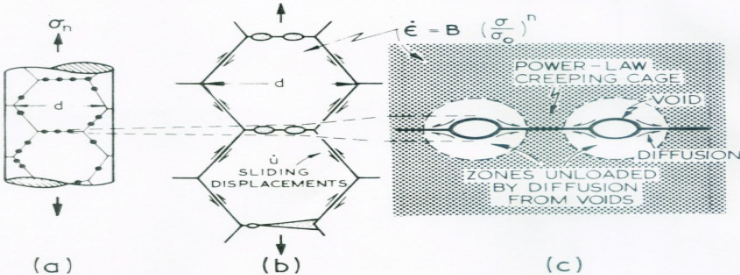
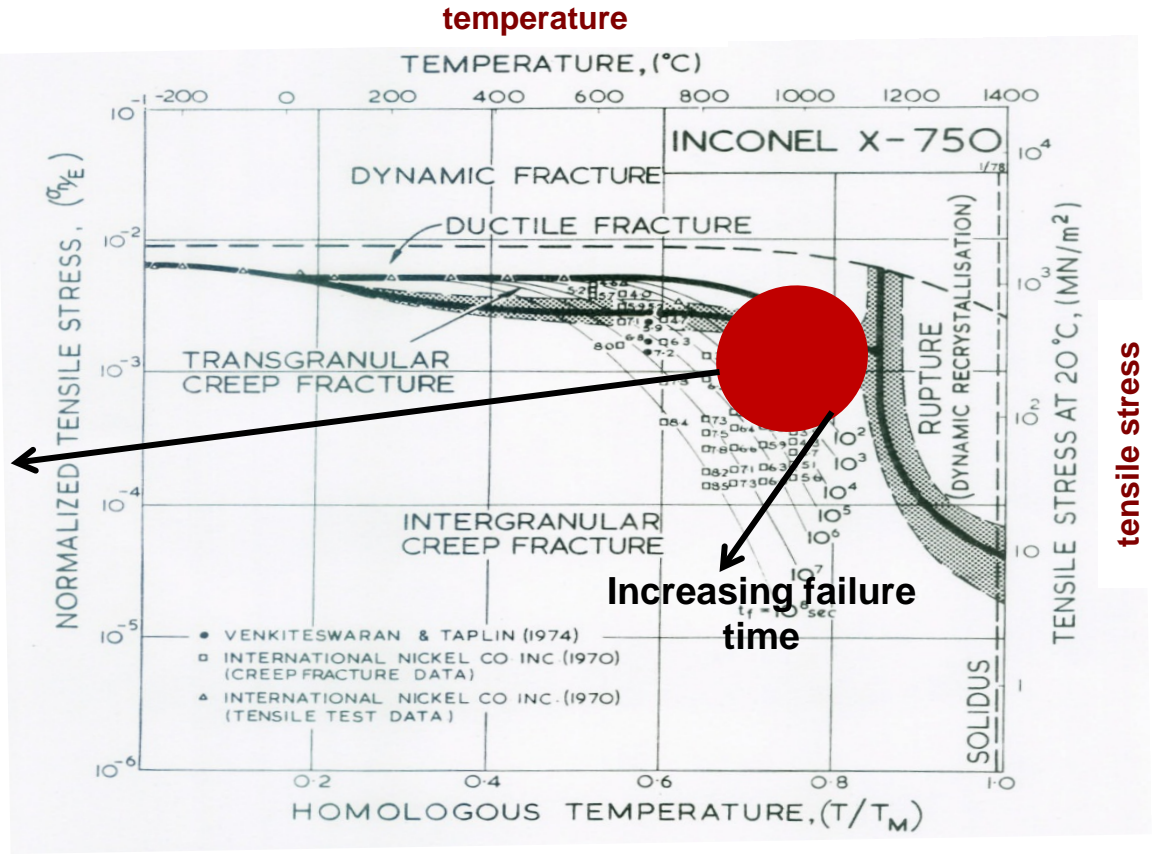


Fig. 4. (a) Grain boundary sliding stimulates the nucleation of grain and (b) boundary voids. (c) The voids grow by diffusion, but the diffusion fields of neighbouring voids do not, in general, overlap, so that each void is contained within a cage of power-law creeping material.

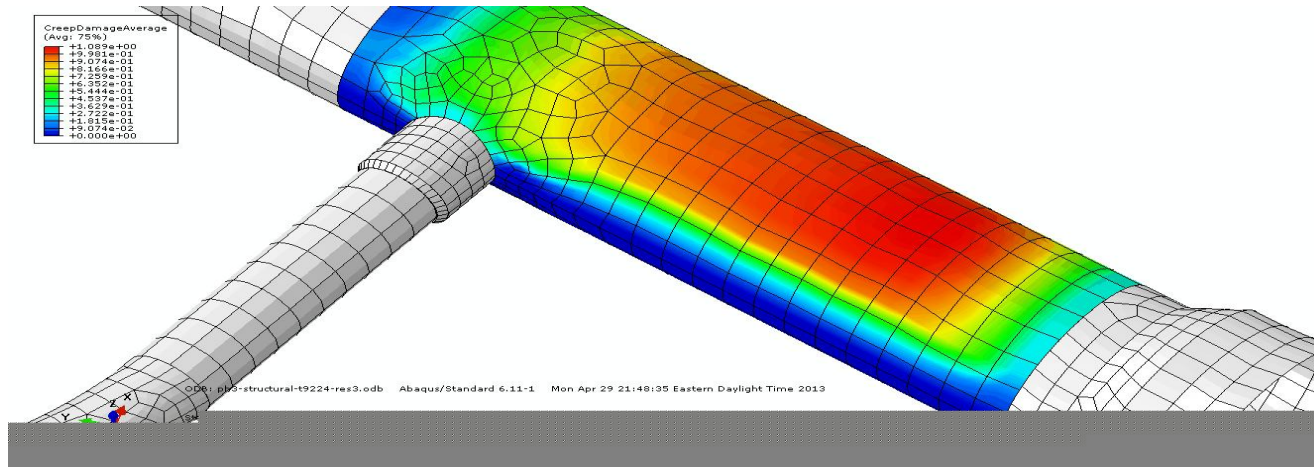
Ashby, Gandhi, and Taplin, 1979

Severe accident  
conditions

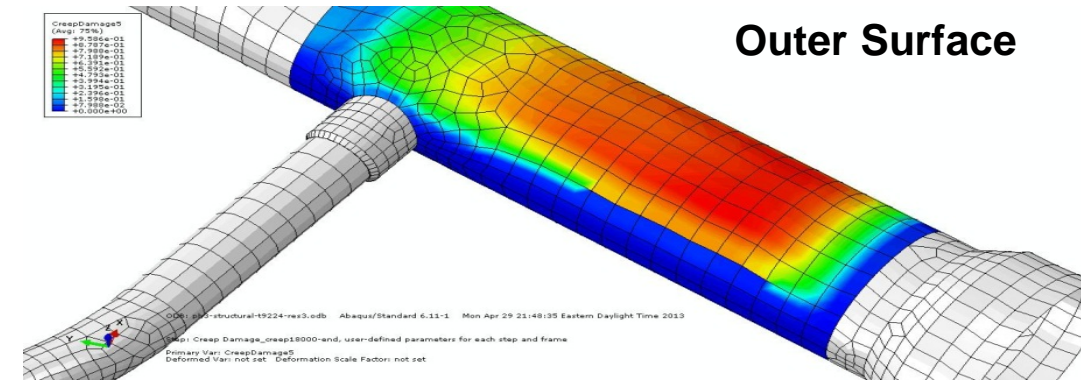


Transient effects and multi-axial stress state influence  
extent and appearance of various regions

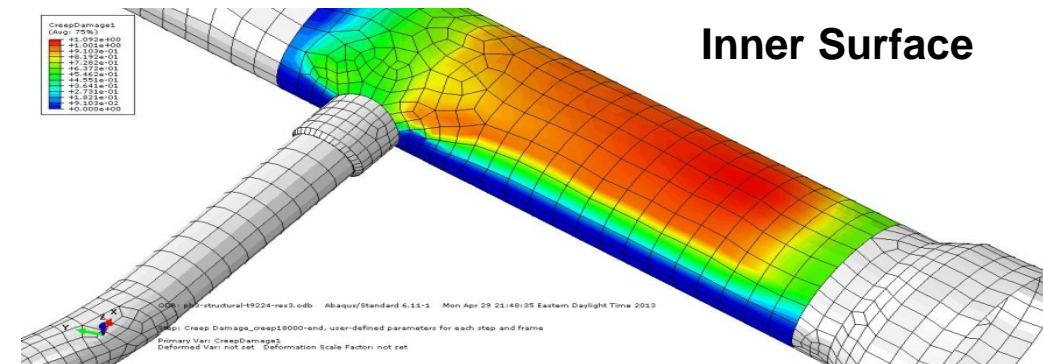
# Damage at $t = 9222 + 3080$ seconds



Through Thickness Damage



Outer Surface



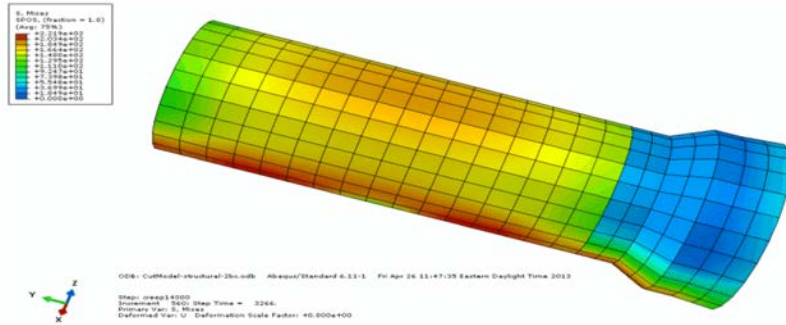
Inner Surface



# Effective Stress Distribution

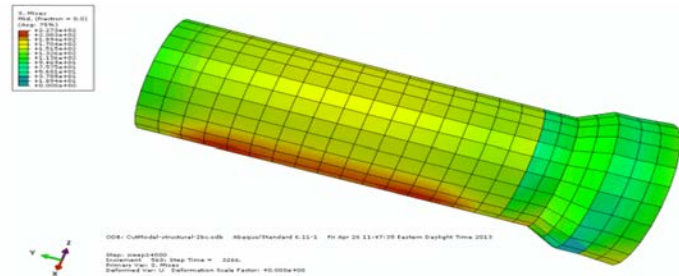
No Weld Overlay ( $t = 9222 + 3206$  secs)

Hot side

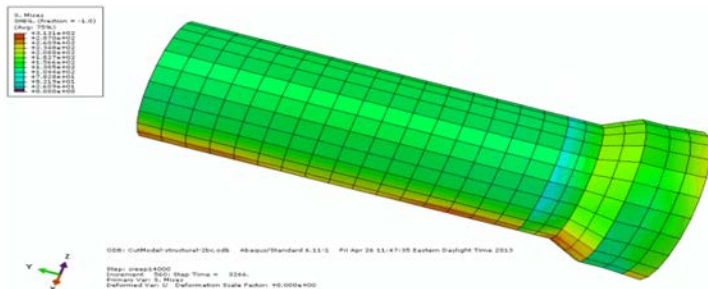


As creep progresses  
stresses relax  
redistribution occurs

Outer Surface

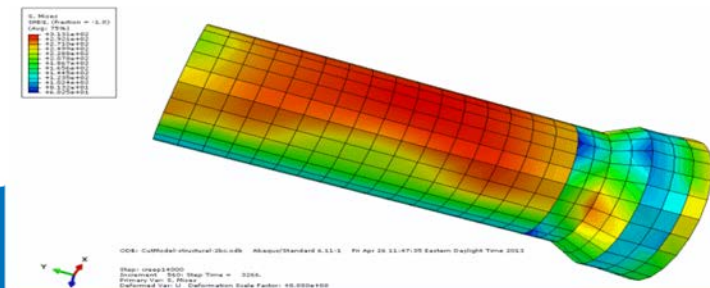
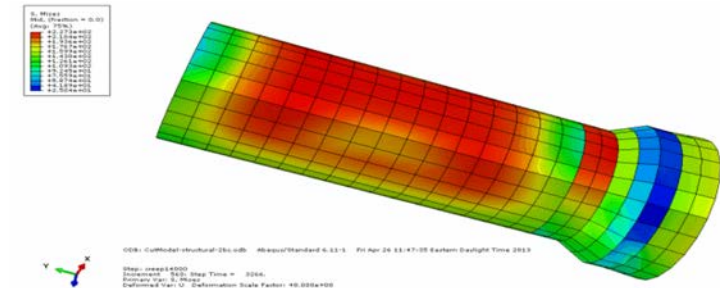
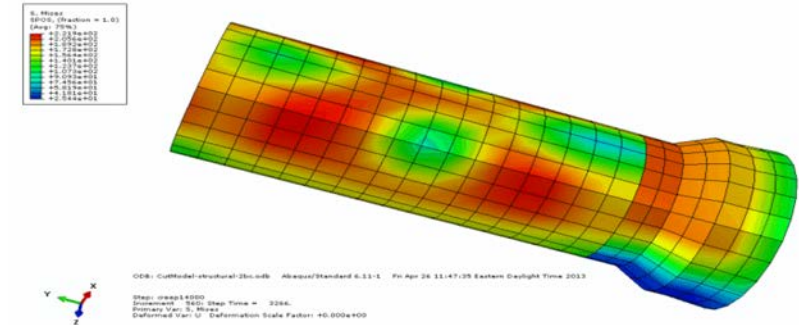


Mid-thickness



Inner Surface

Colder side



# Hydrostatic Stress Distribution

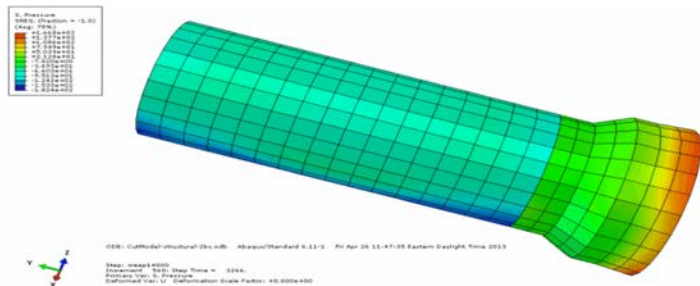
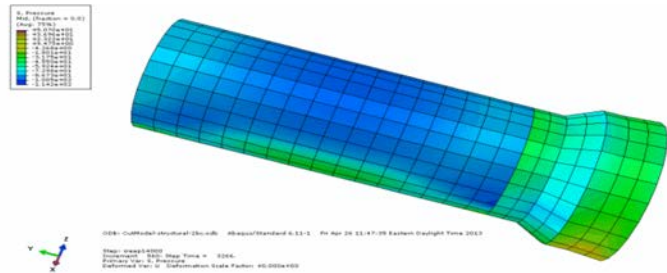
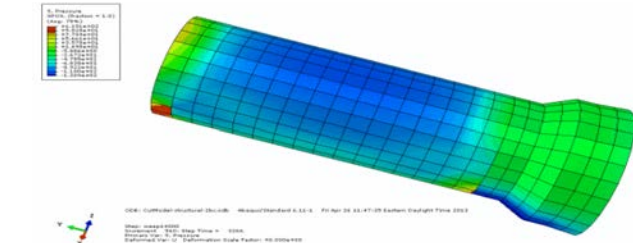
No Weld Overlay ( $t = 9222 + 3206$  secs)

Hot side

Hydrostatic  
tension

As creep progresses  
stresses relax  
redistribution occurs

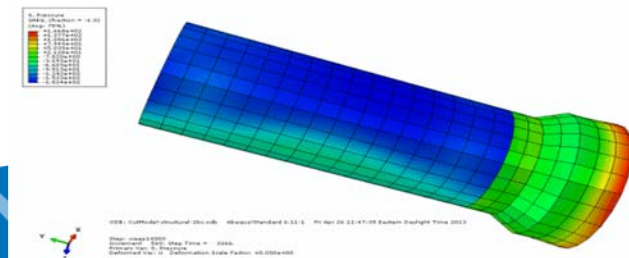
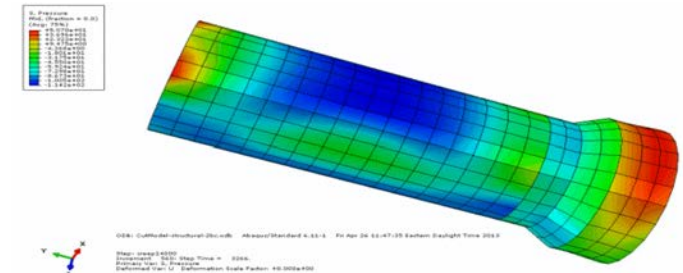
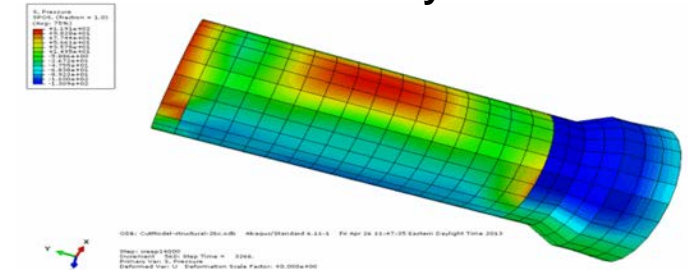
Outer Surface



Mid-thickness

Colder side

Hydrostatic compression



Inner Surface



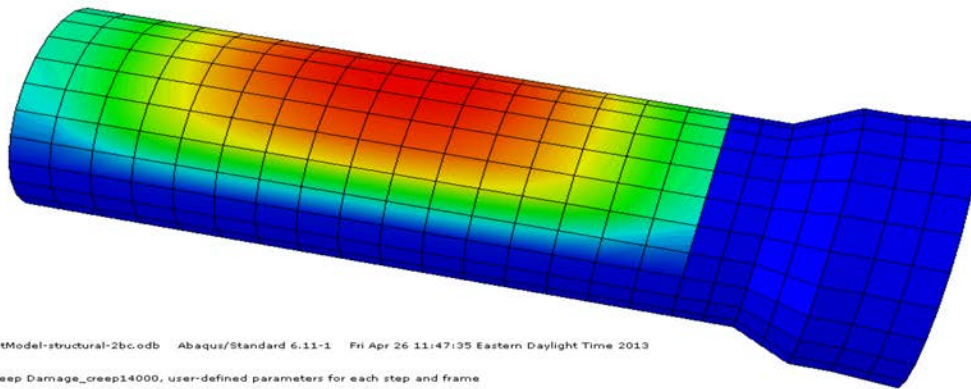
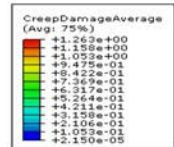


# Damage Accumulation

No Weld Overlay ( $t = 9222 + 3206$  secs)

**Red - Through Thickness Damage > 1**  
**Blue – Little or No Damage**

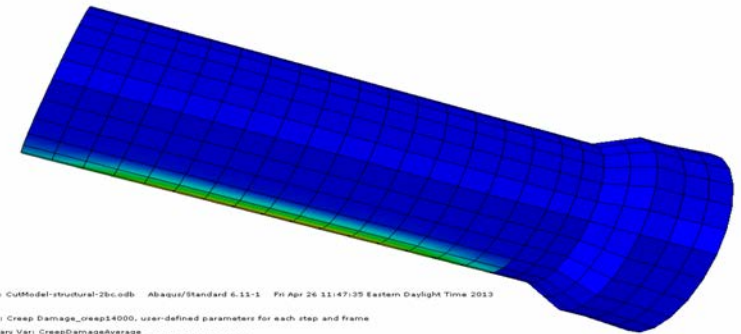
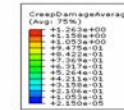
**Hot Side**



ODB: CutModel-structural-2bc.odb Abaqus/Standard 6.11-1 Fri Apr 26 11:47:35 Eastern Daylight Time 2013

Step: Creep Damage\_creep14000, user-defined parameters for each step and frame  
Primary Var: CreepDamageAverage  
Deformed Var: not set Deformation Scale Factor: not set

**Cold Side**



ODB: CutModel-structural-2bc.odb Abaqus/Standard 6.11-1 Fri Apr 26 11:47:35 Eastern Daylight Time 2013

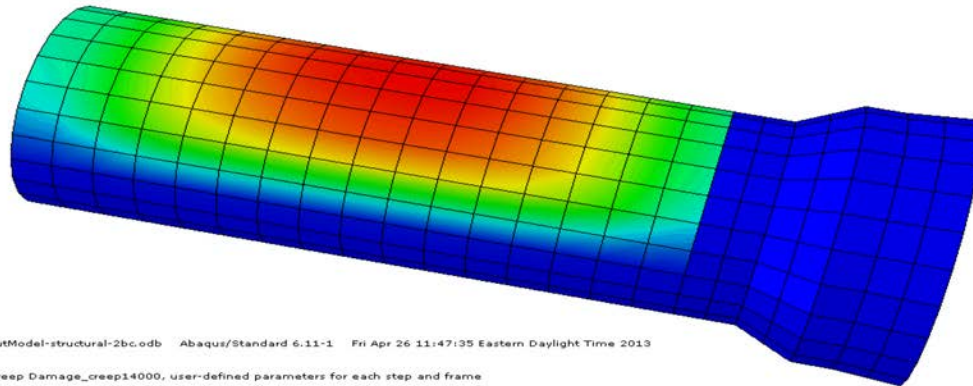
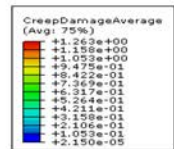
Step: Creep Damage\_creep14000, user-defined parameters for each step and frame  
Primary Var: CreepDamageAverage  
Deformed Var: not set Deformation Scale Factor: not set

# Damage Accumulation

## No Weld Overlay

**Red - Through Thickness Damage > 1**  
**Blue – Little or No Damage**

**ANL Failure Criterion**

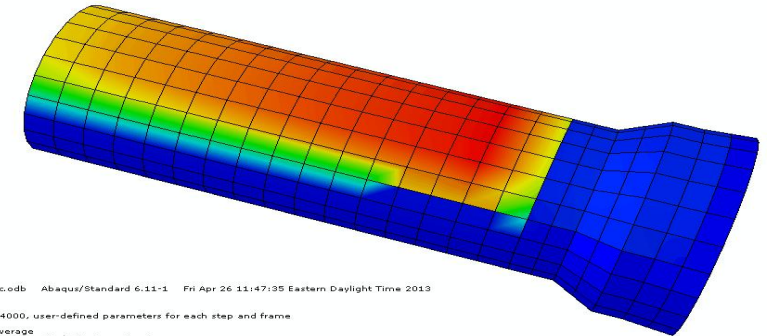
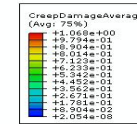


ODB: CutModel-structural-2bc.odb Abaqus/Standard 6.11-1 Fri Apr 26 11:47:35 Eastern Daylight Time 2013

Step: Creep\_Damage\_creep14000, user-defined parameters for each step and frame  
Primary Var: CreepDamageAverage  
Deformed Var: not set Deformation Scale Factor: not set

**T= 3206 secs**

**EPRI Failure Criterion**



ODB: CutModel-structural-2bc.odb Abaqus/Standard 6.11-1 Fri Apr 26 11:47:35 Eastern Daylight Time 2013

Step: Creep\_Damage\_creep14000, user-defined parameters for each step and frame  
Primary Var: CreepDamageAverage  
Deformed Var: not set Deformation Scale Factor: not set

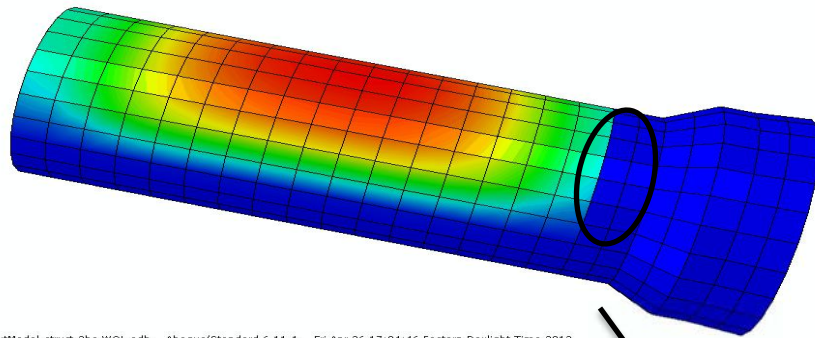
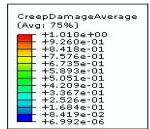
**T= 4010 secs**

# Damage Accumulation

## Weld Overlay (t = 9222 + 3278 secs)

**Red - Through Thickness Damage > 1**  
**Blue - Little or No Damage**

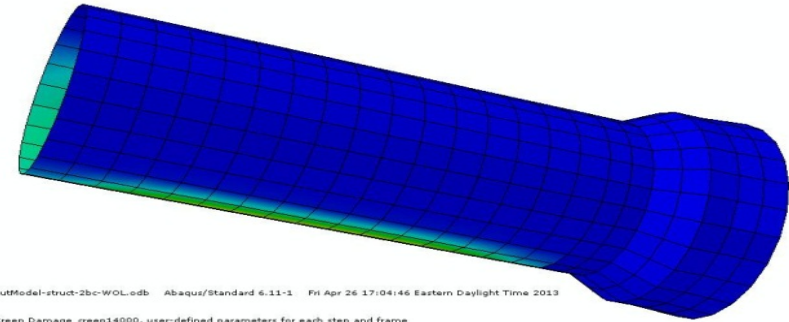
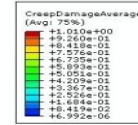
**Hot Side**



ODB: CutModel-struct-2bc-WOL.odb Abaqus/Standard 6.11-1 Fri Apr 26 17:04:46 Eastern Daylight Time 2013  
Step: Creep Damage\_creep14000, user-defined parameters for each step and frame  
Primary Var: CreepDamageAverage  
Deformed Var: not set Deformation Scale Factor: not set

**Overlay**

**Cold Side**



ODB: CutModel-struct-2bc-WOL.odb Abaqus/Standard 6.11-1 Fri Apr 26 17:04:46 Eastern Daylight Time 2013  
Step: Creep Damage\_creep14000, user-defined parameters for each step and frame  
Primary Var: CreepDamageAverage  
Deformed Var: not set Deformation Scale Factor: not set

**Failure time increases by 72 seconds with weld overlay.**

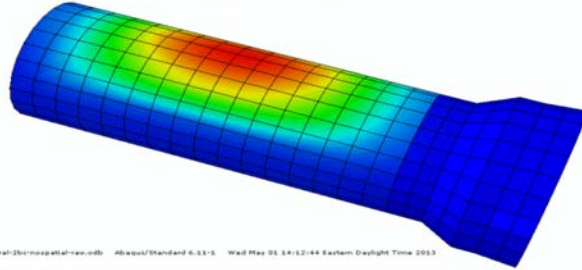
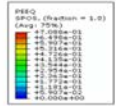
**Failure location does not change.**



# Damage Accumulation

No Weld Overlay ( $t = 9222 + 3386$  secs )

## Accumulated Creep Strain

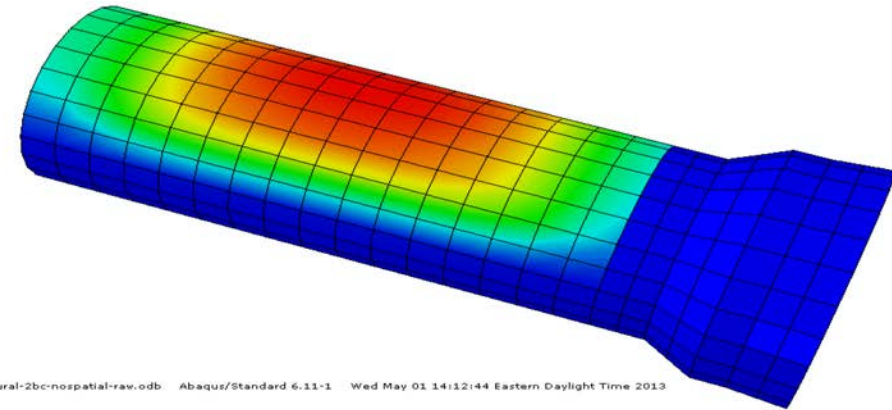
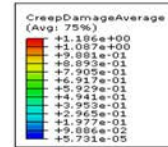


ODB: CutModel-structural-2bc-nospacial-raw.odb Abaqus/Standard 6.11-1 Wed May 01 14:12:44 Eastern Daylight Time 2013

Step: creep13000  
Increment: 500, Step Time = 3386.  
Primary Var: PEEQ  
Deformed Var: U, Deformation Scale Factor: 40.000e+00

No spatial adjustment of heat-transfer coefficient

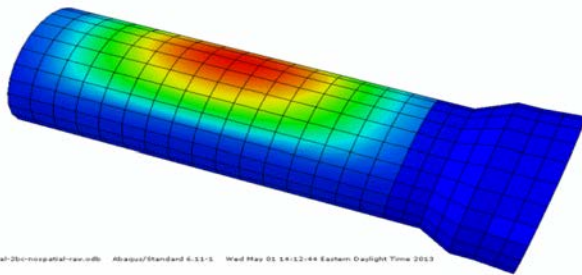
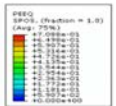
Red - Through Thickness Damage > 1  
Blue - Little or No Damage



ODB: CutModel-structural-2bc-nospacial-raw.odb Abaqus/Standard 6.11-1 Wed May 01 14:12:44 Eastern Daylight Time 2013

Step: Creep Damage\_creep13000, user-defined parameters for each step and frame  
Primary Var: CreepDamageAverage  
Deformed Var: not set, Deformation Scale Factor: not set

## Accumulated Plastic Strain



ODB: CutModel-structural-2bc-nospacial-raw.odb Abaqus/Standard 6.11-1 Wed May 01 14:12:44 Eastern Daylight Time 2013

Step: creep13000  
Increment: 500, Step Time = 3386.  
Primary Var: PEEQ  
Deformed Var: U, Deformation Scale Factor: 40.000e+00

Failure time increases by 180 seconds relative to spatially adjusted HT coefficients

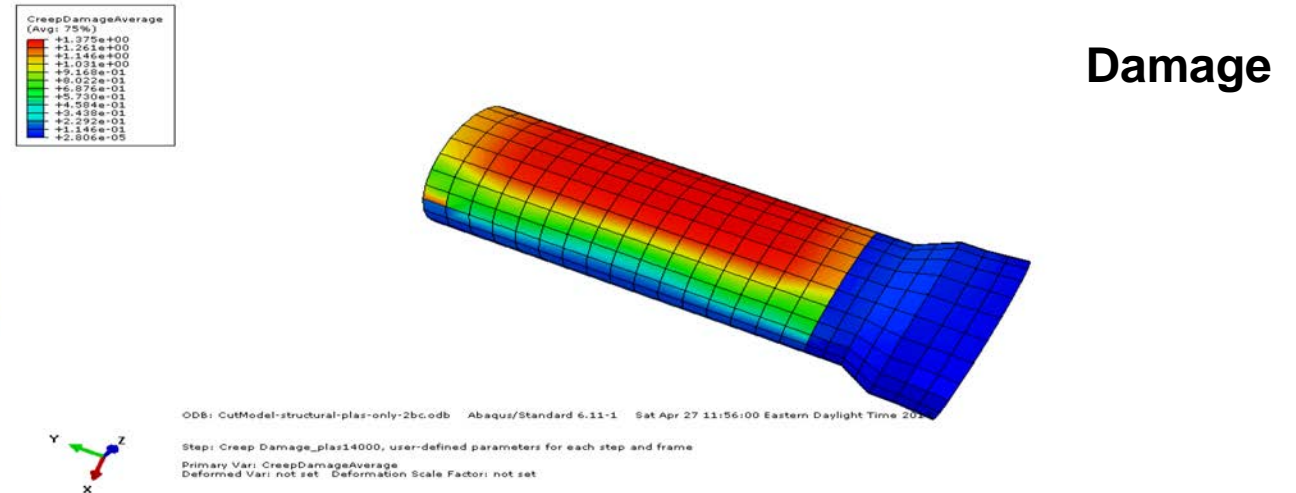
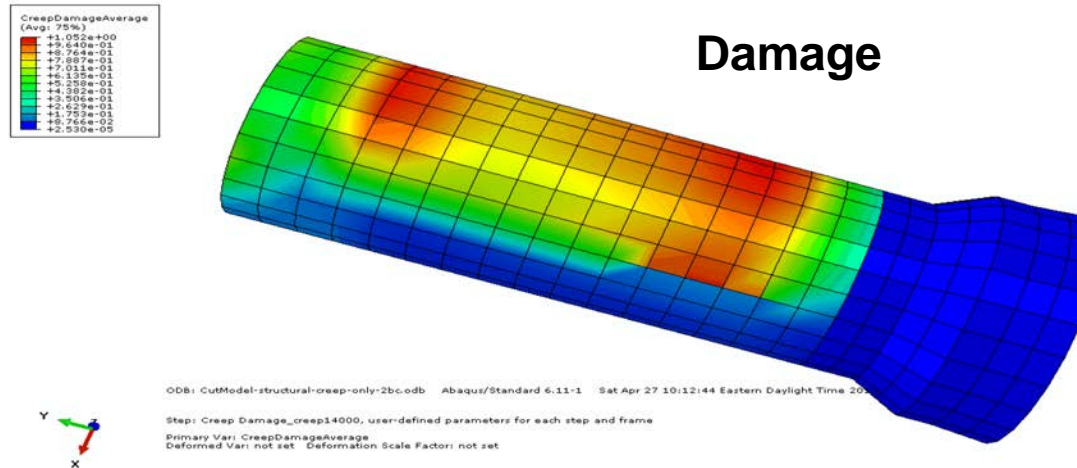
# Damage Accumulation

## No Weld Overlay

**Creep Only**  
( $t = 9222 + 2918$  secs )

Red - Through Thickness Damage  $> 1$   
Blue - Little or No Damage

**Plasticity Only**  
( $t = 9222 + 3802$  secs )



**Plastic Strain**

Shorter failure time when creep is the only dominant inelastic mode of deformation.  
Primarily caused by the stress redistribution due to creep –  
aided by the difference in temperature transients on the hot and cold side





**U.S.NRC**

UNITED STATES NUCLEAR REGULATORY COMMISSION

*Protecting People and the Environment*

# **Severe Accident-Induced Steam Generator Tube Rupture (SGTR)**

## **SG tube Flaw Distribution Characterization**

**Dr. Ali Azarm, Innovative Engineering & Safety Solutions (IESS)**

**Mica Baquera, RES/DE**

**Consequential Steam Generator Tube Rupture (C-SGTR) Subcommittee Briefing**

**April 7, 2015**



# SG tube flaws

- Objective
  - To update the previous study on flaw statistics and provide current statistics sufficient to generate flaw samples for C-SGTR analysis (input to the C-SGTR calculator)
- Background
  - The previous work on estimating SG tube flaw distributions was for 600 MA tube materials (NUREG/CR-6521 Gorman Report) and for cracks only using data that existed pre 1995.
  - These (U-tube) SGs are replaced with those having new SG tube materials (Thermally Treated Alloy 600 and 690).
  - Use of the information from previous studies could not be justified



## SG tube flaws (Cont'd)

- Flaw data for Thermally Treated Inconel 600 and 690 (600TT and 690TT) were collected from selected in-service inspection reports available to the NRC
- Flaw data was manually extracted and compiled into a data base for further analyses
- The data were binned against operating time (*measured in Equivalent Full Power Years-EFPY*) and flaw types

# SG ISI reports Used as Input

| Plant Type   | Inconel 600                   | Inconel 690   |
|--------------|-------------------------------|---|
| Westinghouse | Surry U1 & U2<br>(26 Cycles)* | DC Cook U1 & U2<br>(6 Cycles)<br>McGuire U1<br>(2Cycles)  |
| C-E          | —                             | Millstone U2<br>(3 Cycles)<br>St. Lucie U1<br>(3 Cycle)<br>Calvert Cliffs U1 & U2<br>(7 cycles) |

\* Surry unit 2: 12 RFOs, 13 ISI reports (cycles), 268.5 EFPM (or ~22 EFPY)



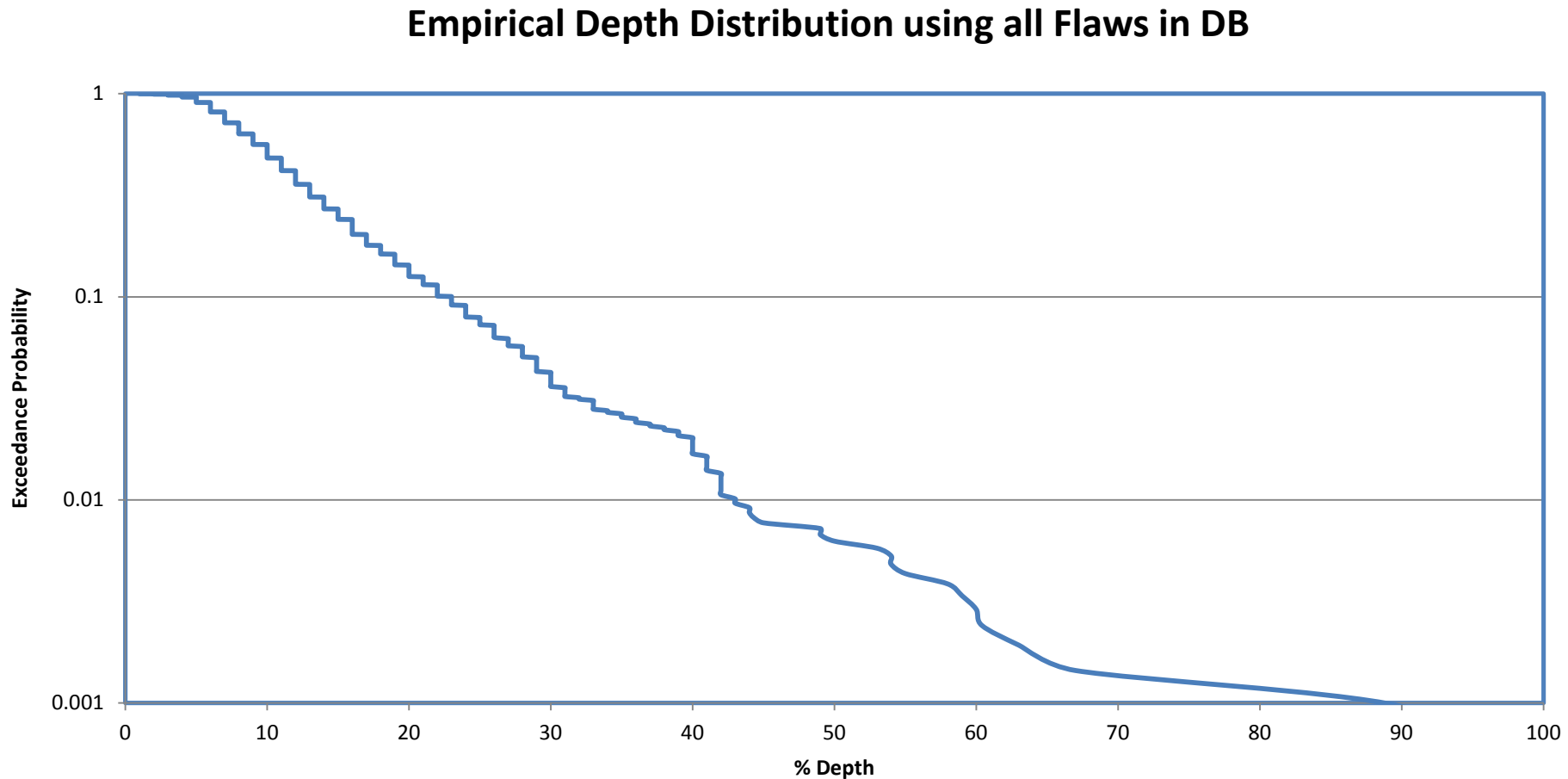
# Flaw Binning for Statistical Evaluation

- Flaw types and names in ISI reports are different for different types of SGs and their design
- For the purpose of statistical analysis and use of calculator software, the flaws were grouped as either volumetric/wear or cracks.

| Flaw Group for Statistical Analysis | Flaw Name in Database   |
|-------------------------------------|---|
| <b>Volumetric Flaw or Wear</b>      | Anti Vibratory Bar (AVB) wear<br>Foreign Object Wear<br>Free-span Wear<br>Pit<br>Volumetric Wear<br>Tube Support Plate (TSP) Wear<br>Loose Part Wear<br>Fan Bar Wear<br>Manufacturing Burnish Mark that changed<br>Lattice Support Wear |
| <b>Crack</b>                        | Single Axial Indication (SAI)<br>Single Circumferential Indication (SAI)  |



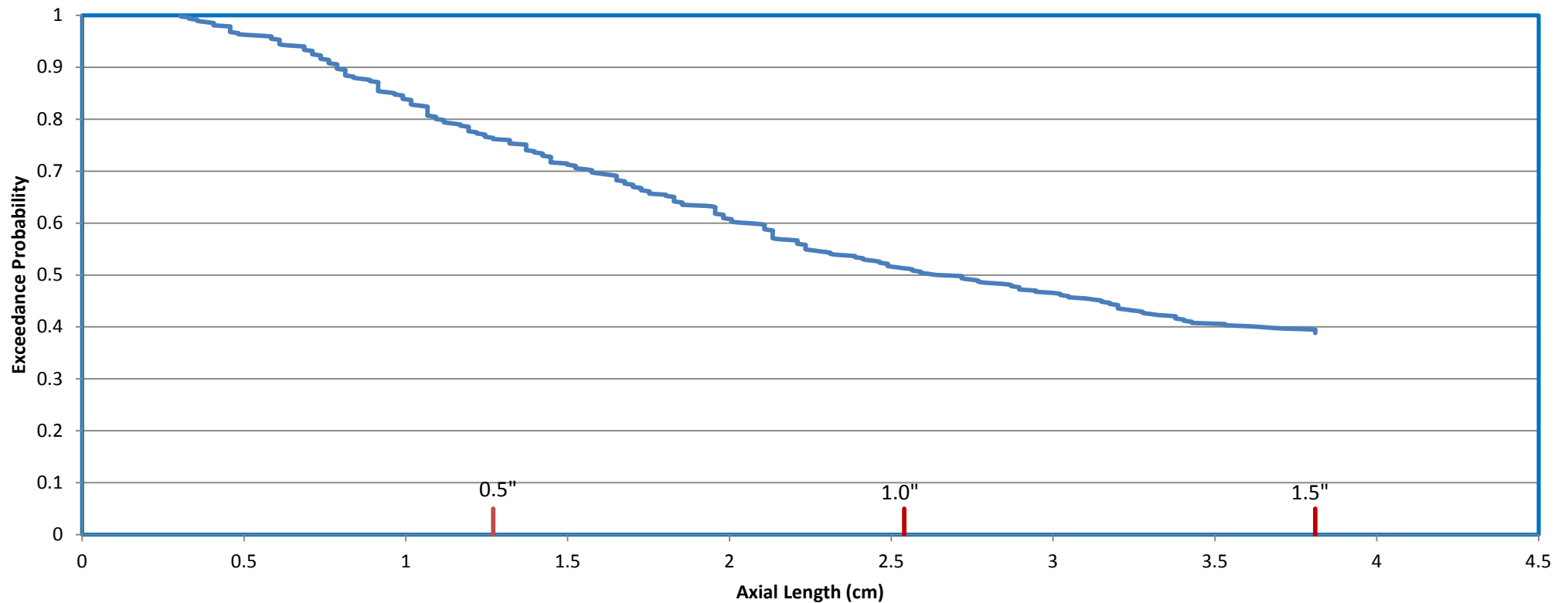
# Graphical Presentation of Aggregate Flaw Data





# Graphical Presentation of Aggregate Flaw Data

Empirical Distribution of Axial Length of all Flaws in DB





# Flaw model (rates)

- Flaw Generation Rate per tube as a function of SG service life [measured in EFPY] for
  - Volumetric/Wear Flaw 600TT
  - Volumetric/Wear Flaw 690TT
  - Axial Cracks 600TT
  - Circumferential Cracks 600TT
  - *No Crack data was found for 690TT*





# Flaw Model (sizes)

- Flaw length Distribution
  - Wear and Cracks
  - One distribution for both 600TT and 690TT
- Circumferential Flaw Length (arcs) Distribution
  - Cracks for 600TT only
- Flaw depth Distribution
  - Wear and Cracks
  - One distribution for both 600TT and 690TT



# Model Parameters

- A flaw model was developed by
  - Linearly increasing rate of volumetric flaws generation as a function of time (i.e. EFPY)
  - Linearly increasing rate of crack flaws generation as a function of EFPY
  - Gamma Distribution of flaw length
  - Gamma Distribution of flaw depth
- Statistical Estimation Approach
  - Regression using Excel routine for estimating the linearly increasing rates
  - Matching the first two moments for estimating the parameters of Gamma distributions



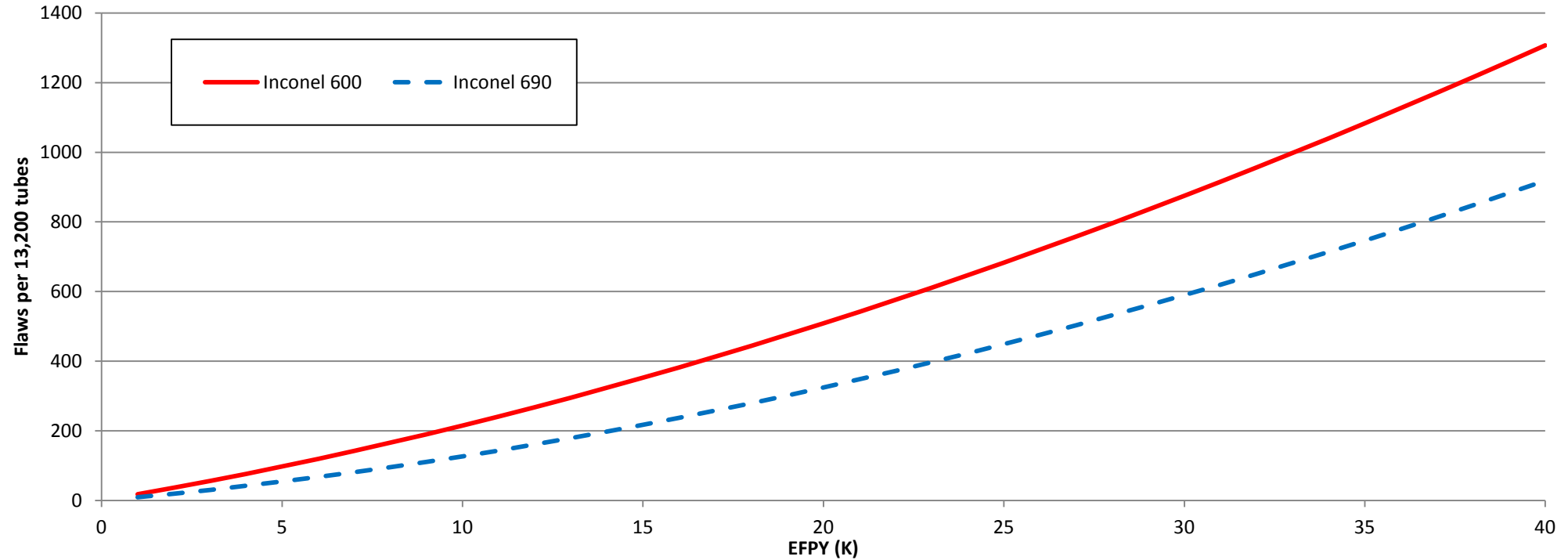
# Summary of Statistical Results

(prior to Adjustment in PRA Analysis)

| Flaw Characteristics   | Thermally Treated Inconel 600  | Thermally Treated Inconel 690   |
|--|--|---|
| Volumetric/Wear Flaw Rates                                       | $h(k) = 6.4166 \cdot 10^{-5} K + 1.3236 \cdot 10^{-3}$<br>$\mu = 6.4166 \cdot 10^{-5}, \Omega = 1.3236 \cdot 10^{-3}$                            | $h(k) = 5.5826 \cdot 10^{-5} K + 6.8627 \cdot 10^{-4}$<br>$\mu = 5.5826 \cdot 10^{-5}, \Omega = 6.8627 \cdot 10^{-4}$ |
| Axial Crack Flaw Rates   | $K < 15, h(k) = \text{Negligible}$<br>$\mu = 0.0, \Omega = 0.0$<br>$K > 15, h(k) = 2.0 \cdot 10^{-4}$<br>$\mu = 0.0, \Omega = 2.0 \cdot 10^{-4}$ | $h(k) = \text{Negligible}$<br>$\mu = 0.0, \Omega = 0.0$   |
| Circumferential Crack Flaw Rates                                 | $K < 15, h(k) = \text{Negligible}$<br>$\mu = 0.0, \Omega = 0.0$<br>$K > 15, h(k) = 1.0 \cdot 10^{-3}$<br>$\mu = 0.0, \Omega = 1.0 \cdot 10^{-3}$ | $h(k) = \text{Negligible}$<br>$\mu = 0.0, \Omega = 0.0$   |
|  |  |   |
| Axial Flaw length: Axial Cracks, Wear Marks, or Volumetric Flaws | $\text{Gamma}(a = 2.33318781, \beta = 2.0847)$   |   |
| Circumferential Crack Angle                                      | $0.58 \cdot \text{Gamma}(a = 28.6565, \beta = 0.4187) + (1 - 0.58) \cdot \text{Gamma}(a = 9.5638, \beta = 0.0670)$                               |   |
| Flaw Depth: Cracks, Wear, Volumetric Flaws                       | $\text{Gamma}(a = 2.0658, \beta = 16.3274)$  |   |

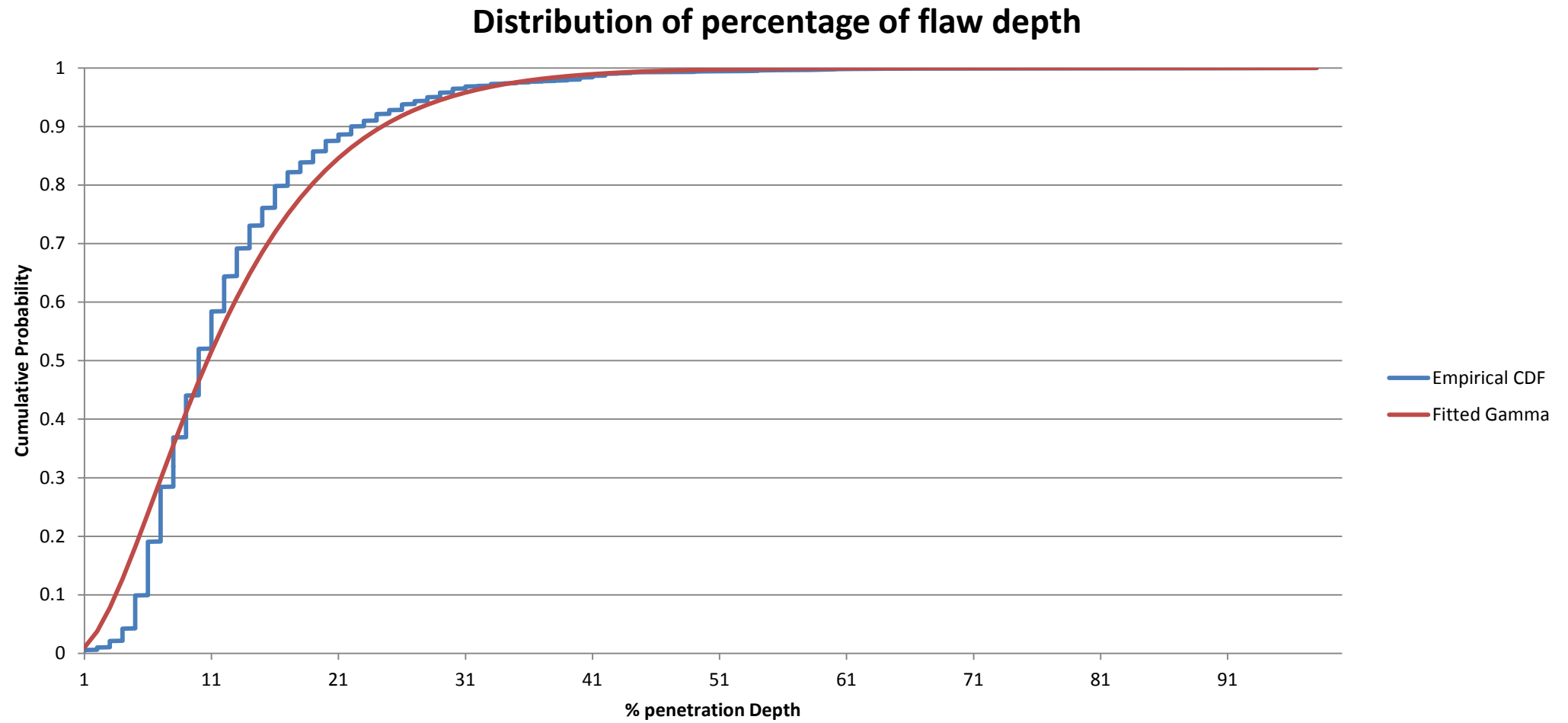


# Average Number of Flaws (both wear and Crack if applicable) as a Function of EFPY for 4 SGs (3300 tubes/SG)





# Flaw Depth Distribution

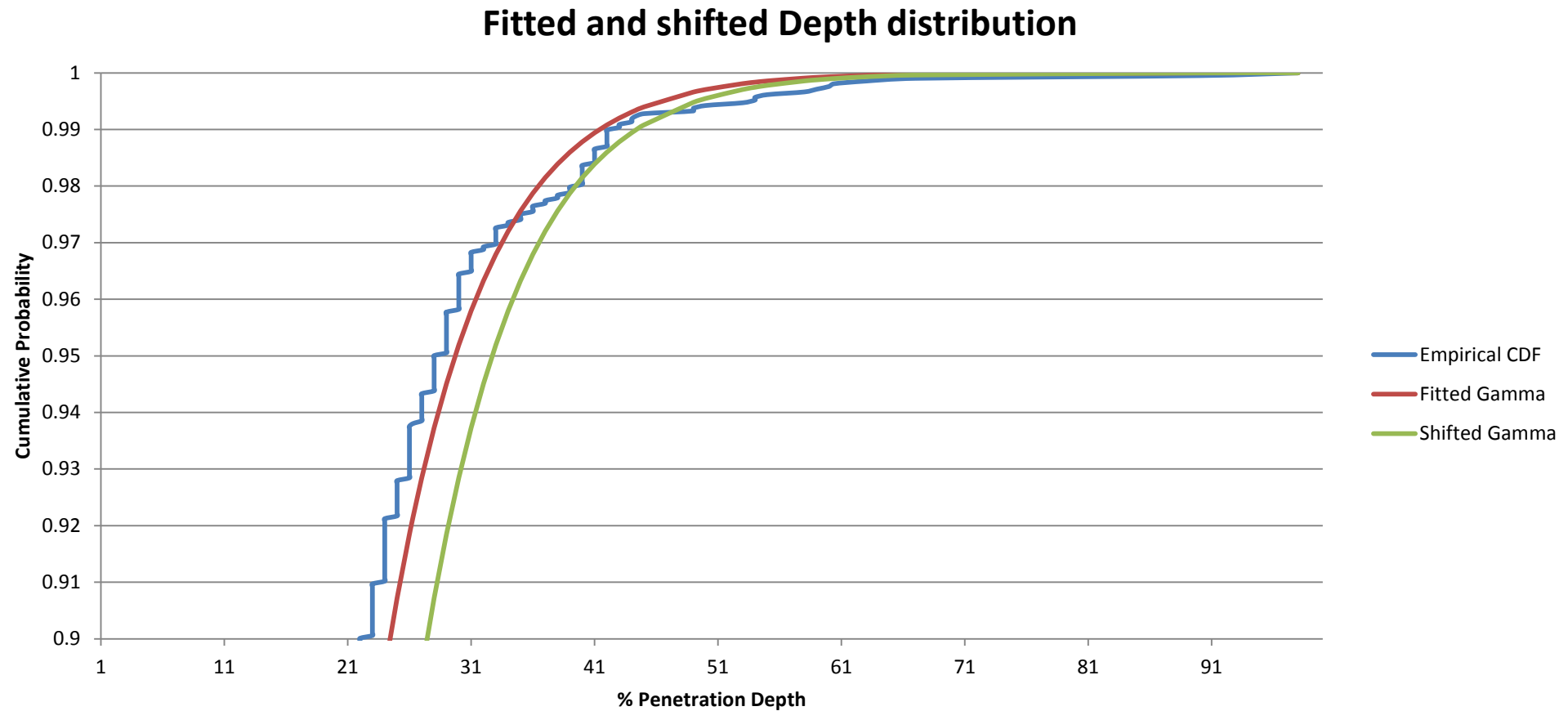


# Adjusted (shifted) Flaw Distributions used in PRA

- During PRA analysis, adjustments were made to the original estimated distributions of flaw depth and length. For example, for Westinghouse plant, the large and deep flaws were the major contributor. A better fits at the tail of distributions of length and depth therefore were examined.
- There were also a large number of unreliable small depth/length measurements; i.e. depth less than 10%, which skewed the size distributions of depths and lengths towards the lower values.
- To improve the distribution fit for large flaws which are more important to C-SGTR and to compensate for the perceived distortion of flaw size distributions towards the shallower and smaller flaws, the previous distribution were shifted by a small amount of depth and length (adding a scale variable to Gamma distribution).
- This adjustment also provided much closer estimates of the number of tubes that are plugged in each cycle (better estimate of the number of large/deep flaws at the tails).

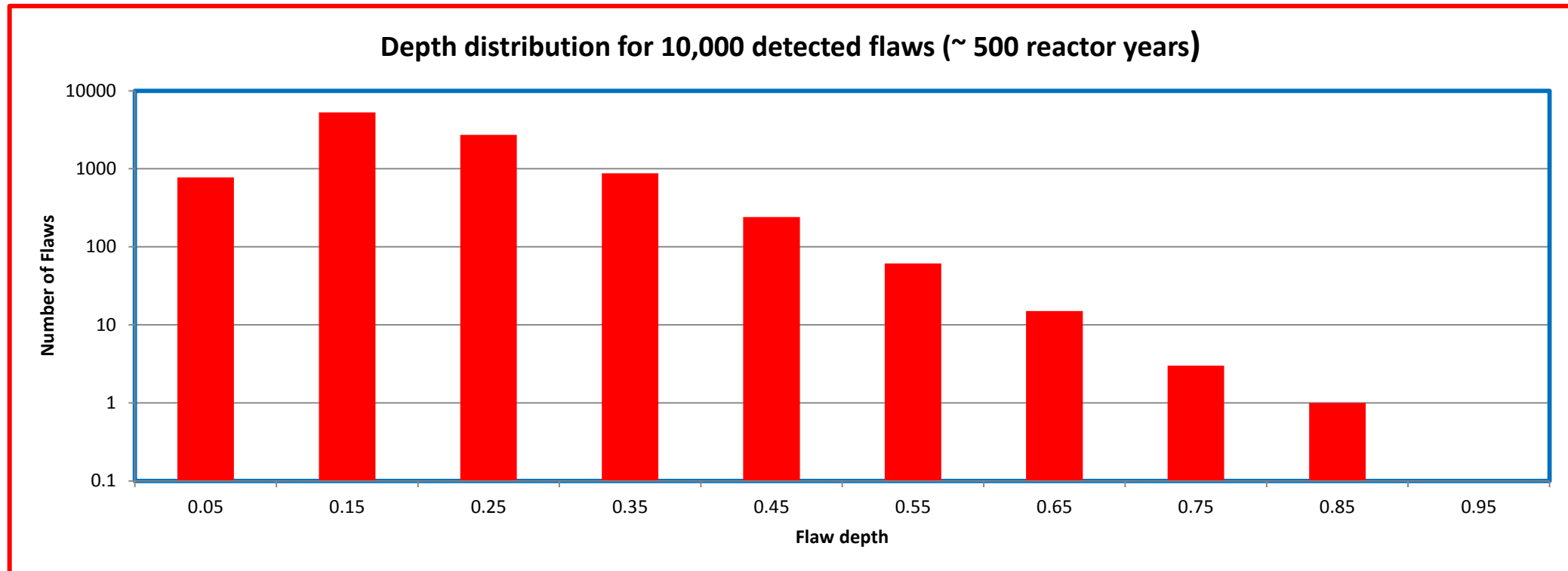


# Flaw Depth Distribution (Shifted Gamma)





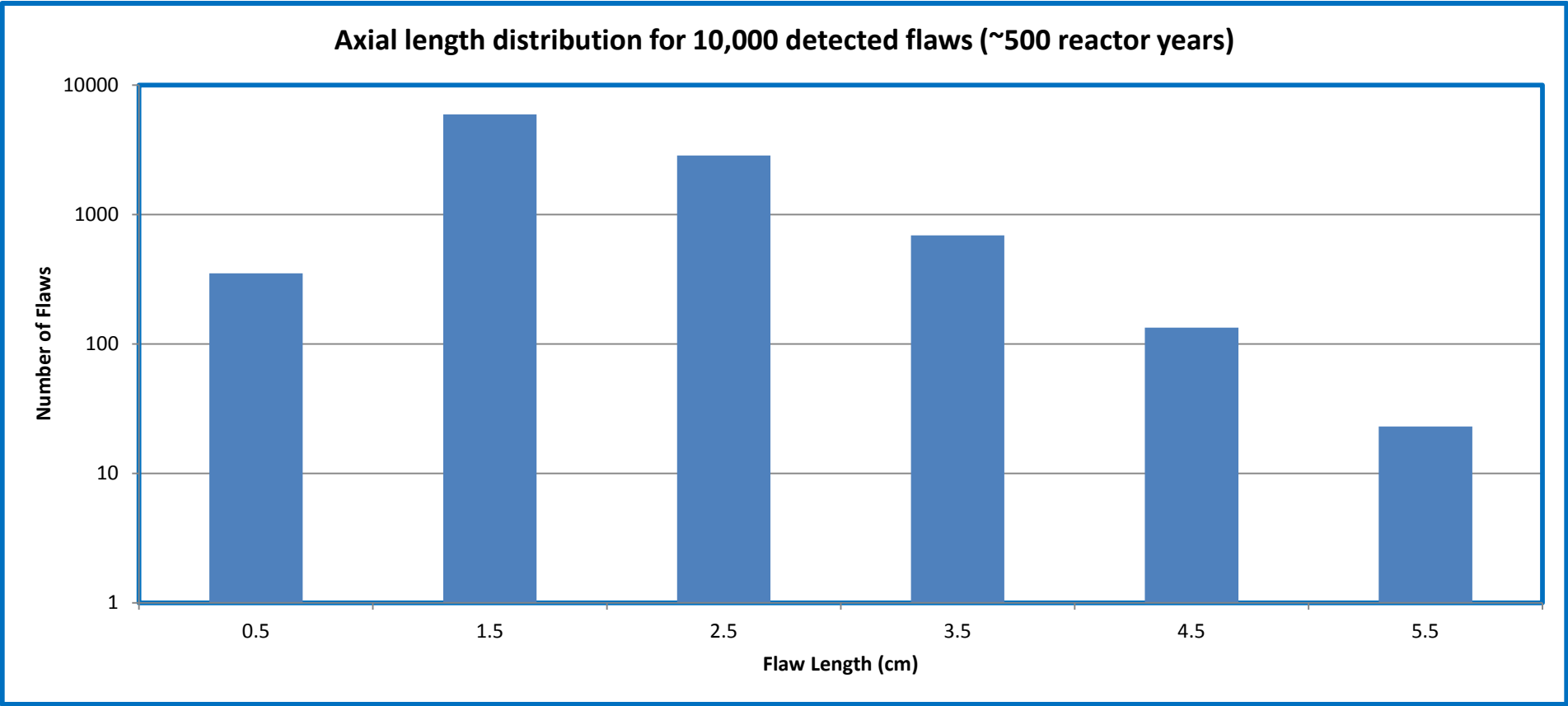
## 600TT Flaws for 10 SGs – Distribution by Depth







# 600TT Flaws for 10 SGs for illustration purposes – Distribution by Length





## General Findings

- Sufficient statistical results were developed to generate flaw samples for the C-SGTR calculator software.
- New material 600TT/690TT flaw rate generation is about an order of magnitude less than what was reported for MA 600.
- The majority of flaws observed are volumetric rather than cracks
- The flaw length and depth distribution is somewhat smaller than MA 600.



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# **Severe Accident-Induced Steam Generator Tube Rupture (SGTR)**

## **C-SGTR Calculator**

**Dr. Ali Azarm, IESS**

**Dr. Selim Sancaktar, RES/DRA**

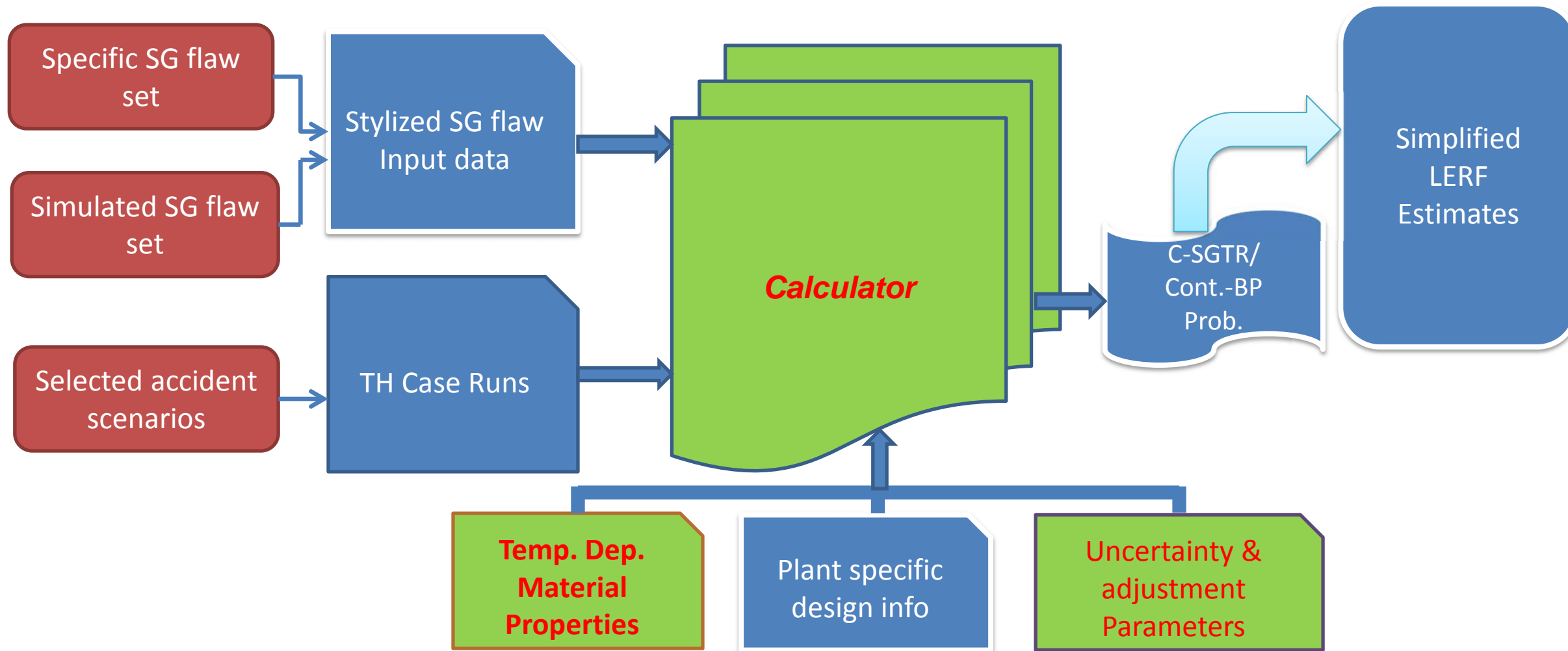
**Consequential Steam Generator Tube Rupture (C-SGTR) Subcommittee Briefing**

**April 7, 2015**

# C-SGTR Calculator

- A software referred to as the C-SGTR Calculator has been developed to support the recent C-SGTR PRA analyses.
- The calculator is used to estimate failure times and leak sizes of SG tubes with different types of flaws.
- The software also has built in models for failure of HL and surge line due to creep rupture failure mechanism to estimate failure times and probabilities of HL and surge line.
- Input material data for thermally-treated Inconel 600 and 690 (TT600 and TT690) is used for SG tubes modeled.

# Role of the Calculator in the C-SGTR PRA Analysis



C-SGTR Mod 1.5.03 b

File Tools Help

Unit Choice: SI

Main Flaws Plants

Plant Name: ZION600TT

Plant Type: Westinghouse

Sequence File Name: C:\Test\TH-153-short-end.txt Select

Tube Material: Inconel 600

No. of SGs in Plant: 4

Tube Inner Radius: 0.984 cm

Tube Thickness: 0.127 cm

Flaw File Name: C:\Test\Flaw-W4-65.txt

Critical Area (AC): 6 cm<sup>2</sup>

Max Flow Area (A0): 6.087 cm<sup>2</sup>

Number of Trials: 1000

Batch File Name: Not Used Select

Calculate Run Using Batch File

# Calculator: Models

- I. Pressure Induced Failure Model for SG tubes and Estimated Leak Area
- II. Creep Rupture Failure Model for SG tube and Estimated Leak Area
- III. Creep Rupture Failure Model for Hot Leg
- IV. Creep Rupture Failure Model for Surge-line



# Calculator: An Overview

- Models
  - Failure of a flawed tube [Mostly NRC models]
    - Wear (volumetric) and Cracks for SG tubes
  - Creep rupture failure for hotleg and surge line [EPRI model]
    - No flaw postulated
- Material Properties as a function of Temperature for:
  - Inconel 600 TT/690 TT [Open literature]
- Larson Miller Creep Rupture Parameters for:
  - Inconel 600TT/690 TT for SG tubes [NRC & Open Literature]
  - Hot leg and surge line [EPRI]





# Calculator: Sequence Input

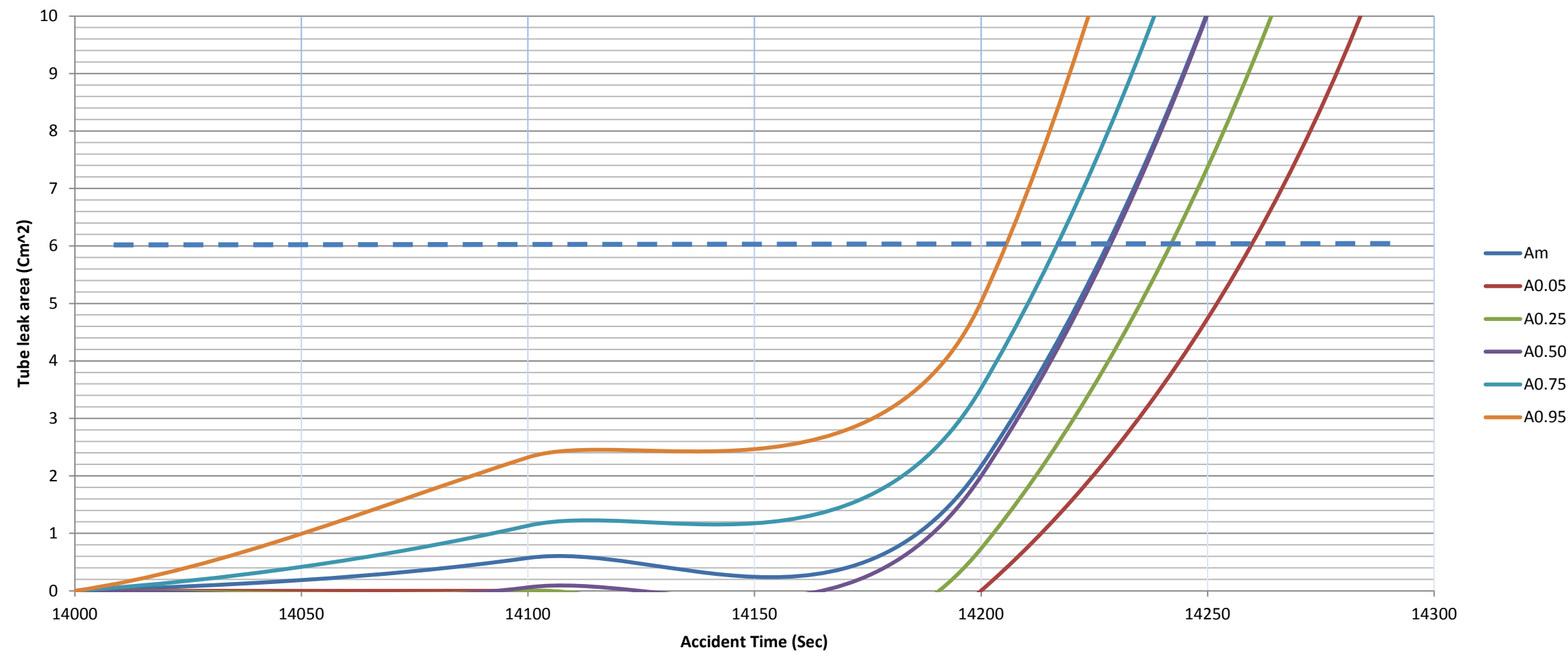
- Thermal Analysis of the accident condition, such as from MELCOR informed by CFD :
  - The fraction of hot tubes and their average temperature
  - The fraction of cold tubes and their average temperature
  - The fraction of hottest tubes and their average temperature
  - Primary/secondary pressure
  - Hot leg temperature
  - Surge-line Temperature



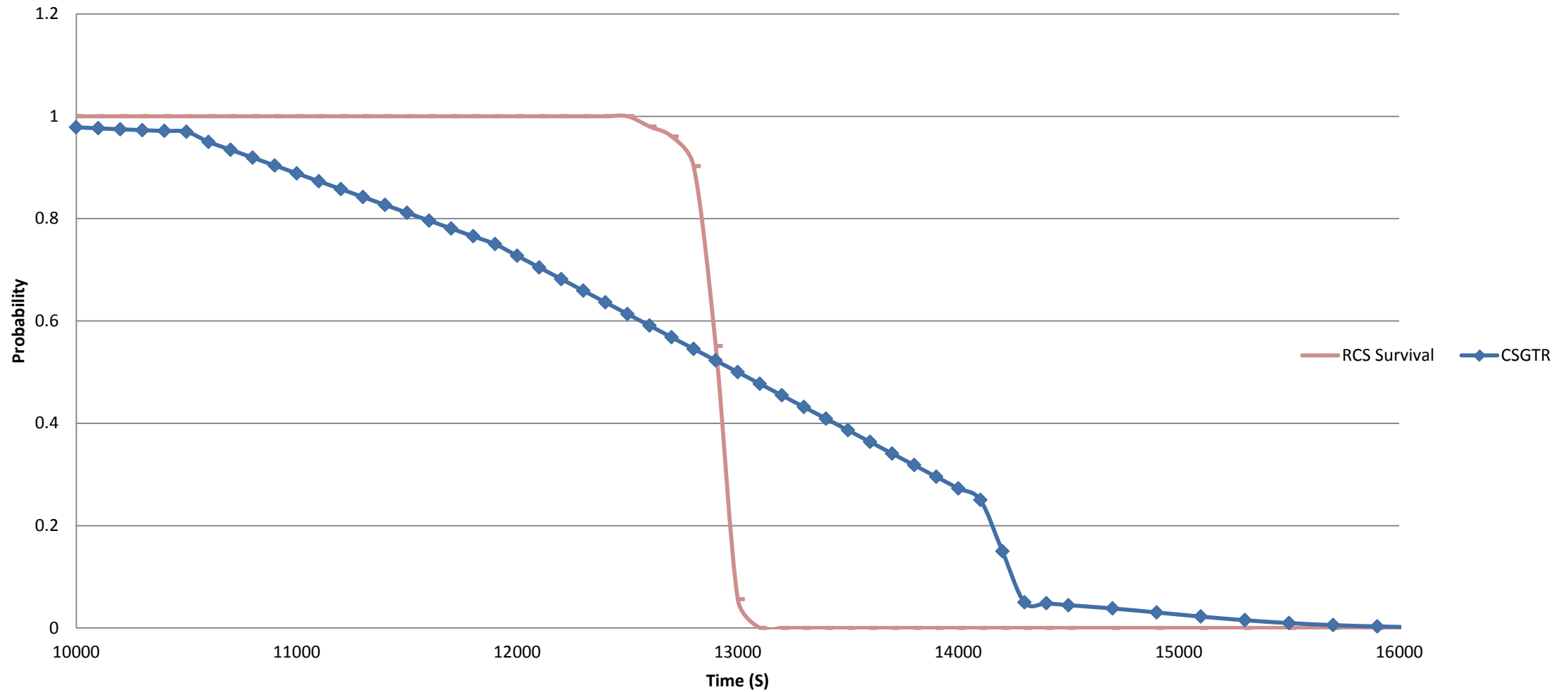
# Calculator: An Overview

- Calculator Output
  - C-SGTR leak area probability distribution [5%, 25%, 50%, 75%, 95%] as a function of accident time
  - Probability of failure of one hot leg or the surge line as a function of time
- Probabilities are estimated when uncertainties and variations are accounted for

# Graphical Presentation of Output: Total SG Tube Leak Area



# Graphical Presentation of Output Information: Survival Probabilities





# Calculator: Overview of Uncertainties

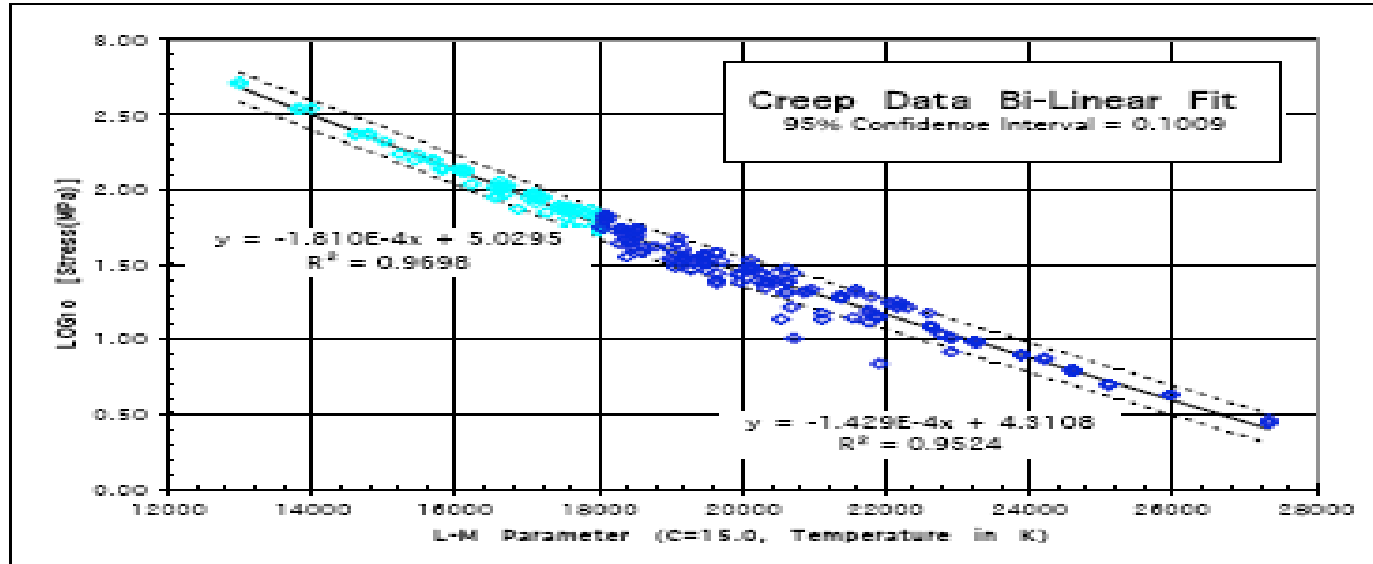
- Modeling uncertainties
  - Parameter uncertainties for creep rupture model for SG tubes, hot leg, and surge line
  - Aggregate (lump) uncertainty for leak rate and failure pressure predictions for both pressure induced and creep rupture failure of SG Tubes
- Measurement Uncertainties
  - Uncertainties in material properties
  - Measurement uncertainties of Flaw size (depth and length)



# Calculator: Overview of Uncertainties

- Numerical Errors in estimation
  - Not handled Formally
  - All runs were performed using 1000 MC samples
- Probabilistic Variations
  - Variations represented by flaw samples [ handled outside the code]
  - Variations of TH analyses results for class of accidents [ handled outside the code]

# Example: Uncertainties for Larson Miller Parameter



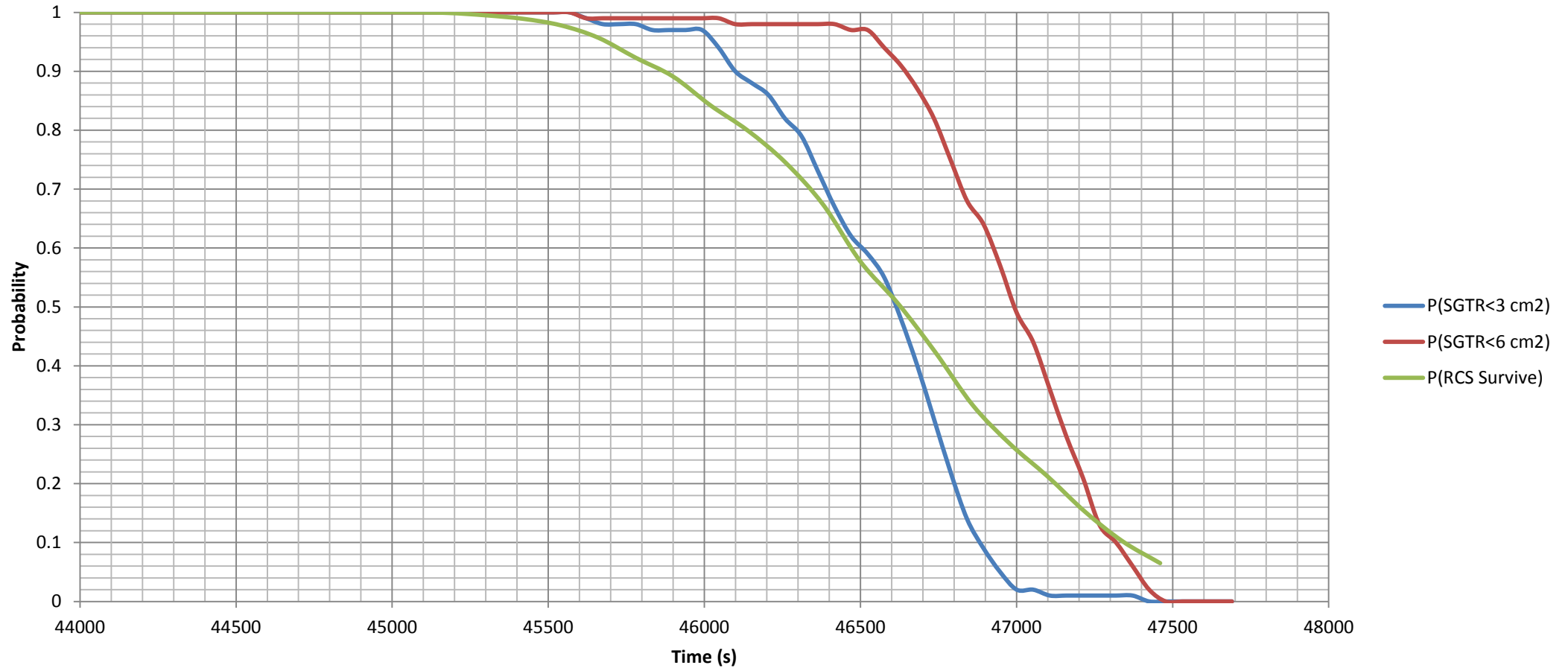
$$P_{LM} = ((27.78 \pm 0.44) - 2.4 \ln(m_p \sigma)) \times 10^3$$

$$m_p \sigma \geq 5.7 \text{ ksi} = 39.3 \text{ Mpa}$$

$$t_R = 10^{\frac{P_{LM}}{T} - 15} \quad \int_0^{t_f} \frac{dt}{t_R} = 1$$

For a T value of 1000 degree Kelvin (~727 C), the overall error interval (two sided 5% and 95%) for time to failure;  $t_f$  can vary by a factor of 10.

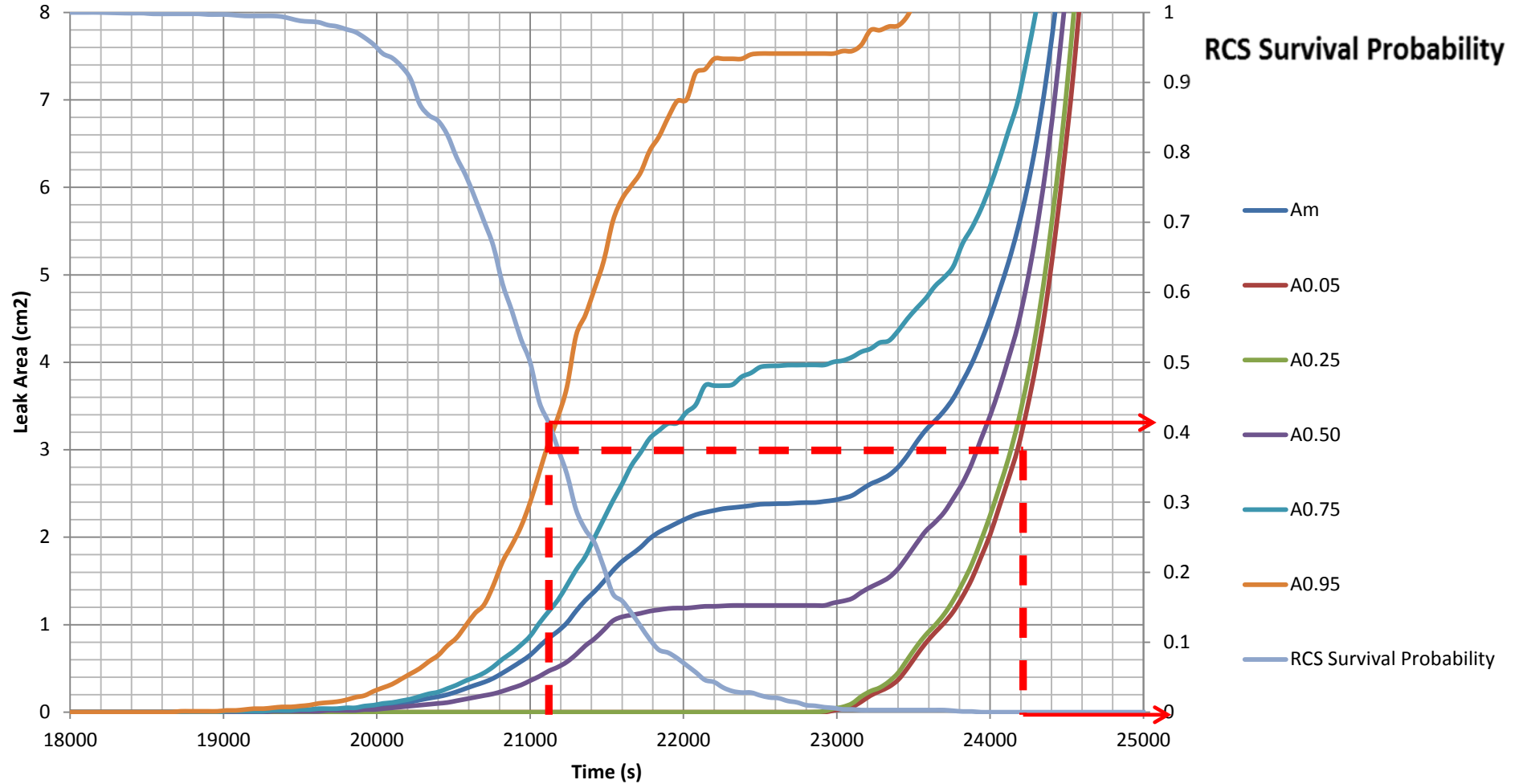
# Illustrative Graphical Examples



The RCS survival Probability and the probability of SGTR with a Leak Area less than 3 and 6 cm<sup>2</sup> for Itsbo-a-b-scf



# Illustrative Graphical Examples



The RCS survival Probability and percentiles of SGTR Leak Areas for stsbo-a-hottest tubes

# Calculator V&V

- Limited results from individual equations were tested against published results from testing
- Case runs for each module was checked against the results obtained from similar MCAD routine
- Initial Version of software and Probabilistic Fracture Mechanics Models for SG tubes were reviewed by Argonne National Laboratory (ANL).
- Models for hotleg and surge line model examined for reasonableness by RES/DE using finite–element program ABAQUS®
- Predicted 50 percentiles of the predictions were compared to deterministic results for limited simple case runs



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# **Severe Accident-Induced Steam Generator Tube Rupture (SGTR)**

## **Probabilistic Risk Analysis of C-SGTR**

**Dr. Ali Azarm, IESS**

**Dr. Selim Sancaktar, RES/DRA**

**Consequential Steam Generator Tube Rupture (C-SGTR) Subcommittee Briefing**

**April 7, 2015**

# Background

- In response to a NRC/NRR user need request, RES has performed a C-SGTR Analysis for two selected plants; a Westinghouse (W) and a Combustion Engineering (CE).
- A draft NUREG report titled  
*Consequential SGTR Analysis for Westinghouse and Combustion Engineering Plants with Thermally-Treated Alloy 600 and 690 Steam Generator Tubes*
- Is completed.
- The draft report contains work done by three disciplines in RES:
  - thermal-hydraulic and computational fluid dynamics analysis (RES/DSA),
  - Fracture Mechanic analyses (RES/DE), and
  - probabilistic risk assessment (RES/DRA)
- This presentation discusses PRA aspects of the work.



## Objective

- To develop a methodology for a quantitative assessment of the risk associated with C-SGTR during a severe accident after the onset of core damage, and during a DBA event before the onset of core damage.
- Estimation of the LERF\* as a result of containment bypass due to C-SGTR and its application to two PWRs: a Westinghouse and a Combustion Engineering design consistent with NRC/NRR user request.
- Estimation of the probability of C-SGTR\* using calculator software.
  - \* C-SGTR is defined by a leakage area greater than a threshold value occurring before a large vent path in RCS is established; either due to failure of RCS components or intentional depressurization.

# C-SGTR before and after the onset of core damage

- After Core Damage
  - A C-SGTR ensuing from a severe accident (CD already postulated) is mainly due to creep rupture (temperature-induced C-SGTR).
  - Such a C-SGTR may increase LERF, but does not affect plant CDF.
  - The race between SG tube failure and failure of another RCS component (hot leg, surge line, PORVs/SRVs, etc.) determines whether the majority of fission products may be retained in the containment or not.
- C-SGTR Before Core Damage
  - A C-SGTR before core damage may be caused by accidents that create a delta pressure across the SG tube walls significantly larger than its nominal value.
    - A C-SGTR Before core damage is mainly caused by pressure induced failures of the SG tubes.
  - Such a C-SGTR will complicate the accident progression and will increase both CDF and LERF.

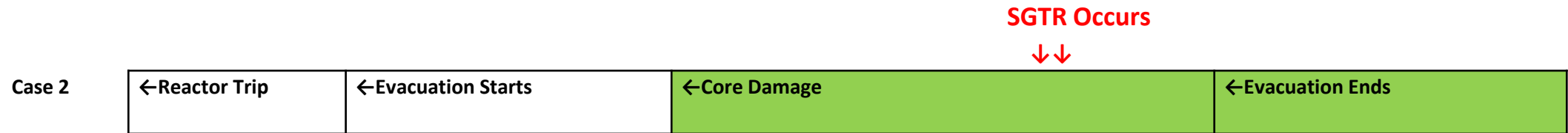
## Example of a C-SGTR after the onset of core damage a fast (short) SBO

- Initial Phase
  - loss of offsite power, failure of diesels, and failure of auxiliary feedwater systems
  - natural circulation is established
  - primary inventory lost through reactor coolant pump seals.
  - Secondary side boils off, secondary side dry
  - Additional primary inventory lost through safety valve cycling and RCP seals
- loop natural circulation stops as primary inventory falls in SG tubes.
  - Counter current flows of superheated steam begins as inventory falls below hot leg; Core and primary system heat up.
- Core uncovers
  - core oxidizes and produces significant power, system heat up accelerates
  - This can induced failure of RCS piping or Steam Generator tubes (A race in time)

# Selected Timelines for C-SGTR after Core Damage

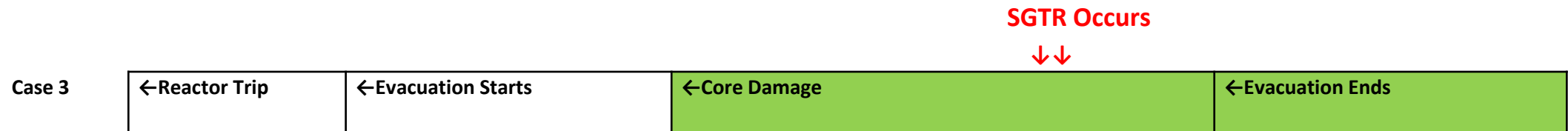


C-SGTR occurs too late to contribute significantly to LERF



↑  
Hot Leg Fails

C-SGTR occurs after hot leg failure thus fission product release is limited



↑  
Hot Leg Fails

C-SGTR occurs before hot leg failure; fission product release not curbed until hot leg failure



## Example of C-SGTR before core damage

- Blow down of one SG

- Rapid and complete blow down
  - Delta Pressure across SG tube increases from approximately 1200 psi (nominal) to about 2250 psi
  - Affected Steam generator dries out
  - Operator fails to isolate the affected SG
  - Primary remains high pressure, High pressure system inject
- One or more SG tubes may rupture if they have a deep flaw( 70% or more flaw depth)
- Operator fail to re-establish HPI (If HPI was terminated early on in response to SG blow down)
  - Core Uncovery and onset of core damage due to loss of primary inventory through ruptured SG tubes and failure to reestablish HPI
- This example scenario could contribute to both CDF and LERF

## Steps for a simple PRA for LERF estimation

### Severe Accidents (CD already postulated)

1. Select accident sequences and estimate their frequencies from the existing PRAs.
2. Determine T&H characteristics of the sequences.
3. Consider a single flaw of various depth and determine the probabilities of SGTR before RCS failure as a function of flaw depth
4. Depending on the results from step 3 generate appropriate flaw samples for the needed calculator runs and calculate the associated flaw probabilities
5. Perform case runs with the calculator software
6. Estimate containment bypass probability
7. Estimate the associated LERF contribution

## 1. Select Accident Sequences and Their Frequencies

- Identify High and Dry Sequences
  - Level 2 analysis is available: High primary and dry secondary are Level 2 binning questions, so this task is straight forward for plants with existing Level 2 analysis
  - Level 1 analysis is available: search the sequences to identify those when at the onset of core damage the primary is at high pressure and the secondary dry [e.g. SBO scenarios, feed and bleed scenarios].
- Consider CDF contributors, internal and external events
  - Consider the potential for multi-unit impact; e.g. extended SBO due to seismic impacting multiple Units

# 1. Select Accident Sequences and Their Frequencies (Cont'd - two Pilot Plants)

| Zion (W-Plant) Sequences                  | Short Term SBO CDF | Long Term SBO CDF |
|---|--------------------|-------------------|
| Internal events including internal floods | 5.23E-7            | 5.2E-6            |
| Seismic                                   | ~5.6E-7            | 5.6E-6            |
| Fire                                      | ~9.5E-7            | 9.5E-6            |
| Total                                     | 2.03E-6            | 2.03E-5           |

| Calvert Cliffs (CE-Plant) Sequences | Short Term SBO | Long term SBO |
|-------------------------------------|----------------|---------------|
| Internal events                     | 2.5E-08        | 1.7E-07       |
| Seismic                             | 6.4E-08        | 2.0E-7        |
| Fire                                | 2.4E-06        | 2.4E-05       |
| Flood                               | $\epsilon$     | 1.6E-06       |
| High wind                           | 4.7E-08        | 4.3E-06       |
| Total                               | 2.6E-06        | 3.1E-05       |

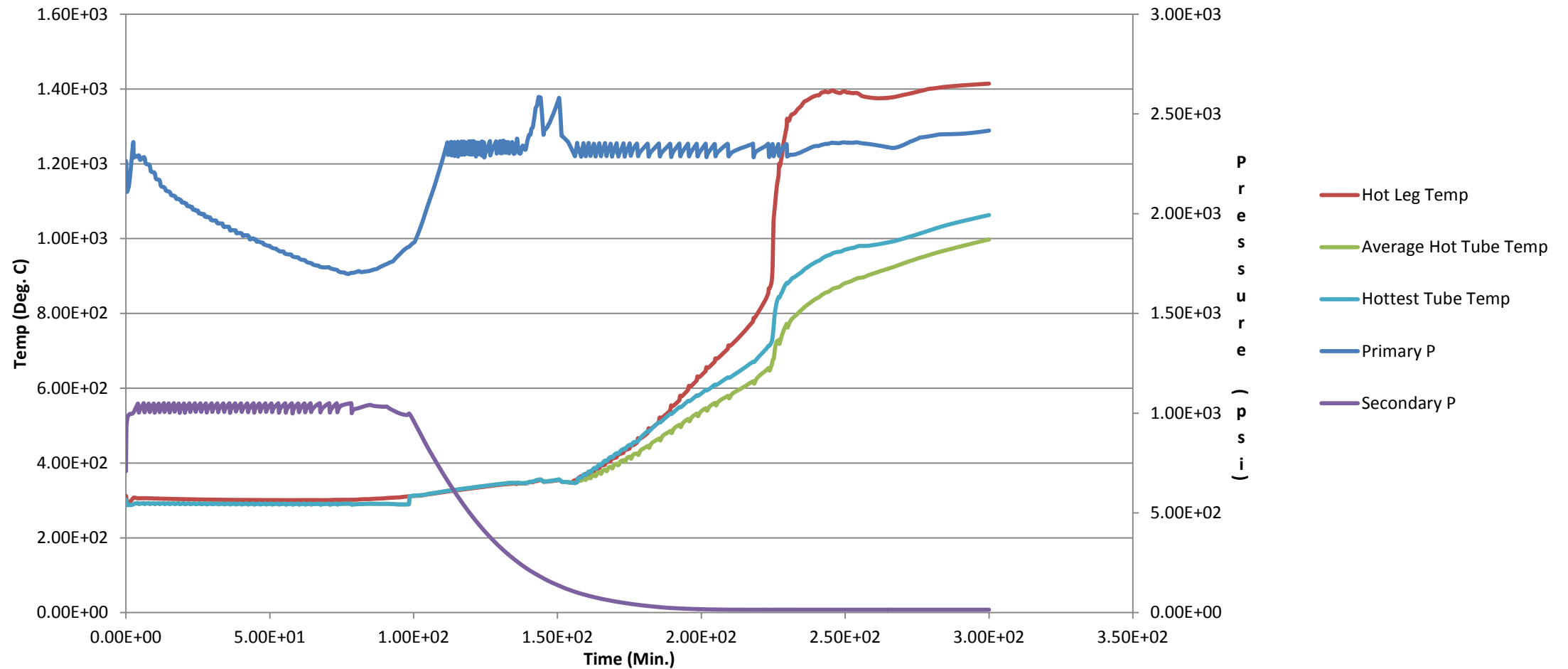
# 1. Select Accident Sequences and Their Frequencies (Potential Sequences for Dual Unit: Calvert Cliffs)

| Initiating Event | Short Term SBO |            | Long term SBO |            | At least one Unit CDF |                 |
|------------------|----------------|------------|---------------|------------|-----------------------|-----------------|
|                  | Single Unit *  | Dual Unit  | Single Unit*  | Dual Unit  | Short Term SBO        | Long term SBO   |
| Internal events  | 1.9E-08        | 5.5E-09    | 4.5E-08       | 1.2E-07    | 2.5E-08 (~13%)        | 1.7E-07 (~87%)  |
| Seismic          | 5.0E-08        | 1.4E-08    | $\epsilon^+$  | 2.0E-07    | 6.4E-08 (24%)         | 2.0E-7 (~76%)   |
| Fire             | $\epsilon$     | 2.4E-06    | 2.2E-05       | 2.2E-06    | 2.4E-06 (~9%)         | 2.4E-05 (~91%)  |
| Flood            | $\epsilon$     | $\epsilon$ | 1.6E-06       | $\epsilon$ | $\epsilon$            | 1.6E-06 (~100%) |
| High wind        | $\epsilon$     | 4.7E-08    | $\epsilon$    | 4.3E-06    | 4.7E-08 (~1%)         | 4.3E-06 (~99%)  |
| Total            | 6.9E-08        | 2.5E-06    | 2.4E-05       | 6.8E-06    | 2.6E-06 (~8%)         | 3.1E-05 (~92%)  |

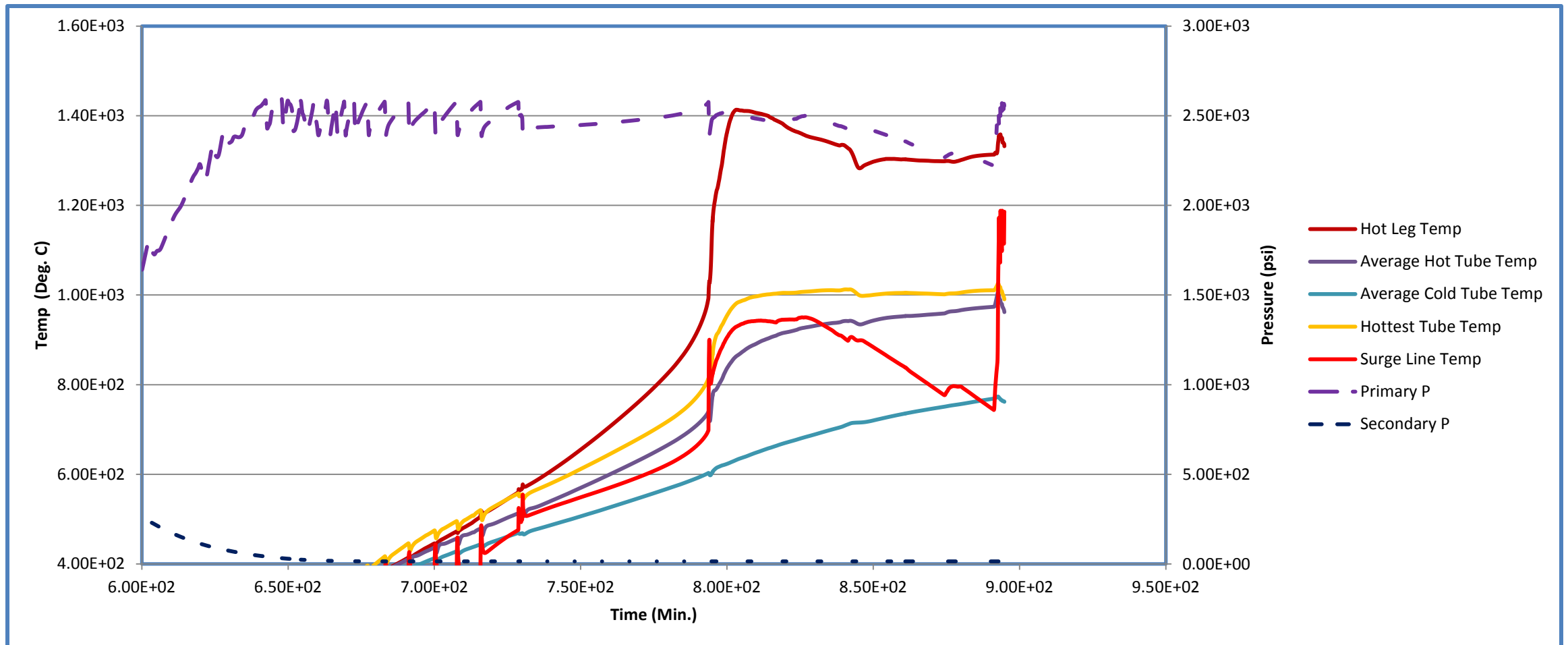
## 2. Determine T&H characteristics of the sequences (RELAP/SCADAP for Zion)

- Base-Case for Short term SBO
  - SBO with early failure of TDAFW
  - 21 gpm RCP leakage per pump
  - 0.5 square inch hole in secondary side of SG
  - No recovery of AC
- Base-case for Long term SBO
  - SBO with Failure of TDAFW after Battery depletion
  - 21 gpm RCP leakage per pump
  - 0.5 square inch hole in secondary side of SG
  - No recovery of AC
- Several sensitivity Case Studies
  - Rapid and early depressurization
  - Different RCP leakage rates
  - Larger hole in secondary including open SG SRV/ARVs
  - Sensitivity of the threshold of C-SGTR leakage areas

# TH Results for Westinghouse SBO Sequence with Failure of TDAFW Pump at T=0



# TH Results for Westinghouse SBO Sequence with Failure of TDAFW Pump at T=4 Hours



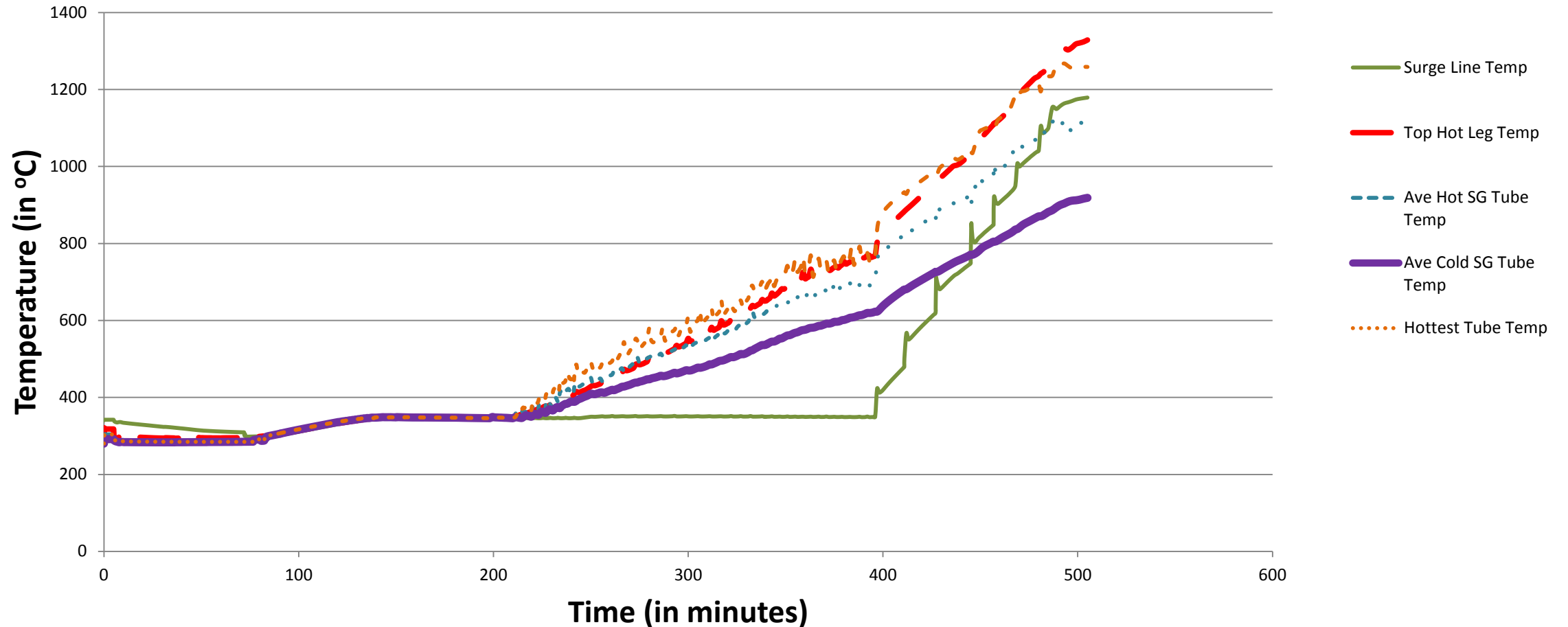


## 2. Determine T&H characteristics of the sequences (MELCOR for Calvert Cliffs)

- Base-Case for Short term SBO
  - SBO with early failure of TDAFW
  - 21 gpm RCP leakage per pump
  - 0.5 square inch hole in secondary side of SG
  - No recovery of AC
  - Differentiated between primary Loop with and without pressurizer
- Base-case for Long term SBO
  - SBO with Failure of TDAFW after Battery depletion
  - 21 gpm RCP leakage per pump
  - 0.5 square inch hole in secondary side of SG
  - No recovery of AC
  - Differentiated between primary Loop with and without pressurizer
- Sensitivity Case Studies
  - Larger hole in secondary - failure of SG SRV to reclose after the first demand
  - With or without failure of RCS component s

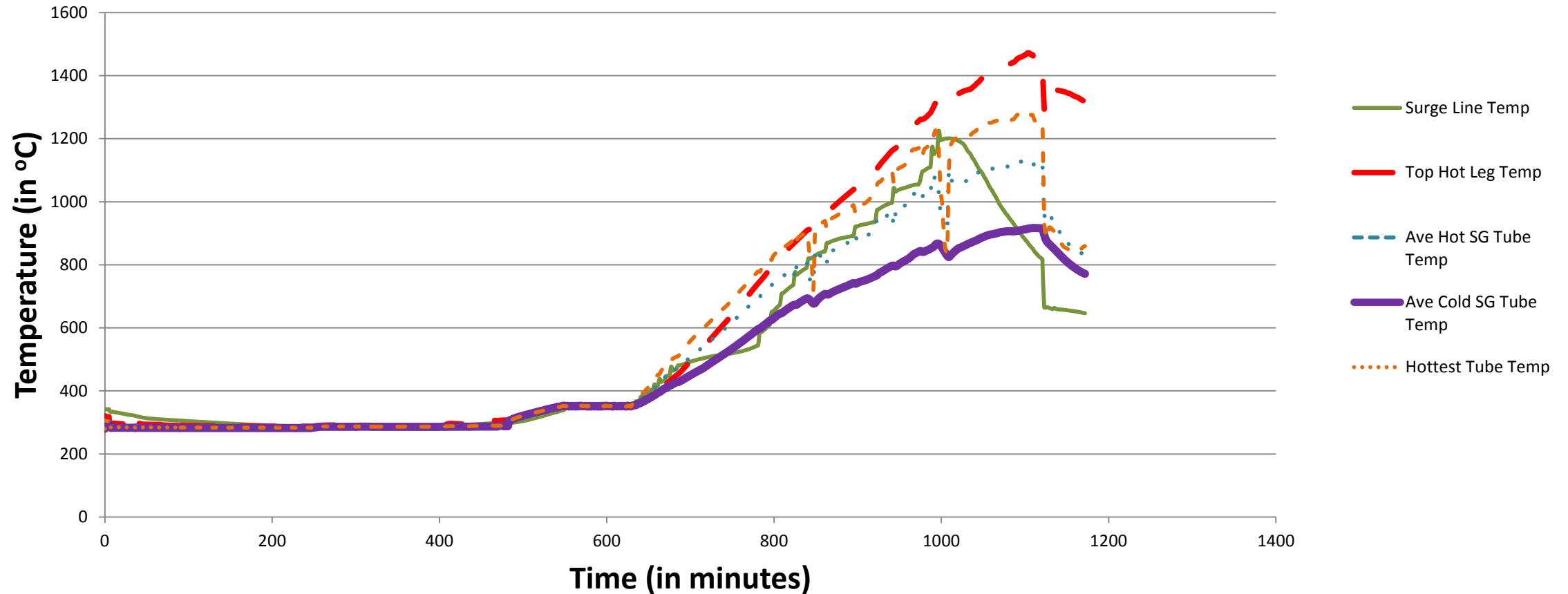
# TH Results for CE SBO Sequence with Failure of TDAFW Pump at T=0 Hours

## SBO with TDAFW Operating for 0 Hours; Calvert Cliffs Loop A



# TH Results for CE SBO Sequence with Failure of TDAFW Pump at T=4 Hours

Extended SBO with TDAFW Operating for 4 Hours; Calvert Cliffs Loop A



### 3. Flaw depth screening using C-SGTR calculator for base case short (fast) SBO scenarios

| Flaw Depth       | West. Representative Plant |              | CE Representative Plant |              |
|------------------|----------------------------|--------------|-------------------------|--------------|
|                  | Ave. Hot Tube              | Hottest Tube | Ave. Hot Tube           | Hottest Tube |
| <0.05 (Pristine) | ~ 0                        | ~ 0          | ~0                      | ~100%        |
| 0.25             | ~ 0                        | ~ 0          | ~5%                     | ~100%        |
| 0.50             | ~ 0                        | ~ 0          | ~80%                    | ~100%        |
| 0.75             | 50%                        | ~100%        | 100%                    | ~100%        |
| 0.9              | 100%                       | ~100%        | 100%                    | ~100%        |

- Only Large Flaws will contribute to C-SGTR probability for the representative Westinghouse plant.
- Both large flaw and medium size flaws are contributing to C-SGTR for the representative CE plants. Small flaws can contribute if located at hottest tubes.
- There is a small fractions of tubes that are exposed to hottest tube temperature and the flaws Will be assigned randomly to them. Failure of pristine tube exposed to hottest temperature are not expected to create large leakage area.

## 4. Flaw samples for calculator case runs

- I. For cases where a few large/deep flaws (much larger than SG tube plugging criteria) are the major contributor to C-SGTR; Perform the analysis with a small sample of large flaws.
  - In such cases we expect low C-SGTR probability, since the probability for one or more very large flaws within a cycle is expected to be small.
- II. For cases where flaws of all sizes contribute to C-SGTR probability; Perform analysis using average set of flaws in addition to sensitivity analysis using several sets of flaws for addressing the uncertainty due to flaw variation .
  - In such cases we expect high probability of C-SGTR and some uncertainties due to variations in flaw samples.

#### *4. Flaw Samples for Calculator Case runs (cont'd)*

- For the Representative Westinghouse Plants
  - Used a limited sample of large flaws
  - Estimated the frequency that there could be one, two, or more large flaws within a cycle
- For the Representative CE Plant
  - Develop average or expected sample bins to estimate the mean probability of C-SGTR
  - When needed, developed limited sample flaws for sensitivity analysis and addressing the uncertainties

## 4. Flaw Samples for Calculator Case runs (cont'd)

**For Rep. West. Plant: Large Flaws only**

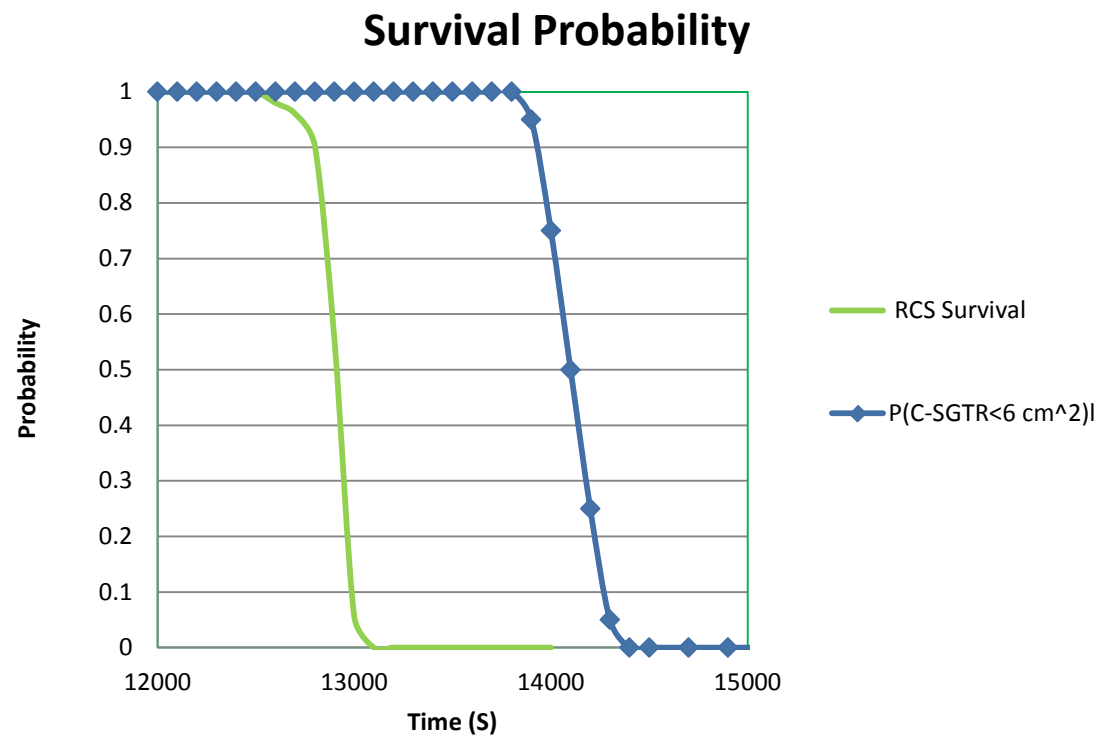
| Depth Bin    | Probability of Flaw Belonging to Depth Bin | Expected Number of Flaws in Depth Bin |
|--------------|--|---------------------------------------|
| 0.6 – 0.7    | 1.46E-03                                   | 0.0453                                |
| 0.7 – 0.8    | 3.39E-04                                   | 0.0105                                |
| 0.8 – 0.9    | 7.70E-05                                   | 0.00239                               |
| 0.9 – 1.0    | small                                      | small                                 |
| <b>Total</b> | 1.86E-3                                    | 0.06                                  |

**For CE Plant :Expected Number of Flaws for both SGs**

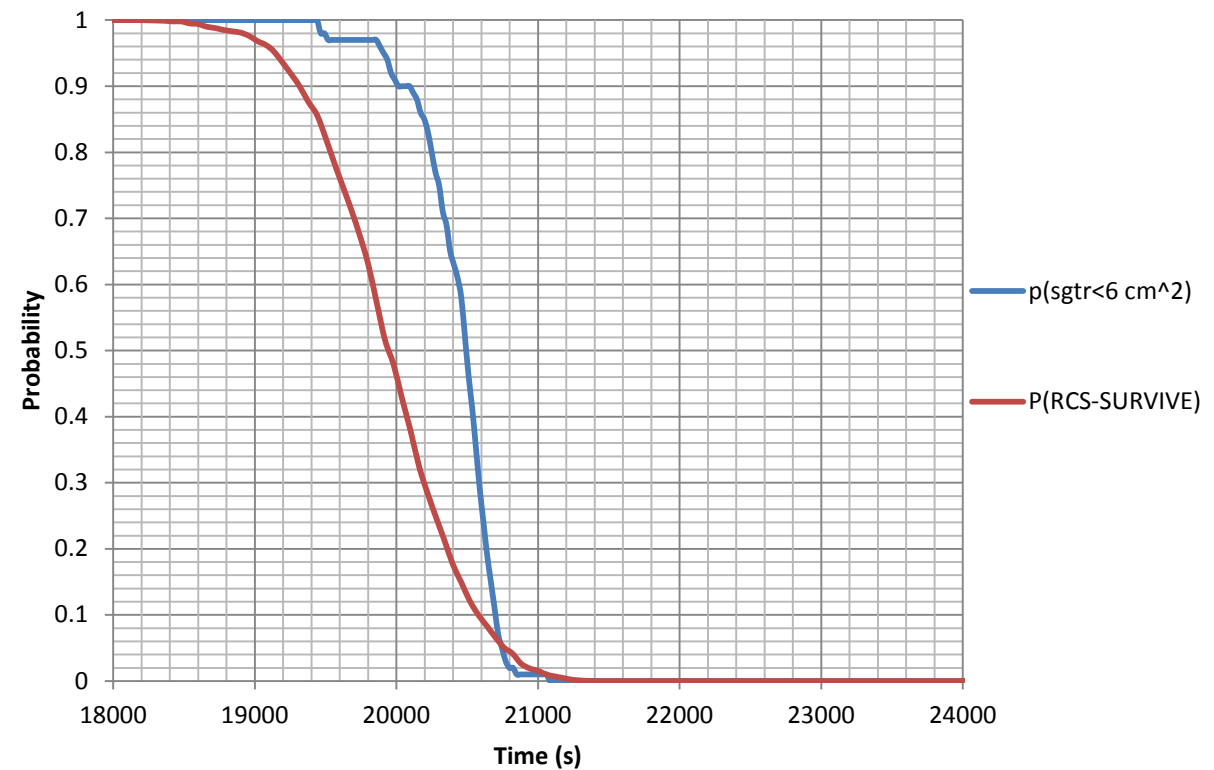
| Depth / Length | 1 cm | 2 cm | 3 cm | 4 cm | 5 cm | 6 cm | Total |
|----------------|------|------|------|------|------|------|-------|
| 0.1            | 1    | 13   | 7    | 2    | 0    | 0    | 22    |
| 0.2            | 6    | 88   | 43   | 11   | 2    | 1    | 151   |
| 0.3            | 3    | 45   | 22   | 5    | 1    | 0    | 76    |
| 0.4            | 1    | 1    | 1    | 0    | 0    | 0    | 3     |
| 0.5            | 0    | 1    | 0    | 0    | 0    | 0    | 1     |
| 0.6            | 0    | 0    | 0    | 0    | 0    | 0    | 0     |
| 0.7            | 0    | 0    | 0    | 0    | 0    | 0    | 0     |
| 0.8            | 0    | 0    | 0    | 0    | 0    | 0    | 0     |
| 0.9            | 0    | 0    | 0    | 0    | 0    | 0    | 0     |
| <b>Total</b>   | 10   | 148  | 73   | 18   | 3    | 1    | 253   |

## 5. Case Runs with Calculator Software (short/fast SBO)

### West. Rep. Plant: Very Small C-SGTR Probability



### CE. Rep. Plant: relatively high C-SGTR Probability





## 6. Estimate containment bypass probability

- Containment bypass Mathematical Equation for Each Set of Flaw

$$Prob(CSGTR) = \int Prob(RCS \text{ survive at } t) * Prob(CSGTR \text{ occurs between } t \text{ and } (t + dt)) * dt$$

- The integration is summed over all flaw samples accounting for their probabilities
- The calculations generally performed using a Fortran routine or using MS-Excel worksheet.

## 6. Estimate containment bypass probability (Cont'd)

| CSGTR Leak Area                                   | Probability Of Containment Bypass |                       |   |                     |
|---|-----------------------------------|-----------------------|---|---------------------|
|   | SBO with Early Failure of TDAFWs  |                       | SBO with Failures of TDAFWs after Battery Depletion |                     |
|   | CE-690<br>(with SG SRV open)      | WEST. 600<br>(690)    | CE  | WEST. 600<br>(690)  |
| Greater than one tube<br>(~6 cm <sup>2</sup> )    | 0.22<br>(0.99)                    | 1.31E-02<br>(8.90E-3) | 0.31<br>(~1)  | 2.6E-02<br>(1.8E-2) |
| Greater than two tubes<br>(~ 12 cm <sup>2</sup> ) | 0.06<br>(NC*)                     | 8.23E-5<br>(3.85E-5)  | 0.10<br>(NC)  | 1.6E-4<br>(7.8E-5)  |
| Greater than three tubes                          | (NC)                              | ~0                    | (NC)  | ~0                  |

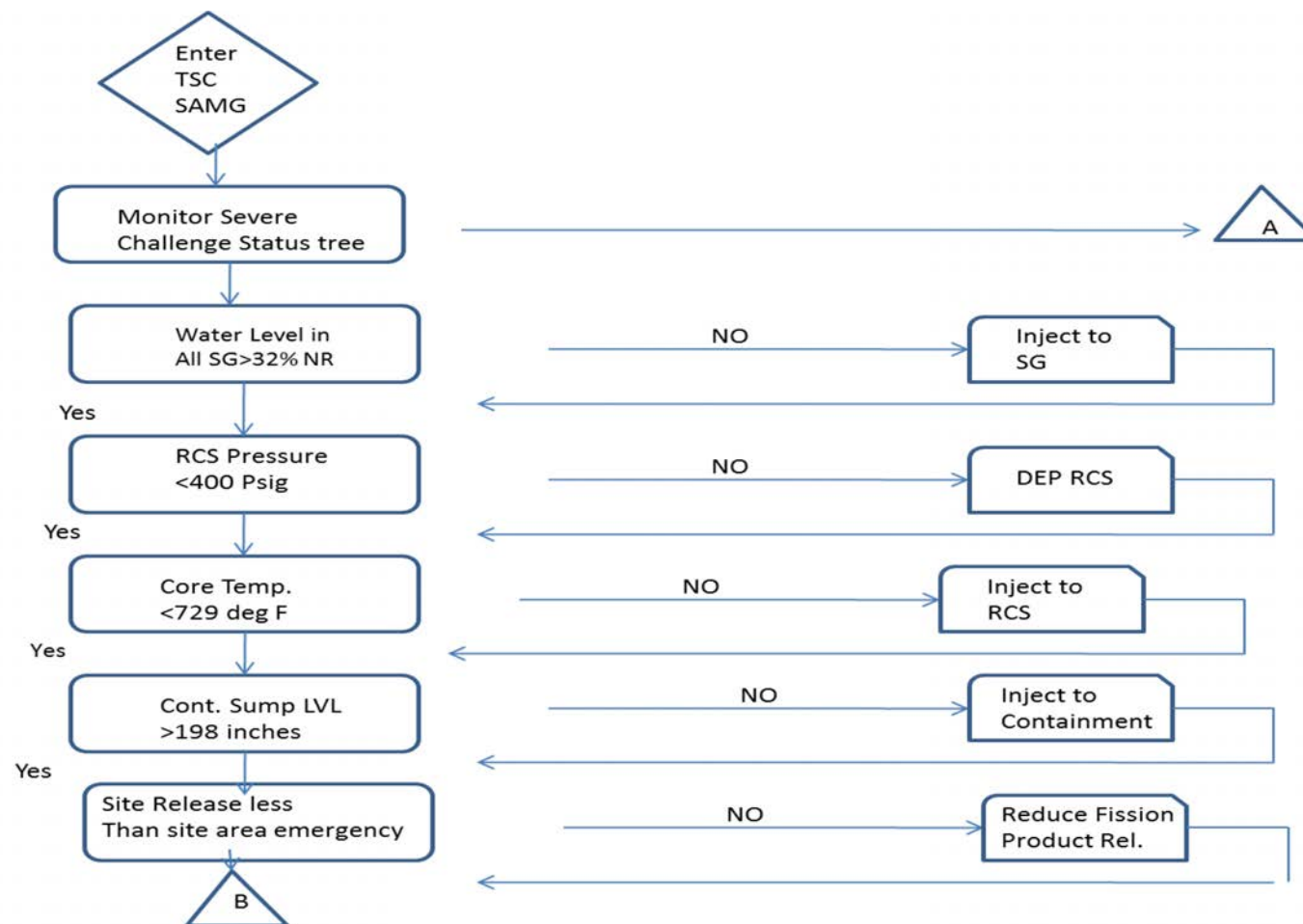
\*NC: Not Calculated

## 7. Simplified LERF Model

- Detail Level 2 Models
  - Advantages
    - Differentiate between Large and small releases
    - Account for SAMG activities
    - Provide detail timing of releases
  - Challenges
    - Equipment operations after onset of core damage (PORV, SG SRVs, ARVs, etc.)
    - HRA associated with SAMG actions
    - Adequate differentiation in magnitude of source terms and release timing
- Bounding LERF analysis

## 7. Simplified LERF Model

### Typical SAMG Actions for C-SGTR



## 7. Simplified LERF Model

### SAMG actions related to C-SGTR

- Objectives of SAMG
  - To arrest the core melt within the vessel by depressurization and injection
  - To reduce radioactive release magnitude (scrubbing) by depressurizing and injecting to/refilling the SGs
- Actions depends on
  - AC recovery
  - DC availability
- Additional issues related to C-SGTR
  - Bump RCPs
  - Injection of cold water into a dry SG

## 7. Simplified LERF Model

- Simplified bounding LERF Evaluation using factor analysis
  - Frequency of severe accident sequences with potential for C-SGTR ( $f_{AC}$ ),
  - Containment Bypass Probability due to C-SGTR ( $P_{CSGTR}$ ),
  - Conditional Probability that the subsequent failure of RCS including the stuck open relief valves do not occur ( $P_{NDEP}$ )
  - Failure Probability of all SAMG actions ( $P_{SAMG}$ )
  - Probability that early effective evacuation is not successful ( $P_{EVAC}$ )

## Conditional LERF Probabilities for an SBO with Early and Late Failures of TDAFW for W plant

| Factors     | Applicability                                       | LERF Factors |
|-------------|---|--------------|
| $P_{CSGTR}$ | Due to one or more tube breaks in a SBO CD Sequence | 1.3E-02      |
|             | - Due to single tube break only                     | 1.3E-02      |
|             | - Due to multiple tube breaks                       | 8.2E-05      |
|             | - Loop seal cleared                                 | 1.0          |
| $P_{NDEP}$  | Multiple tubes with loop seal cleared               | 1.0          |
|             | Break of one SG tube and w/o loop seal cleared      | 1.0          |
| $P_{SAMG}$  | Multiple tubes with loop seal cleared               | 1.0          |
|             | Break of one SG tube and w/o loop seal cleared      | 1.0          |
| $P_{EVAC}$  | In a SBO, CD Sequence with early failure of TDAFW   | 1.0          |
|             | In a SBO, CD Sequence with late failure of TDAFW    | 0            |

## Conditional LERF Probabilities for SBO with Early and Late Failures of TDAFW for CE plant

| Factors            | Applicability   | LERF Factors<br>(early, late) |
|--------------------|---|-------------------------------|
| $P_{\text{CSGTR}}$ | Sequences with no stick open primary or secondary relief valves | (0.22, 0.31)                  |
|                    | Sequence with loop seal clearing                                | (1.0, 1.0)                    |
| $P_{\text{NDEP}}$  | Sequence without loop seal clearing                             | (1.0, 1.0)                    |
|                    | Sequence with loop seal clearing                                | (1.0, 1.0)                    |
| $P_{\text{SAMG}}$  | Sequence without loop seal clearing                             | (1.0, 1.0)                    |
|                    | Sequence with loop seal clearing                                | (1.0, 1.0)                    |
| $P_{\text{EVAC}}$  | For all sequences   | (1.0, 0.0)                    |



# Summary Results

| SG TYPE | Tube Material | #of SGs | EFPY | Hazard Category  | SBO CDF (per RY)<br>(short & Long) | Cont.-Bypass Frequency per year | LERF Fraction (%) | LERF (per RY)        |
|---------|---------------|---------|------|------------------|------------------------------------|---------------------------------|-------------------|----------------------|
| CE      | 690           | 2       | 15   | All <sup>1</sup> | 3.3E-05                            | 1.01E-05 <sup>2</sup>           | 5.6% <sup>2</sup> | 5.7E-07 <sup>2</sup> |
| CE      | 690           | 2       | 15   | Internal         | 1.9E-07                            | 5.65E-08                        | 9.5%              | 5.4E-09              |
|         |               |         |      |                  |                                    |                                 |                   |                      |
| W       | 600           | 4       | 15   | All              | 2.03E-05                           | 8.8E-07 <sup>3</sup>            | 3.7%              | 3.2E-08              |
| W       | 600           | 4       | 15   | Internal         | 5.23E-06                           | 2.3E-07                         | 3.6%              | 8.4E-09              |
| W       | 690           | 4       | 15   | All              | 2.03E-05                           | 6.3E-07                         | 3.5%              | 2.2E-08              |
| W       | 690           | 4       | 15   | Internal         | 5.23E-06                           | 1.6E-07                         | 3.5%              | 5.8E-9               |

1. All refers to contribution of CDF from internal events, internal flood, fire, and seismic PRA.
2. CDF for short and long SBO from all hazards models are  $\sim 2.6\text{E-}6/\text{RY}$  and  $3.1\text{E-}5/\text{RY}$  respectively. The total containment bypass probability is estimated by  $[(2.6\text{E-}6 \cdot .22 + 3.1\text{E-}5 \cdot .31)] = [5.72\text{E-}7 + 9.61\text{E-}5] = 1.02\text{E-}5$ . The LERF contribution is from the short sbo. It is estimated at  $5.7\text{E-}7$  or about 5.6%.
3. As discussed in Section 7.1.5, the probability of C-SGTR is about  $1.3\text{E-}2$  for short SBO with Inconel 600 materials and  $8.9\text{E-}3$  for Inconel 690. The probability of C-SGTR caused by a cleared loop seal due to RCP seal failures was also estimated at  $2.5\text{E-}3$ . The overall probability of C-SGTR is estimated to be about  $1.6\text{E-}2$  and  $1.1\text{E-}2$  for short SBO and for Inconel 600 and 690, and  $2.85\text{E-}2$  and  $2.0\text{E-}2$  for long SBO and for Inconel 600 and 690.

# Pressure Induced C-SGTR Scenarios

- Identify Scenarios where the delta P across the tubes is two or more times its nominal value during normal At-Power operation
- Develop scenario Frequencies from existing PRAs
- Identify simplified bounding pressure-temperature curves for the accident
- Estimate the C-SGTR probability equivalent to one or more tubes
- Modify the existing accident progression tree and related HRA to account for C-SGTR
- Re-quantify LERF and CDF

# Summary of Pressure Induced C-SGTR for Westinghouse Plant

| Pressure Induced Accidents                | f(IE)<br>per year | P(CSGTR IE) | P(CD IE,CS<br>GTR) | P(LERF IE,CS<br>GTR,CD) | $\Delta$ -CDF<br>per year | $\Delta$ -LERF<br>per year |
|---|-------------------|-------------|--------------------|-------------------------|---------------------------|----------------------------|
| ATWS-Electrical                           | 1.5E-5            | 0.01        | 1.6E-4             | 1                       | <1.0E-9                   | <1.0E-9                    |
| ATWS-Failure of rods                      | 1.2E-6            | 0.01        | 1                  | 1                       | 1.2E-08                   | 1.2E-08                    |
| SLBIC                                     | 1.0E-3            | 2.50E-03    | 3.2E-02            | 0                       | 8.0E-08                   | 0                          |
| Spurious opening of SG relief<br>valves   | 3.0E-3            | 2.50E-03    | 3.2E-02            | 1                       | 2.4E-07                   | 2.4E-07                    |
| SLBOC                                     | 4.0E-5            | 2.50E-03    | 3.2E-02            | 1                       | 3.2E-9                    | 3.2E-9                     |
| High Pressure Feed and Bleed<br>Scenarios | 2.0E-5            | 0.01        | 2.5E-2             | 1                       | 5.0E-9                    | 5.0E-9                     |
| All IES – Total Contribution              |                   |             |                    |                         | 3.4E-7                    | 2.6E-7                     |

# Summary of Pressure Induced C-SGTR for CE Plant

| Pressure Induced Accidents                | f(IE)<br>per year | P(CSGTR IE) | P(CD IE,CS<br>GTR) | P(LERF IE,CS<br>GTR,CD) | $\Delta$ -CDF<br>per year | $\Delta$ -LERF<br>per year |
|---|-------------------|-------------|--------------------|-------------------------|---------------------------|----------------------------|
| ATWS-Electrical                           | 1.5E-5            | 8.0E-3      | 1.6E-4             | 1                       | <1.0E-09                  | <1.0E-09                   |
| ATWS-Failure of rods                      | 1.2E-6            | 8.0E-3      | 1                  | 1                       | 9.6E-09                   | 9.6E-09                    |
| SLBIC                                     | 1.0E-3            | 4.0E-3      | 3.2E-02            | 0                       | 1.3E-07                   | 0                          |
| Spurious opening of SG relief<br>valves   | 3.0E-3            | 4.0E-3      | 3.2E-02            | 1                       | 3.8E-07                   | 3.8E-07                    |
| SLBOC                                     | 4.0E-5            | 4.0E-3      | 3.2E-02            | 1                       | 5.1E-09                   | 5.1E-09                    |
| High Pressure Feed and Bleed<br>Scenarios | 2.0E-5            | 8.0E-3      | 2.5E-2             | 1                       | 4.0E-09                   | 4.0E-09                    |
| All IES – Total Contribution              |                   |             |                    |                         | 5.3E-7                    | 4.0E-7                     |

# PRA Summary

- PRA results indicate that the conditional containment bypass probability (given high-dry-low conditions) is approximately an order of magnitude greater for the CE plant analyzed by this study compared to the analyzed W plant
- PRA results indicates that  $\Delta$ -LERF and  $\Delta$ -CDF due to C-SGTR during DBA accidents prior to onset of core damage is expected to be  $<5.0E-7$  per year based on somewhat bounding analysis.
- Plant features that reduce the likelihood of severe accident high-dry-low conditions (e.g., diversity in AFW system) can reduce containment bypass frequency
- The loop seal clearing for the pilot Westinghouse plant was considered for very large RCP seal failures and was found not be significant. No analysis currently available for CE plants.

# PRA Insights

- The conditional probability of C-SGTR during severe accidents is reduced by:
  - Avoidance of large and deep SG tube flaws (particularly for Westinghouse-type SG designs)
  - Plant and SG design features (e.g., SG inlet plenum and hot leg geometry) that increase the temperature difference between hot leg and hot (or hottest) SG tubes during severe accidents (therefore increasing the probability of hot leg failure prior to SG tube failures).
  - Depressurization of reactor coolant system
- The conditional probability of C-SGTR during DBA accidents can be reduced by:
  - Avoidance of large and deep SG tube flaws

# Other PRA Insights

- The critical size of C-SGTR Leak area may depend on the details of the accident sequences; an area of 6 cm<sup>2</sup> which approximately equals to guillotine break of one tube in a W-plant is assumed. The following issues were considered for estimating the critical area:
  - Sufficient to pressurize the secondary side forcing the opening of the secondary relief valves and subsequent failures to reclose
  - Sufficient to provide sufficient release path before RCS failure or vessel breach to be considered LERF (source term/release fraction)
  - Not too large to disturb the counter current flow
- Importance of SAMG Operation
  - Increasing the battery life to facilitate longer operation of TDAFW and SAMG operations
  - Probability of equipment survivability post on set of core damage – during severe accidents (PORVs, SG SRVs and ARVs)



**U.S.NRC**

UNITED STATES NUCLEAR REGULATORY COMMISSION

*Protecting People and the Environment*

# **Severe Accident-Induced Steam Generator Tube Rupture (SGTR)**

## **Regulatory Implications**

Antonios Zoulis, NRR/DRA

**Consequential Steam Generator Tube Rupture (C-SGTR) Subcommittee Briefing**

**April 7, 2015**



## **NRR Perspective**

NRR:

- Endorses the completion of the draft NUREG for review and public comment summarizing the information and research developed over the past 5 years.
- Plans to develop Risk Assessment Standardization Project (RASP) Handbook guidance and update Inspection Manual Chapter (IMC) 0609 appendices to support risk assessments (SDP) for the Reactor Oversight Program
- Considers evaluating findings using generic issues processes – potential actions:
  - Issue information notice on issuance of final NUREG
  - Evaluate issue under the generic issues program